
# ACAS II Guide

## Airborne Collision Avoidance System II (incorporating version 7.1)

July 2014

EUROCONTROL

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## NOTE

This Guide has been designed to support the training of people involved in the use of the Airborne Collision Avoidance System (ACAS). However, it is not, per se, designed for the complete training of controllers or pilots. The principal and essential technical and operational features of ACAS II are introduced. For a deeper knowledge, the reader is advised to refer to documentation listed in the bibliography section.

This Guide describes the ACAS II concept and technical details as well as operation principles of TCAS II versions 7.0 and 7.1. TCAS II version 6.04a and TCAS I are not covered because they are outside the scope.

The information contained in this Guide, EUROCONTROL ACAS II Bulletins and training presentations is based on the ICAO provisions and other applicable regulations. The information is considered to be accurate at the time of publishing but is subject to change

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## ACKNOWLEDGMENTS

This *ACAS II Guide* has been developed by EUROCONTROL with the help of QinetiQ and the German Air Line Pilots' Association (Vereinigung Cockpit).

The Guide is partially based on the *ACAS II Brochure* that was originally developed for the EUROCONTROL ACASA project (ACAS Analysis) in 2000. CENA (Centre d'Études de la Navigation Aérienne) and EUROCONTROL have contributed to the development of the Brochure.

Some sections of this Guide are based on the information contained in the FAA-published *Introduction to TCAS II version 7.1* booklet.

## HISTORY OF CHANGES

| EDITION NUMBER | EDITION DATE | REASON FOR CHANGE | PAGES AFFECTED |
|---|---|---|---|
| 1.0 | 12 January 2012 | First edition. | All |
| 1.1 | 18 March 2013 | Corrections and updates. | All |
| 1.2 | 25 July 2014 | Corrections and updates. | All |

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## PREFACE

The Airborne Collision Avoidance System (ACAS) II concept (realised as Traffic alert and Collision Avoidance System (TCAS) II equipment) is an airborne avionics system which acts independently of ATC as a last resort safety net to mitigate the risk of midair collision.

ACAS tracks aircraft in the surrounding airspace through replies from their ATC transponders. If the system diagnoses a risk of impending collision it issues a Resolution Advisory (RA) to the flight crew which directs the pilot how best to regulate or adjust his vertical speed so as to avoid a collision. Experience, operational monitoring and simulation studies have shown that when followed promptly and accurately, the RAs issued by ACAS II significantly reduce the risk of midair collision.

The carriage of ACAS II version 7.0 has been mandated in Europe since 1 January 2005 by all civil fixed-wing turbine-engined aircraft having a maximum take-off mass exceeding 5700 kg or a maximum approved passenger seating configuration of more than 19.

Amendment 85 to ICAO Annex 10 (volume IV) published in October 2010 introduced a provision stating that all new ACAS installations after 1 January 2014 shall be compliant with version 7.1 and after 1 January 2017 all ACAS units shall be compliant with version 7.1.

In December 2011, the European Commission published an Implementing Rule mandating the carriage of ACAS II version 7.1 within European Union airspace earlier than the dates stipulated in ICAO Annex 10: from 1 December 2015 by all aircraft currently equipped with version 7.0 and from 1 March 2012 by all new aircraft above 5700 kg maximum take-off mass or a maximum approved passenger seating capacity of more than 19.

For ACAS to deliver the maximum safety benefit in the airspace while minimising the disruption to flights and normal ATC operations it is essential that flight crew and controllers are familiar with the principles of operation of ACAS and correct procedures for its use.

This guide provides the background for a better understanding of ACAS II by personnel involved in its implementation and operation. It includes sections on the historical background to TCAS and the changes introduced with the new version 7.1 software; the system components and the presentation in the cockpit; the principles of ACAS operation and the alerts that the system can generate; and the correct procedures for both flight crew and controllers in response to ACAS alerts. A list of additional training resources and applicable ICAO provisions are provided as well.

# INTRODUCTION

## HISTORICAL BACKGROUND

Over the years, air traffic has continued to increase. The developments of modern air traffic control systems have made it possible to cope with this increase, whilst maintaining the necessary levels of safety.

The risk of collisions is mitigated by pilots exercising the "see and avoid" principal and staying away from other aircraft and by ground based Air Traffic Control (ATC) which is responsible for keeping aircraft separated. Despite technical advances in ATC systems, there are cases when the separation provision fails due to a human or technical error. Any separation provision failures may result in an increased risk of a midair collision.

To compensate for any limitations of "see and avoid" and ATC performance, an airborne collision avoidance system, acting as a last resort, has been considered from the 1950s. In 1955, Dr John S. Morrel proposed the use of the slant range between aircraft divided by the rate of closure or range rate for collision avoidance algorithms (i.e. time rather than distance, to the closest point of approach). Today's airborne collision avoidance system is based on this concept.

In 1956, the collision between two airliners, over the Grand Canyon in the USA[1], prompted both the airlines and the aviation authorities to advance the development of an airborne collision avoidance system. It was determined in the early 1960s that, due to technical limitations, the development could not be progressed beyond the overall concept.

During the late 1960s and early 1970s, several manufacturers developed prototype aircraft collision avoidance systems. Although these systems functioned properly during staged aircraft encounter testing, it was concluded that in normal airline operations, these systems would generate a high rate of unnecessary alarms in dense terminal areas. This problem would have undermined the credibility of the system with the flight crews.

In the mid-1970s, the Beacon Collision Avoidance System (BCAS) was developed. BCAS used reply data from the Air Traffic Control Radar Beacon System (ATCRBS) transponders to determine an intruder's[2] range and altitude.

In 1978, the collision between a light aircraft and an airliner over San Diego, California[3] led the US Federal Aviation Administration to initiate, three years later, the development of TCAS (Traffic alert and Collision Avoidance System) utilizing the basic BCAS design for interrogation and tracking with some additional capabilities.

In 1986 the collision between an airliner and a light aircraft over Cerritos, California[4] resulted in a US Congressional mandate that required some categories of US and foreign aircraft to be equipped with TCAS II for flight operations in US airspace.

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[1] A Douglas DC-7 and Lockheed L-1049 Super Constellation were involved in this collision. The flight paths of the aircraft intersected over the Grand Canyon, the pilots did not see each other during weather avoidance and they collided at a closing angle of about 25 degrees. 128 people were killed.

[2] In the context of TCAS, an 'intruder' is any other aircraft that is tracked regardless of whether it is or is not a collision threat.

[3] A Boeing 727 and a Cessna 172 were involved in this collision. The aircraft collided as the Boeing crew failed to comply with the provisions of a maintain-visual-separation clearance and the Cessna departed from the cleared flight path. 135 people onboard plus 7 on the ground were killed.

[4] A Douglas DC-9 and a Piper PA-28 Archer were involved in this collision. The Piper inadvertently entered the controlled airspace and both crews could not to see each other due to the geometry of the conflict. 67 people onboard plus 15 on the ground were killed.

In parallel to the development of TCAS equipment, ICAO (International Civil Aviation Organization) has developed, from the beginning of the 1980s, standards for Airborne Collision Avoidance Systems (ACAS).

## ACAS AND TCAS

Currently, TCAS II is the only implementation that meets the ACAS ICAO Standards and Recommended Practices (SARPs). Therefore, the term **ACAS II** is typically used when referring to the standard or concept and **TCAS II** when referring to the implementation. However, often both terms are used interchangeably.

## ACAS PRINCIPLES

ACAS is designed to work both autonomously and independently of the aircraft navigation equipment and any ground systems used for the provision of air traffic services.

Through antennas, ACAS interrogates the ICAO standard compliant transponders of aircraft in the vicinity. Based upon the replies received, the system tracks the slant range, altitude (when it is included in the reply message) and bearing of surrounding traffic.

ACAS can issue two types of alerts:

- Traffic Advisories (TAs), which aim to help the pilots in the visual acquisition of the intruder aircraft, and to alert them to be ready for a potential resolution advisory.
- Resolution Advisories (RAs), which are avoidance manoeuvres recommended to the pilot. When the intruder aircraft is also fitted with an ACAS II system, both systems coordinate their RAs through the Mode S data link, in order to select complementary resolution senses.

ACAS was recognised by ICAO on 11 November 1993. Its descriptive definition appears in Annex 2; its use is regulated in Annex 6, PANS-OPS (Doc. 8168) and PANS-ATM (Doc. 4444). In November 1995, the SARPs for ACAS II were approved, and they have been published in ICAO Annex 10 volume IV. In 2006 ICAO published Doc. 9863 – Airborne Collision Avoidance System (ACAS) Manual. The purpose of the Manual is to provide guidance on technical and operational issues applicable to ACAS. Relevant excerpts from ICAO documents can be found in the Appendix (page 65) of this document.

## ACAS STANDARDS

Three types of ACAS have been specified in ICAO Annex 10:

- ACAS I provides information as an aid to “see and avoid” action but does not include the capability for generating RAs.
- ACAS II provides vertical RAs in addition to TAs.
- ACAS III provides vertical and horizontal RAs in addition to TAs[5].

ACAS I provides TAs but does not provide collision avoidance manoeuvre indications (RAs are not issued). ICAO SARPs for ACAS I are published in ICAO Annex 10, volume IV and are limited to interoperability and interference issues with ACAS II. Currently the only implementation of the ACAS I concept is TCAS I. TCAS I Minimum Operational Performance Standards (MOPS) have been published by RTCA (DO-197A).

ACAS I is not, nor has it ever been, mandated in Europe and there are no operational rules regarding the use of ACAS I. The main purpose of ACAS I is to aid pilots in acquiring threats visually; the collision

[5] Sometimes referred to as TCAS IV.

avoidance manoeuvre direction is left to pilots' discretion. ACAS I operations cannot be coordinated with ACAS II.

The latest TCAS II MOPS have been developed jointly by RTCA and EUROCAE (European Organisation for Civil Aviation Equipment). For the current TCAS II version (7.1) the Standards have been published in RTCA document DO-185B and EUROCAE document ED-143. In order to be certified, any ACAS II equipment must meet the standards specified in the MOPS.

Although ACAS III is mentioned as a future system in ICAO Annex 10, ACAS III is unlikely to materialise due to difficulties the current surveillance systems have with horizontal tracking. Currently, research is being conducted to develop a future collision avoidance system under the working name of ACAS X, (see page 17). ACAS X is not expected to provide any horizontal resolutions.

ACAS equipment is available from three principle vendors, all of them based in the USA[6]. Systems by other manufacturers may become available. While each vendor's implementation is slightly different, they provide the same core functions and the collision avoidance and coordination algorithms ("the logic") contained in each implementation is the same.

## EARLY VERSIONS OF TCAS II (VERSIONS 6.02 AND 6.04A)

Throughout the 1980s, the performance evaluations of early versions of TCAS II contributed to the gradual enhancement of the equipment and software. In September 1989 the design of version 6.02 was completed and put into operations from April 1990.

In order to determine the TCAS II system performance, ICAO commissioned a worldwide operational evaluation in the late 1980s. The evaluation was conducted in the early 1990s.

As a result of the evaluation a number of improvements were suggested. That led to the development and release of version 6.04a in 1993. The new version aimed to reduce the number of nuisance alerts, which were occurring at low altitudes and during level-off encounters.

## TCAS II VERSION 7.0

After the implementation of version 6.04a, further operational evaluations were carried out and proposed performance improvements led to the development of version 7.0. It was approved in December 1997 and became available at the beginning of 1999.

Version 7.0 further improved TCAS II compatibility with the air traffic control system. The most significant enhancements were the introduction of a horizontal miss distance filter and 25-foot vertical tracking, more sophisticated multi-threat logic, compatibility with Reduced Vertical Separation Minima (RVSM) operations and the reduction of electromagnetic interference.

[6] Honeywell, ACSS and Rockwell Collins.

## TCAS II VERSION 7.1

Based on an extensive analysis of version 7.0 performance, two changes were identified to improve the TCAS logic.

### New Level Off RA

In the course of analysing recorded and reported events, many cases – as many as 23 per year – were found in which pilots did not respond correctly to the "Adjust vertical speed, adjust" RAs. In those cases involving an incorrect response, the pilots increased their vertical speed instead of reducing it, consequently causing a deterioration of the situation (see Figure 1). The Adjust Vertical Speed RA is the only RA whose aural annunciation does not clearly communicate what exact manoeuvre is required. It is also the most common RA, representing up to two-thirds of total RAs, all of which increases the potential for incorrect pilot response.

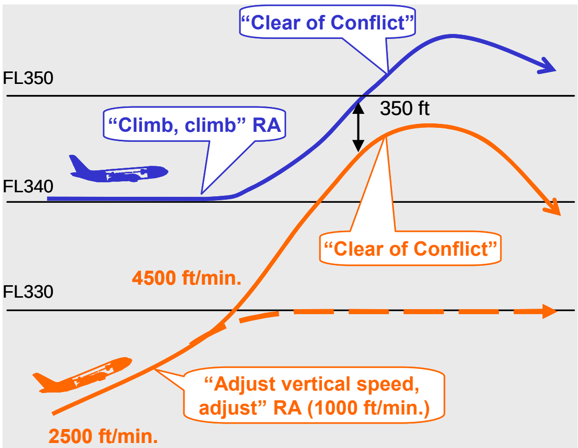


Figure 1: Unintentional opposite response to Adjust Vertical Speed RA in version 7.0.

Additionally, there have been numerous cases of level bust when pilots following the Adjust Vertical Speed RA went through their cleared level, often causing a follow up RA for the other aircraft above or below, and disrupting ATC operations (see Figure 2).

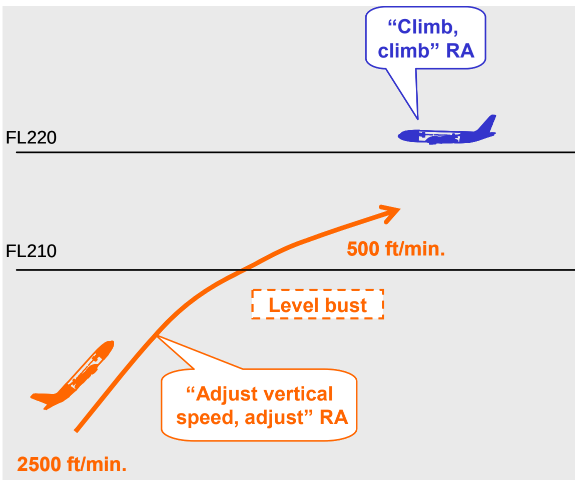


Figure 2: Level bust resulting from the response to Adjust Vertical Speed RA in version 7.0.

To address these issues, in version 7.1 the "Adjust vertical speed, adjust" RA has been replaced with a new "Level off, level off" RA. The Adjust Vertical Speed RA in version 7.0 requires a reduction of the vertical rate to 0, 500, 1000, or 2000 ft/min. The "Level off, level off" RA requires a reduction of vertical rate to 0 ft/min. The level off is to be achieved promptly, not at the next standard flight level (e.g. FL200, FL210, etc.). The "Level off, level off" RA may be issued as an initial RA (as illustrated in Figure 3) or as a weakening RA (following, for instance, a "Climb, climb" or "Descend, descend" RA) when the vertical distance between the aircraft increases after the initial RA has been issued.

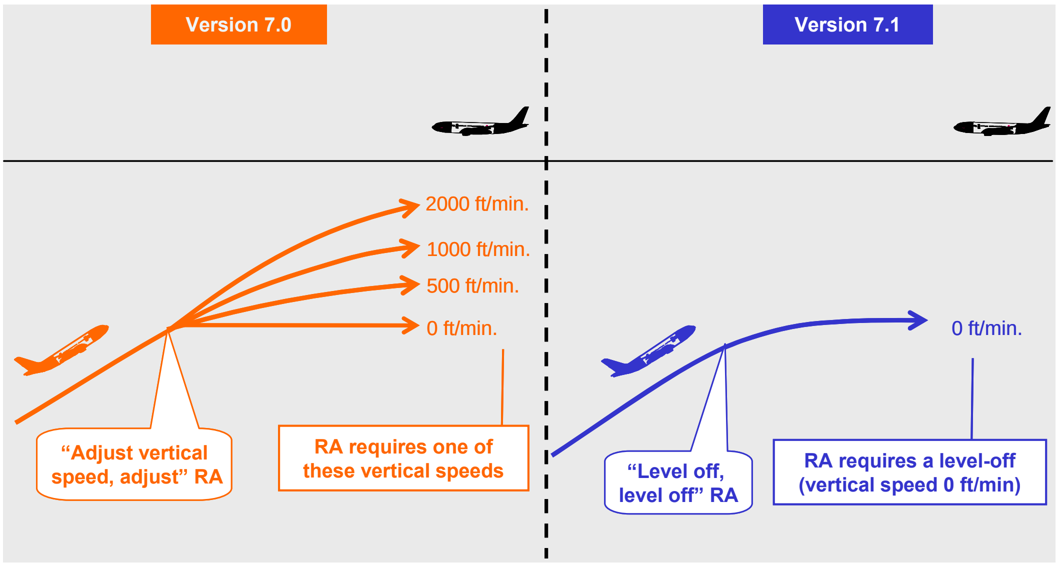

Figure 3: Comparison of Adjust Vertical Speed (version 7.0) and Level Off (version 7.1) RAs.

The aural message "Level off, level off" has the benefit of being intuitive and the associated manoeuvre corresponds to the standard levelling off manoeuvre.

Additionally, replacing the multiple climb/descent rates of the "Adjust vertical speed, adjust" RA, the "Level off, level off" RA will minimise the altitude deviations induced by TCAS (level busts while "flying the green arc" – see Figure 4), thus reducing the impact on ATC operations. It will contribute to the overall reduction of RA occurrences because follow up RAs resulting from the "green arc level bust" should no longer occur.

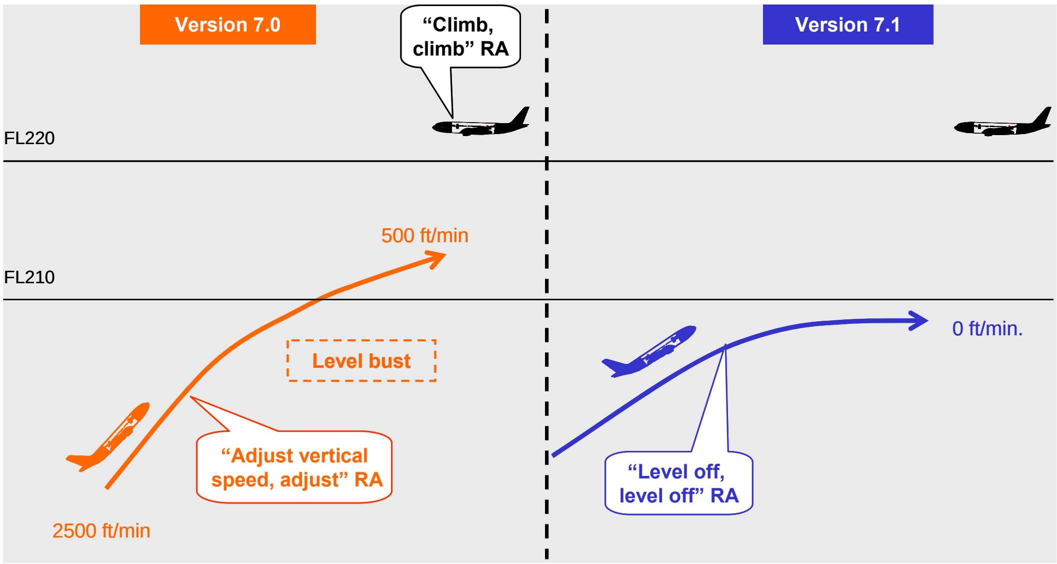

Figure 4: Comparison of Adjust Vertical Speed (version 7.0) and Level Off (version 7.1) RAs: minimised altitude deviations.

### Improved reversal logic

The design of TCAS II version 7.0 allowed for reversal RAs (i.e. "Climb, climb NOW" and "Descend, descend NOW") to be issued in coordinated encounters when the current RA is no longer predicted to provide sufficient vertical spacing.

After version 7.0 was introduced in the early 2000s, a weakness in the sense reversal logic was discovered: version 7.0 failed to reverse an RA if two aircraft converging in altitude remain within 100 feet (see Figure 5). This scenario can occur when one aircraft is not following the RA or is not TCAS II equipped, and follows an ATC instruction or performs an avoidance manoeuvre based on visual acquisition. A number of these cases have occurred, the most notable events being the Yaizu (Japan) midair accident January 2001[7] and the Überlingen (Germany) midair collision in July 2002[8].

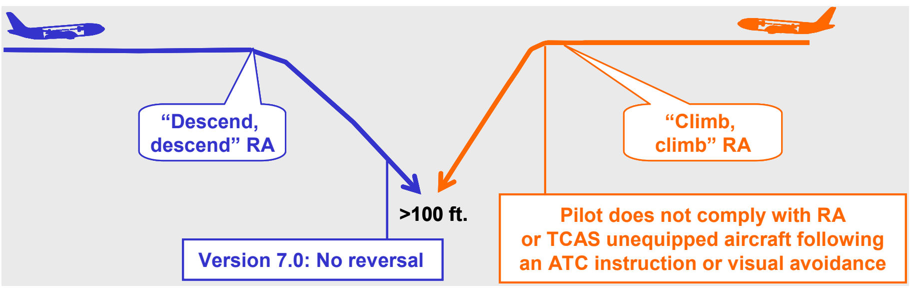

Figure 5: Geometry in which where version 7.0 does not reverse an RA.

Version 7.1 brings improvements to the reversal logic by detecting situations in which, despite the RA, the aircraft continue to converge vertically.

[7] A DC-10 and a Boeing 747 were involved in this accident. The generation of RAs on both aircraft coincided with the controller instruction for the Boeing pilot to descend. The Boeing crew followed the ATC instruction, rather than the RA manoeuvre in the opposite direction. Late, aggressive visual avoiding manoeuvres by both pilots prevented the collision; however 100 people on board of the Boeing were injured. The two aircraft narrowly missed each other.

[8] A Tupolev 154 and a Boeing 757 were involved in this collision. The controller was unaware that RAs had been issued on both aircraft and instructed the Tupolev to descend while the RA called for a climb. The Tupolev pilot complied with the ATC instruction while the Boeing pilot followed his descend RA. The aircraft collided killing 71 people.

A feature has been added to the TCAS II logic which monitors RA compliance in coordinated encounters (i.e. when both aircraft are TCAS II equipped). When version 7.1 detects that an aircraft is not responding correctly to an RA, it will issue a reversal RA to the aircraft which manoeuvres in accordance with the RA (i.e. "Climb, climb NOW" or "Descend, descend NOW" RA) and will change the sense of RA issued to the aircraft that is not responding correctly to be compatible with the reversal, e.g. "Maintain vertical speed, maintain" RA (see Figure 6).

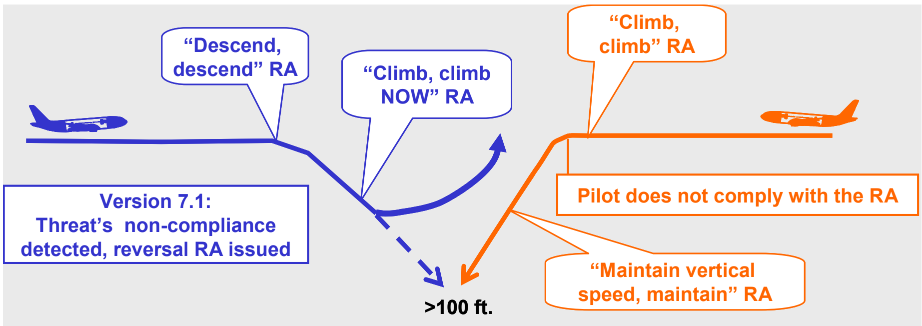


Figure 6: Improvement of reversal logic in version 7.1 (both aircraft equipped).

In single equipage encounters, version 7.1 will recognise the situation and will issue a reversal if the unequipped threat aircraft moves in the same vertical direction as the TCAS II equipped aircraft (see Figure 7).

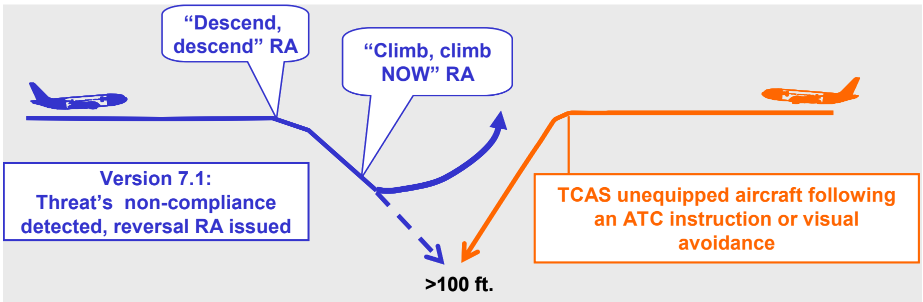


Figure 7: Improvement of reversal logic in version 7.1 (only one aircraft equipped).

Although the reversal logic change is transparent to flight crews, it will, nevertheless, bring significant safety improvements.

## HISTORY OF CARRIAGE MANDATE

The carriage of TCAS II equipment was mandated for flights in United States airspace from 30 December 1993 for all civil fixed-wing turbine-engined aircraft capable of carrying more than 30 passengers.

Following the US mandate, the number of long range aircraft, fitted with TCAS II and operating in European airspace continued to increase, although the system carriage and operation was not mandatory. However, the continuing studies and evaluations demonstrated the safety benefits of TCAS II and some airlines commenced equipping their fleets on a voluntary basis.

In 1995, the EUROCONTROL Committee of Management approved an implementation policy and schedule for the mandatory carriage of ACAS II in Europe. This was then ratified by the European Air Traffic Control Harmonisation and Integration Programme (EATCHIP) Project Board.

The approved policy required that:

- from 1 January 2000, all civil fixed-wing turbine-engined aircraft having a maximum take-off mass exceeding 15,000 kg or a maximum approved passenger seating configuration of more than 30 will be required to be equipped with ACAS II, and
- from 1 January 2005, all civil fixed-wing turbine-engined aircraft having a maximum take-off mass exceeding 5700 kg, or a maximum approved passenger seating configuration of more than 19 will be required to be equipped with ACAS II.

This gradually increasing implementation of the use of ACAS II, arising from the perceived safety benefits of the equipment, and the November 1996 midair collision over Charkhi Dadri (India)[9] initiated the ICAO proposal for worldwide mandatory ACAS II carriage.

In order to guarantee the complete effectiveness of ACAS II, ICAO has phased in, based upon the rules of applicability in the European policy, a worldwide mandated of ACAS II carriage and use of pressure altitude reporting transponders, which are a pre-requisite for the generation of RAs.

After the midair collision between two military transport aircraft off the Namibian coast in September 1997[10], urgent consideration was given to the need to equip military transport aircraft with TCAS II. Currently, many military transport aircraft have been equipped with TCAS II.

## CURRENT TCAS II/ACAS II EQUIPAGE MANDATES

Amendment 85 to ICAO Annex 10 volume IV, published in October 2010, introduced a provision[11] stating that:

- all new ACAS installations after 1 January 2014 shall be compliant with version 7.1; and
- all ACAS units shall be compliant with version 7.1 after 1 January 2017.

On 20 December 2011, the European Commission published an Implementing Rule[12] mandating the carriage of ACAS II version 7.1 within European Union airspace earlier than the dates stipulated in ICAO Annex 10:

- by all aircraft with a maximum certified take-off mass exceeding 5700 kg or authorised to carry more than 19 passengers from 1 March 2012;
- with the exception of aircraft with an individual certificate of airworthiness issued before 1 March 2012 that must be equipped as of 1 December 2015;
- aircraft not referred above but which will be equipped on a voluntary basis with ACAS II, must be equipped with version 7.1.

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[9] An Ilyushin 76 and a Boeing 747 were involved in this collision. Neither of the aircraft was TCAS equipped nor required to be equipped at the time. The Ilyushin descended below its cleared level and collided with the Boeing. 349 people were killed.

[10] A Tupolev 154 and a C141 Starlifter were involved in this collision. Neither of the aircraft was TCAS equipped nor required to be equipped at the time. Both aircraft were cruising at the same flight level and collided killing 33 people.

[11] See Appendix on page 65 for the full text of ICAO Annex 10 provision.

[12] Commission Regulation (EU) No 1332/2011 of 16 December 2011 laying down common airspace usage requirements and operating procedures for airborne collision avoidance published in the Official Journal of the European Union on 20 December 2011:
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:336:0020:0022:EN:PDF

## FUTURE OF COLLISION AVOIDANCE: ACAS X

The FAA has funded research and development of a new approach to airborne collision avoidance (known as ACAS X[13]) since 2008. This new approach takes advantage of recent advances in 'dynamic programming' and other computer science techniques (which were not available when TCAS II was first developed) to generate alerts using an off-line optimisation of resolution advisories. It is the intention that ACAS X will eventually replace TCAS II.

It is envisaged that ACAS X will provide an improvement in safety while reducing the unnecessary alert rate. ACAS X will use the same hardware (antennas, processors, and displays) as the current TCAS II system and the same range of available RAs will be used. Consequently, pilots and controllers would perceive no change with the transition to the new system, which will be fully compatible with current TCAS II systems.

Two of the key differences between TCAS II and the current concept for ACAS X are the collision avoidance logic and the sources of surveillance data.

TCAS II relies exclusively on interrogation mechanisms using transponders on-board aircraft to determine the intruder's current and projected future position. If the tracked aircraft is declared a threat and is also TCAS-equipped, the two TCAS II units coordinate complementary advisories. Current TCAS II advisory logic issues alerts against a potential threat on the basis of time of closest approach and projected miss distance. This relies on a fixed set of rules, modelling the spectrum of pilots' responses.

Instead of using a set of hard-coded rules, ACAS X alerting logic is based upon a numeric lookup table optimised with respect to a probabilistic model of the airspace and a set of safety and operational considerations.

The following benefits are foreseen through the introduction of ACAS X:

- Reduction of 'unnecessary' advisories: TCAS II is an effective system operating as designed, but it can issue alerts in situations where aircraft will remain safely separated.
- Adaptability to future operational concepts: Both SESAR[14] and NextGen[15] plan to implement new operational concepts which will reduce the spacing between aircraft. TCAS II in its current form is not compatible with such concepts and would alert too frequently to be useful.
- Extending collision avoidance to other classes of aircraft: To ensure advisories can be followed, TCAS II is restricted to categories of aircraft capable of achieving specified performance criteria (e.g. aircraft must be able to achieve a rate of climb of 2,500 ft/min.), which excludes the likes of General Aviation (GA) and Unmanned Aircraft Systems (UAS) or Remotely Piloted Aircraft Systems (RPAS).
- Use of future surveillance environment: Both SESAR and NextGen make extensive use of new surveillance sources, especially satellite-based navigation and advanced ADS-B functionality. TCAS II however relies solely on transponders on-board aircraft which will limit its flexibility to incorporate these advances.
- Safety improvement: It is envisaged that ACAS X will provide an improvement in safety while reducing the unnecessary alert rate.
- Minimal changes: ACAS X will use the same hardware (antennas, processors, and displays) as the current TCAS II system and the same range of available RAs will be used. Consequently, pilots and controllers should perceive no change with the transition to the new system, which will be fully compatible with current TCAS II systems.

As well as the standard ACAS X (known as ACAS Xa) variants are under consideration to extend collision avoidance protection to situations and user classes that currently do not benefit from TCAS II:

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[13] Pronounced "*Ay-cas eks*" rather than "*Ay-cas ten*".

[14] Single European Sky ATM Research Programme (SESAR) is the European air traffic control infrastructure modernisation programme that aims at developing the new generation air traffic management system capable of ensuring the safety and fluidity of air transport worldwide over the next 30 years.

[15] Next Generation Transportation System (NextGen) is a name for the transformation of the National Airspace System (NAS) of the United States, planned in stages between 2012 and 2025.

- ACAS Xa – The general purpose ACAS X that makes active interrogations to establish the range of intruders. The successor to TCAS II.
- ACAS Xp – A version of ACAS X that relies solely on passive ADS-B to track intruders and does not make active interrogations. It is intended for general aviation aircraft (that are not currently required to fit TCAS II).
- ACAS Xo – A mode of operation of ACAS X designed for particular operations for which ACAS Xa is unsuitable and might generate an unacceptable number of nuisance alerts (e.g. procedures with reduced separation, such as closely spaced parallel approaches)
- ACAS Xu – designed for Unmanned Aircraft Systems UAS or Remotely Piloted Aircraft Systems (RPAS)

As of May 2014, MOPS are being developed for ACAS Xa and ACAS Xo within RTCA and EUROCAE standardization working arrangements. The completion is currently scheduled for 2018 and ACAS X may become operational in 2020.

## TECHNICAL DESCRIPTION OF TCAS II

### SYSTEM COMPONENTS

Figure 8 below shows a block diagram of the TCAS II system. A TCAS II is composed of:

**Computer unit** – which performs airspace surveillance, intruder tracking, threat detection, avoidance manoeuvre determination and the generation of advisories.

**TCAS/transponder control panel** – the operating capability level of the TCAS system is set by the pilot from the control panel:

- **Stand-by**: TCAS is off. Power is applied to the TCAS Processor and the Mode S transponder, but TCAS does not issue any interrogations and the transponder will reply only to 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**: only TAs can be issued. The Mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. However, TCAS will only issue TAs; RAs will be inhibited.
- **Automatic** or **TA/RA**: normal TCAS operation. 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.

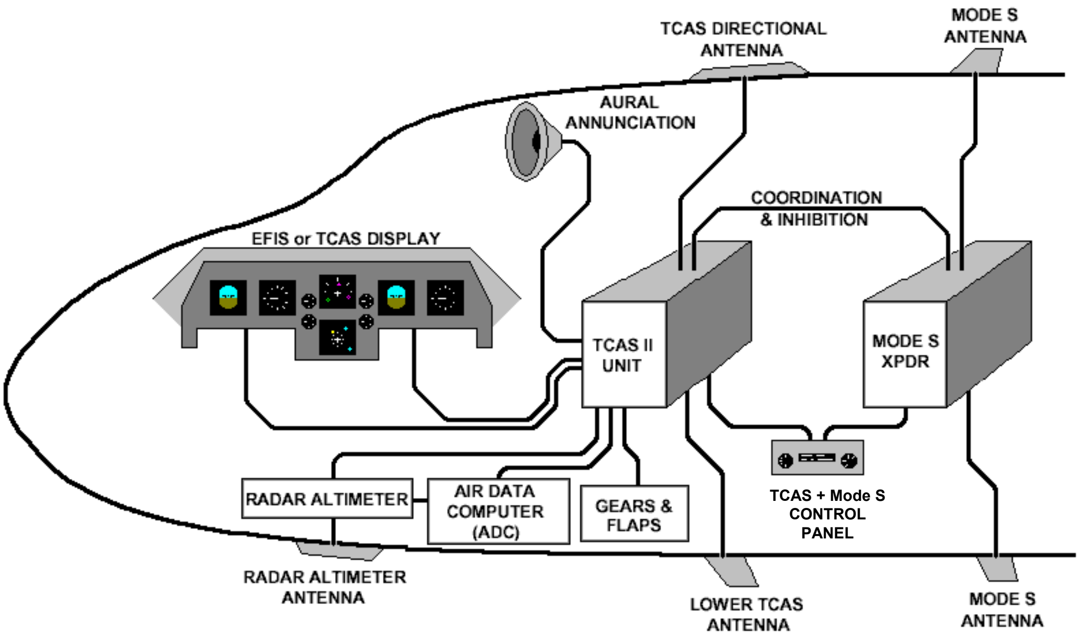


Figure 8: TCAS II installation schematic diagram.

**Two antennas** – The antennas used by TCAS II include a directional antenna that is mounted on the top of the aircraft and either an omni-directional 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-degree 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 optimise signal strength and reduce multi-path interference. Transponder-TCAS integrated systems only require two antennas that are shared by the transponder and TCAS.

Because the TCAS II unit and transponder each generate transmission signals at the receiver frequency of the other, the TCAS II and transponder are connected to an aircraft suppression bus that disables one when the other is transmitting.

**Connection with the Mode S transponder** – to issue complementary and coordinated resolution advisories, when both aircraft are equipped with TCAS II.

**Connection with the altimeter** – to obtain pressure altitude, and/or with the on board Air Data Computer (ADC) if fitted.

**Connection with the radar (radio) altimeter** – on one hand to inhibit RAs when the aircraft is in close proximity to the ground, and on the other hand to determine whether aircraft tracked by TCAS are on the ground.

**Loudspeakers** – for the aural annunciations.

**Cockpit presentation: traffic display and RA display** – These two displays can be implemented in a number of ways, including incorporating both displays into a single, physical unit. Regardless of the implementation, the information provided is identical. The standards for both the traffic display and the RA display are defined in TCAS II MOPS (RTCA DO-185B or EUROCAE ED-143).

See the next section for more information concerning traffic and RA displays.

Additionally some other data, relating to aircraft performance are also taken into account, such as, landing gear and flap status, operational performance ceiling, etc.

However, TCAS II is not connected to the autopilot[16], nor the FMS (Flight Management System). TCAS II remains independent and will continue to function in the event of the failure of either of these systems.

A Mode S transponder is required to be installed and working 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 Stand-by. The Mode S transponder performs the normal functions to support the ground-based ATC systems. The Mode S transponder is also used to provide air-to-air data exchange between TCAS II equipped aircraft so that coordinated, complementary RAs can be issued when required.

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[16] An exception here is the Airbus AP/FD (Auto pilot/flight director) TCAS solution, currently implemented on the A380 fleet and planned for the implementation across of the Airbus aircraft family. The AP/FD TCAS solution is a guidance mode which allows the aircraft to automatically fly the RA if the auto pilot is on or gives the pilot guidance through the Flight Director command bar to hand fly the RA.

## COCKPIT PRESENTATION

### Traffic display

The traffic display depicts the position of nearby traffic, relative to own aircraft. It indicates the relative horizontal and vertical position of other aircraft based on the replies from their transponders.

Displayed traffic information also indicates Proximate, TA, and RA status. The primary purpose of the traffic display is to aid the flight crew in the visual acquisition of transponder equipped aircraft. The secondary purpose of the traffic display is to provide the flight crew with confidence in proper system operation, and to give them time to prepare to manoeuvre the aircraft in the event an RA is issued.

The traffic display can be implemented on either a part-time or full-time basis. If implemented on a part-time basis, the display will automatically activate whenever a TA or an RA is issued. Current implementations include dedicated traffic displays; display of the traffic information on shared weather radar displays, map presentation displays, Engine Indication and Crew Alerting System (EICAS) displays, Navigation Display (ND), and other displays such as a Cockpit Display of Traffic Information (CDTI) used in conjunction with Automatic Dependent Surveillance - Broadcast (ADS-B) applications.

A majority of the traffic displays also provide the pilot with the capability to select multiple ranges and to select the altitude band for displayed traffic. These capabilities allow the pilot to display traffic at longer ranges and with greater altitude separation while in cruise flight, while retaining the capability to select lower display ranges in terminal areas to reduce the amount of display clutter.

Examples of traffic displays are shown in Figure 9 below and Figure 10 and in Figure 11.

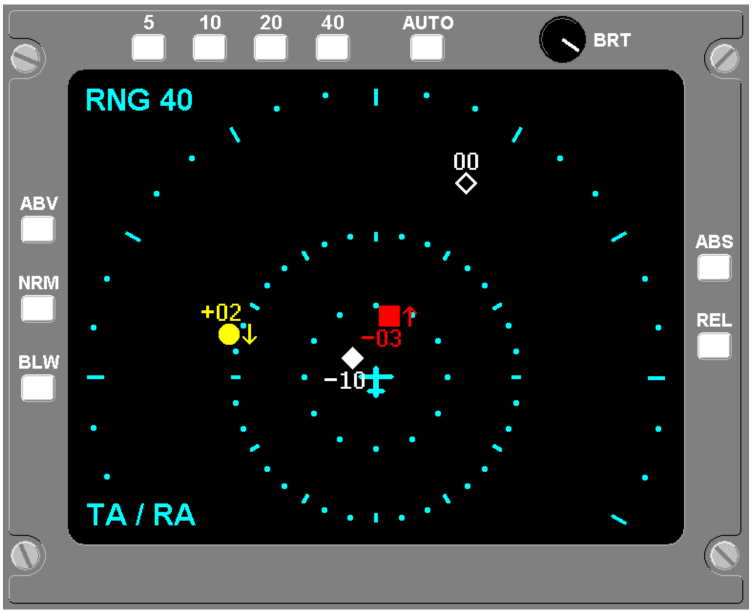



Figure 9: TCAS traffic display example - dedicated display.


Figure 10: TCAS traffic display example - IVSI combined with TCAS traffic display.


Figure 11: TCAS traffic display example - Electronic Flight Instrument System (EFIS).

**Traffic display symbology**

On the TCAS traffic display both colour and shape are used to assist the pilot in interpreting the displayed information.

The background to the display is dark.

Own-aircraft is depicted as a white or cyan (light blue) aircraft-like symbol. The location of own aircraft symbol on the display is dependent on the display implementation.

Targets are displayed by different symbols, according to their threat status:

- **hollow cyan (light blue) or white diamond**[17] – for other traffic.
- **solid cyan (light blue) or white diamond** – for proximate traffic.
- **solid yellow or amber circle** – for intruders (i.e. aircraft which trigger a TA).
- **solid red square** – for threats (i.e. aircraft which trigger an RA).

Traffic display symbology is shown in Figure 12.

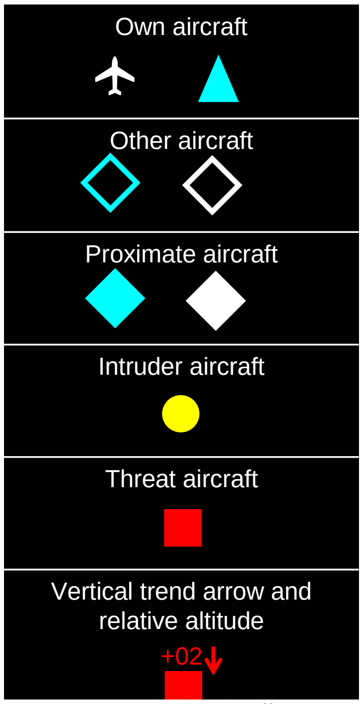



Figure 12: Standardised traffic display symbology.

Non-intruding traffic, which are within 6 NM and 1200 feet of own aircraft, are called proximate traffic and are differentiated from other traffic by a solid white or cyan (light blue) diamond. In the event of an advisory, this symbol indicates that the aircraft is not the intruder generating the advisory, when the closest traffic may not necessarily be the most threatening. Each symbol is displayed according to its relative position to own aircraft. The display accuracy depends on the selected scale. When the 10 NM scale is in use the positional accuracy is approximately ±1 NM in range and approximately ±10 degrees in bearing.

[17] The colour is distinct from the own aircraft symbol, i.e. if one is cyan the other is white, and vice versa.

Vertical data is also shown next to the relevant symbol (when the intruder is reporting altitude). The relative altitude is displayed in hundreds of feet, above the symbol if the intruder is above own aircraft and below the symbol in the opposite case. In some aircraft, the flight level of the intruder can be displayed instead of its relative altitude. Additionally an "up" or "down" arrow is shown when the target aircraft is climbing or descending, respectively, at more than or equal to 500 ft/min.

In some instances, TCAS may not have a reliable bearing for an intruder causing a TA or RA. Since bearing information is used for TCAS traffic display purposes only, the lack of bearing information does not affect the ability of TCAS II to issue TAs and RAs. When a "No-Bearing" TA or RA is issued, the threat level, as well as the range, relative altitude, and vertical rate of the intruder are written on the traffic display (without an accompanying symbol). This text is shown in red for an RA and in yellow or amber for a TA.

Because of the interference limiting algorithms, not all proximate transponder-equipped aircraft may be displayed in areas of high-density traffic. When a TA or RA occurs, the aircraft causing the TA or RA as well as all proximate traffic (i.e. traffic within the 6 NM radius and ±1200 feet) and within the selected display range, will be displayed.

The bearing displayed by TCAS II is not sufficiently accurate to support the initiation of horizontal manoeuvres based solely on the traffic display. Furthermore, the reference for the traffic display is own aircraft position which can lead to misinterpretation of relative motion of other traffic on the display. Consequently, horizontal manoeuvres based solely on information displayed on the TCAS II traffic display are prohibited.

### Altitude band for traffic display

The normal altitude band for the display of traffic is ±2700 feet from own aircraft. If an intruder causing a TA or RA is outside this altitude band, it will be displayed with the appropriate relative or reported altitude indicated. Proximate and other traffic outside the normal altitude band may also be displayed while a TA or RA is displayed.

In some implementations, as an option, a pilot selectable mode may be provided to allow the expansion of the normal altitude band. With this option, two additional modes, "Above" and "Below", are provided. In the "Above" mode, tracked traffic is displayed if it is between 2700 feet below and up to the maximum of 9900 feet above own aircraft. In the "Below" mode, tracked traffic is displayed if it is between 2700 feet above and up to the maximum of 9900 feet below own aircraft. These modes are intended to improve the pilot's awareness of proximate traffic while climbing ("Above" mode) or descending ("Below" mode). As a further option, a pilot selectable mode may be provided to permit the simultaneous selection of the "Above" and "Below" mode.

### RA display: classical instrumentation

The traffic display is incorporated into the centre of the Instantaneous Vertical Speed Indicator (IVSI) – see Figure 10 and Figure 11. A 2-NM radius circle is shown by dots or lines around the own aircraft symbol.

An RA is shown by the display of a red arc, which indicates the range of vertical speeds, which are to be **avoided**. When appropriate, a green arc, shown next to the red arc, indicates to the pilot that he should manoeuvre the aircraft to reach the required vertical speed, shown in the green arc. If there is more than one threat, two red arcs may flank the range of the required vertical speeds.

Table 1 shows examples of TCAS II advisories as shown on an IVSI implementation.

### EFIS (Electronic Flight Instrument System)

On Electronic Flight Instrument System (EFIS) cockpit displays TCAS information is shown on the Primary Flight Display (PFD) for RAs and the Navigation Display (ND) for the traffic display (see Figure 11).

There are two PFD concepts:

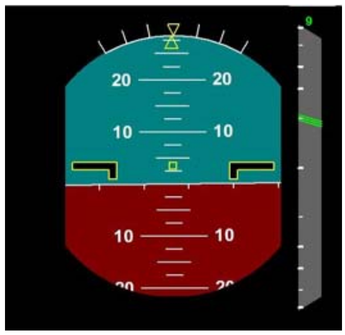
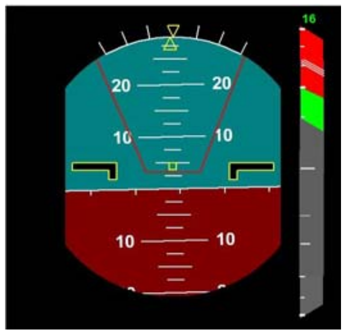
- display on the artificial horizon: a resolution advisory is shown by a red or orange isosceles trapezoid delineating an area showing the flight attitude values which are to be avoided. This provides direct guidance on the pitch angle to be achieved by the pilot. This form of display does not include any green fly-to area.
- display on the vertical speed indicator: the RA is shown in the same way as in "classic" cockpits. A red area marks the range of vertical speeds to be avoided, a green area indicates to the pilot the required vertical speed.

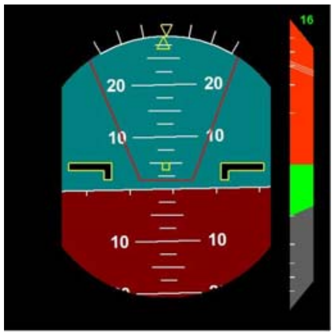
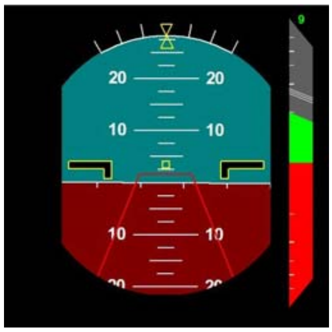
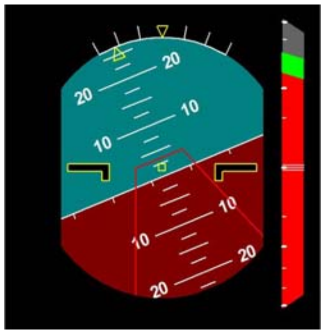
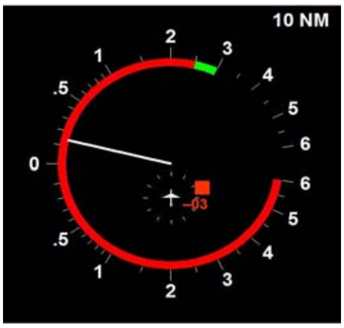
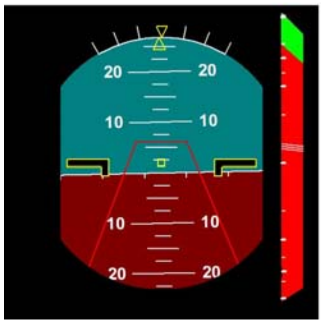
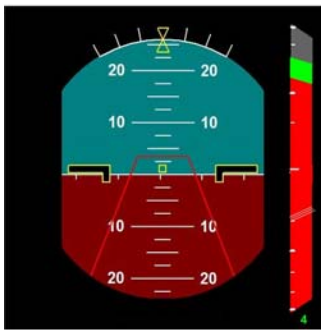
Table 1 shows examples of TCAS II advisories as shown on EFIS instrumentation.

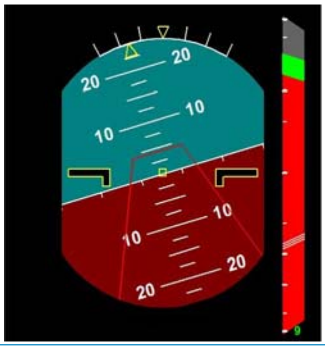
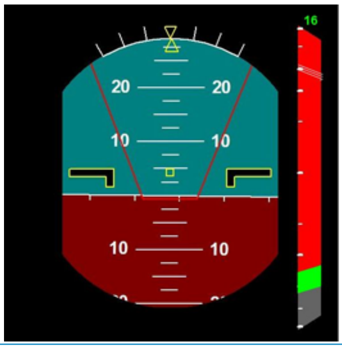
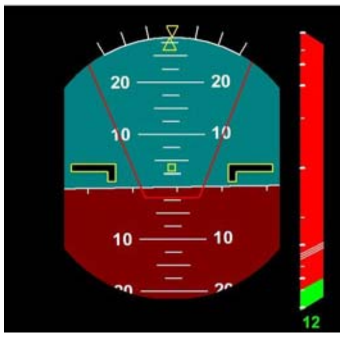
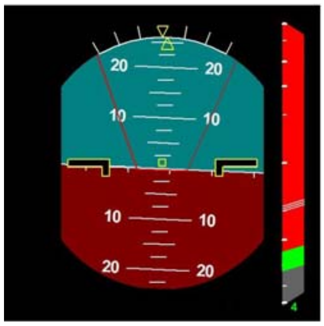
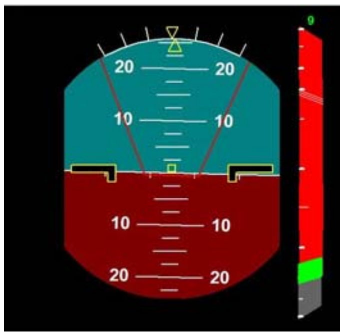
### Aural annunciations

Loudspeakers located in the cockpit alert the crew, by means of aural annunciations, of TCAS II advisories. Additionally, some implementations provide aural annunciations via the crew's headsets. All aural annunciations are inhibited below 500 feet AGL or when higher priority warning system (windshear or GPWS) has an active warning. The aural messages are listed in Table 2 for version 7.0 and in Table 3 for version 7.1.

Table 1: TCAS II advisories as shown on (generic) IVSI and EFIS displays.

<table>
<tr><th>Advisory</th><th>Aural</th><th>IVSI</th><th>EFIS</th></tr>
<tr><td>Traffic advisory</td><td>Traffic, traffic</td><td>
</td><td>
</td></tr>
<tr><td>Adjust Vertical Speed<br>*(in this example reduction to 1000 ft/min.)*<br>*(version 7.0 only)*</td><td>Adjust vertical speed, adjust</td><td>
</td><td>
</td></tr>
</table>

| Advisory | Aural | IVSI | EFIS |
|---|---|---|---|
| Level Off<br>(initial RA)<br><br>*(version 7.1 only)* | Level off, level off |  |  |
| Level Off<br>*(weakening RA)*<br><br>*(version 7.1 only)* | Level off, level off |  |  |
| Climb | Climb, climb |  |  |
| Increase Climb | Increase climb, increase climb |  |  |
| Crossing Climb | Climb, crossing climb; climb, crossing climb |  |  |

| Advisory | Aural | IVSI | EFIS |
|---|---|---|---|
| Reversal Climb | Climb, climb NOW; climb, climb NOW |  |  |
| Descend | Descend, descend |  |  |
| Increase Descent | Increase descent, increase descent |  |  |
| Crossing Descend | Descend, crossing descend; descend, crossing descend |  |  |
| Reversal Descent | Descend, descend NOW; descend, descend NOW |  |  |

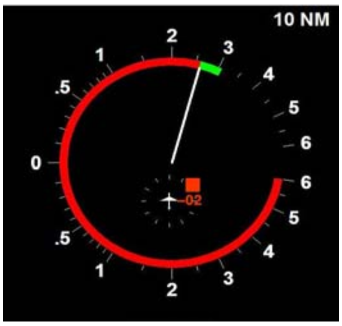
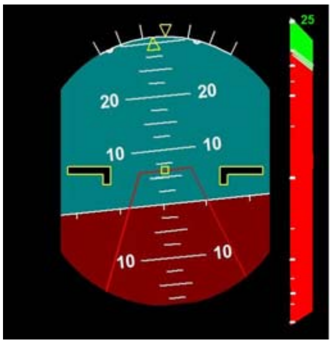
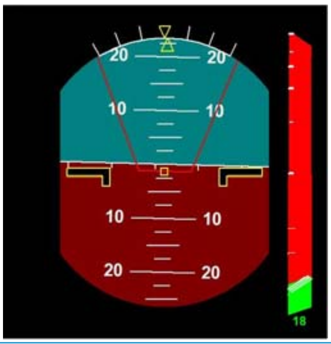
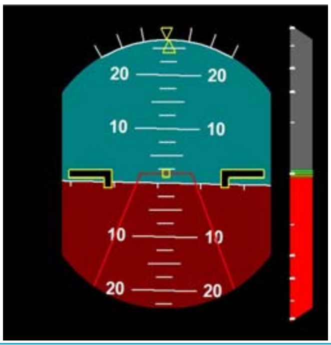
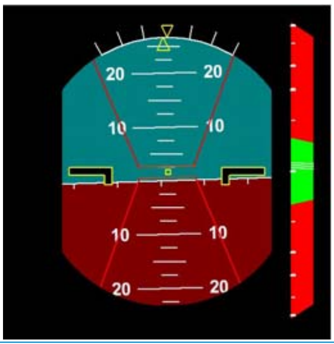
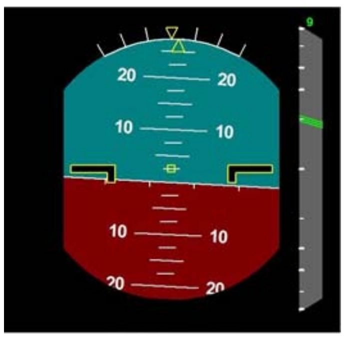
| Advisory | Aural | IVSI | EFIS |
|---|---|---|---|
| Maintain Vertical Speed | Maintain vertical speed, maintain |  |  |
| Crossing Maintain Vertical Speed | Maintain vertical speed, crossing maintain |  |  |
| Monitor Vertical Speed | Monitor vertical speed |  |  |
| Multi-threat RA | In this example:<br><br>Adjust vertical speed, adjust *(version 7.0)*<br><br>Level off, level off *(version 7.1)* |  |  |
| RA Removed | Clear of conflict |  |  |

Table 2: TCAS II version 7.0 RAs and aural annunciations.

| Upward sense | | | Downward sense | | |
|---|---|---|---|---|---|
| **RA** | **Required vertical rate (ft/min.)** | **Aural** | **RA** | **Required vertical rate (ft/min.)** | **Aural** |
| Climb | 1500 | Climb, climb | Descend | – 1500 | Descend, descend |
| Crossing Climb | 1500 | Climb, crossing climb; climb, crossing climb | Crossing Descent | – 1500 | Descend, crossing descend; descend, crossing descend |
| Maintain Climb | 1500 to 4400 | Maintain vertical speed, maintain | Maintain Descent | – 1500 to – 4400 | Maintain vertical speed, maintain |
| Maintain Crossing Climb | 1500 to 4400 | Maintain vertical speed, crossing maintain | Maintain Crossing Descent | – 1500 to – 4400 | Maintain vertical speed, crossing maintain |
| Reduce Descent [1] | 0<br>– 500<br>– 1000<br>– 2000 | Adjust vertical speed, adjust | Reduce Climb [1] | 0<br>500<br>1000<br>2000 | Adjust vertical speed, adjust |
| Reversal Climb [2] | 1500 | Climb, climb NOW; climb, climb NOW | Reversal Descent [2] | – 1500 | Descend, descend NOW; descend, descend NOW |
| Increase Climb [2] | 2500 | Increase climb, increase climb | Increase Descent [2] | – 2500 | Increase descent, increase descent |
| Preventive RA | No change | Monitor vertical speed | Preventive RA | No change | Monitor vertical speed |
| RA Removed | n/a | Clear of conflict | RA Removed | n/a | Clear of conflict |

[1] Replaced by "Level off, level off" in version 7.1

[2] Not possible as an initial RA

Table 3: TCAS II version 7.1 RAs and aural annunciations.

| Upward sense | | | Downward sense | | |
|---|---|---|---|---|---|
| RA | Required vertical rate (ft/min.) | Aural | RA | Required vertical rate (ft/min.) | Aural |
| Climb | 1500 | Climb, climb | Descend | – 1500 | Descend, descend |
| Crossing Climb | 1500 | Climb, crossing climb; climb, crossing climb | Crossing Descent | – 1500 | Descend, crossing descend; descend, crossing descend |
| Maintain Climb | 1500 to 4400 | Maintain vertical speed, maintain | Maintain Descent | – 1500 to – 4400 | Maintain vertical speed, maintain |
| Maintain Crossing Climb | 1500 to 4400 | Maintain vertical speed, crossing maintain | Maintain Crossing Descent | – 1500 to – 4400 | Maintain vertical speed, crossing maintain |
| Level Off [1] | 0 | Level off, level off | Level Off [1] | 0 | Level off, level off |
| Reversal Climb [2] | 1500 | Climb, climb NOW; climb, climb NOW | Reversal Descent [2] | – 1500 | Descend, descend NOW; descend, descend NOW |
| Increase Climb [2] | 2500 | Increase climb, increase climb | Increase Descent [2] | – 2500 | Increase descent, increase descent |
| Preventive RA | No change | Monitor vertical speed | Preventive RA | No change | Monitor vertical speed |
| RA Removed | n/a | Clear of conflict | RA Removed | n/a | Clear of conflict |

[1] New RA in version 7.1, replacing "Adjust vertical speed, adjust" from version 7.0

[2] Not possible as an initial RA

# SURVEILLANCE

## THE SURVEILLANCE FUNCTION

The surveillance function enables a TCAS II equipped aircraft to interrogate surrounding Mode S and Mode A/C transponders. The requirement is to determine the relative positions and altitudes of the intruder aircraft. TCAS II can simultaneously track up to 30 aircraft, within a nominal range of 14 NM for Mode A/C targets and 30 NM for Mode S targets.

Own aircraft will use the air data computer (which typically reports own altitude in 1-foot increments) as the source of altitude for own TCAS II calculations. For intruders the altitude used will be in 25-foot increments (when available) for Mode S equipped aircraft or 100-foot increments for Mode A/C.

### Intruders fitted with Mode S transponders

TCAS II surveillance of Mode S equipped aircraft is based on the selective address feature of the Mode S transponder. TCAS II listens for the spontaneous transmissions (squitters) sent once per second by Mode S transponders. The individual address of the sender is contained within the squitter.

Following receipt of a squitter, TCAS II sends a Mode S interrogation to the Mode S address contained in the message. TCAS II uses the reply received to determine range, bearing and altitude of the intruder aircraft.

TCAS II tracks the range, bearing, and altitude of each Mode S aircraft within cover. This data is provided to the collision avoidance logic to determine the requirement for TAs or RAs.

### Intruders fitted with Mode A transponders

Aircraft equipped with only Mode A transponders are not tracked nor detected by TCAS II because TCAS II does not use Mode A interrogations.

### Intruders fitted with Mode A/C transponders

TCAS II uses a modified Mode C interrogation to interrogate Mode A/C transponders. This interrogation is known as the *Mode C only all-call*.

If the aircraft is equipped with a Mode A/C transponder but does not provide altitude information (Mode C) this aircraft will be tracked as a non-altitude reporting target using range and bearing information and it will be shown on TCAS traffic display. Neither a data tag nor a trend arrow will be shown with the traffic symbol for an intruder that is not reporting altitude. TAs will be generated against non-altitude reporting aircraft when the range test for TA generation is satisfied. Non-altitude reporting aircraft are deemed to be at the same altitude as own aircraft (i.e. the worst case scenario).

The replies from Mode A/C transponders are tracked in range, bearing and altitude. This data is provided to the collision avoidance logic to determine the requirement for TAs or RAs.

Synchronous and non-synchronous garbling problems, and ground-reflected replies, make it more complicated for TCAS II to monitor Mode A/C equipped aircraft than those equipped with Mode S transponders.

When a *Mode C only all-call* interrogation is sent by TCAS, all Mode A/C transponders, which receive it, reply. Due to the duration of the reply, all Mode A/C equipped aircraft, at a similar range from the TCAS aircraft, can produce replies which overlap when received by the TCAS aircraft. This is described as *synchronous garble*.

Various techniques are employed to reduce this phenomenon:

- Algorithms allow the reliable decryption of up to three overlapping replies.
- The combined use of a sequence of interrogations of variable power and suppression pulses permit the reduction of the number of transponders replying to any individual interrogation. This technique, known as *whisper-shout*, takes advantage of differences between the receiver sensitivity of transponders and the transponder antenna gains of intruder aircraft.
- Another technique for reducing synchronous garble is the use of directional transmissions, which reduces the number of potential overlapping replies. However, slightly overlapping coverage must be provided to ensure 360 degree coverage.

Non-synchronous garble is caused by the receipt of undesired transponder replies, which follow an interrogation sent by a surveillance radar or another TCAS. These replies, called FRUIT (False Replies from Unsynchronised Interrogator Transmissions) are transitory. They are identified and discarded by reply-to-reply correlation algorithms. The probability that a surveillance track based on FRUIT replies will be started and maintained is extremely low.

Avoiding the initiation of surveillance tracks based on multi-path replies is an aspect of TCAS II design. The multi-path effect is caused by the reflection of an interrogation by flat ground, which produces more than one reply, to the interrogation, coming from the same aircraft. The reflected reply is of a lower intensity. To control this effect, the direct-path power level is used; it determines the minimum triggering level of the TCAS II receiver. This technique, called DMTL (Dynamic Minimum Triggering Level) discards these delayed and weaker signals.

## INTERFERENCE LIMITING

The surveillance function contains a mechanism limiting electromagnetic interference in the 1030/1090 MHz band. Each TCAS II unit is designed to limit its own transmissions. TCAS II is able to count the number of TCAS units, within cover, due to the broadcast, every 8 seconds, of a *TCAS presence* message, which contains the Mode S address of the sender. As the number of TCAS units increases above a certain level, the number and the power of the interrogations are reduced.

Additionally, in dense traffic areas at altitudes lower than FL180, the rate of interrogation, usually 1 per second, becomes 1 per 5 seconds for intruders considered non-threatening and at least 3 NM from own aircraft, and which would not trigger an advisory in the next 60 seconds. This mechanism is called "reduced surveillance".

These interference limiting techniques aim to avoid transponder overload due to high levels of its own TCAS interrogation and replies to interrogations from other TCAS aircraft. The result, in very high-density airspaces, is that the TCAS surveillance range might be reduced to as little as 5 NM.

## HYBRID SURVEILLANCE

Hybrid surveillance is a method that decreases the number of Mode S surveillance interrogations made by an aircraft's TCAS II unit. This feature, new to TCAS version 7.1, may be included as optional functionality in TCAS II units.

TCAS II units equipped with hybrid surveillance use passive surveillance instead of active surveillance to track intruders that meet validation criteria and are not projected to be near-term collision threats. With active surveillance, TCAS II transmits interrogations to the intruder's transponder and the transponder replies provide range, bearing, and altitude for the intruder. With passive surveillance, position data provided by an on-board navigation source is broadcast from the intruder's Mode S transponder. The position data is typically based on GNSS and received on own aircraft by the use of Mode S extended squitter, i.e. 1090 MHz ADS-B, also known as 1090ES. Standards for Hybrid Surveillance have been published in RTCA DO-300.

The intent of hybrid surveillance is to reduce the TCAS II interrogation rate through the judicious use of validated ADS-B data provided via the Mode S extended squitter without any degradation of the safety and effectiveness of TCAS II.

Active interrogations are used to track any intruder which is perceived to be a threat (see Figure 13).

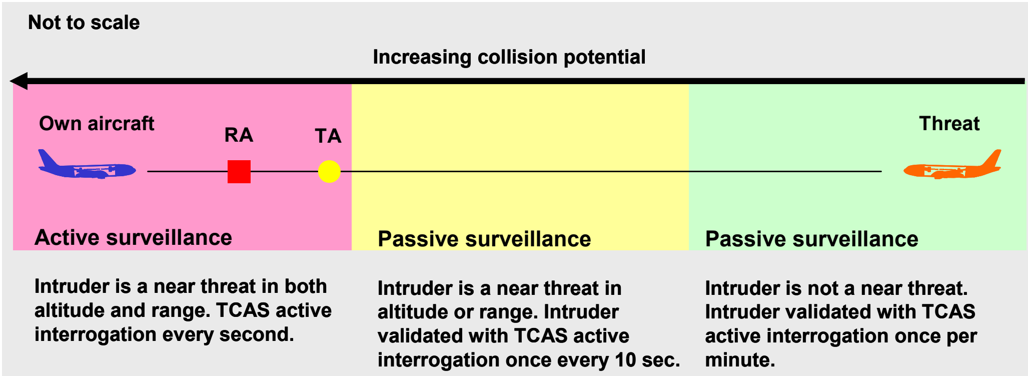


Figure 13: Hybrid surveillance – transition from passive to active surveillance.

## THE COLLISION AVOIDANCE LOGIC

### Concepts

The collision avoidance logic, or CAS (Collision Avoidance System) logic is based on two basic concepts: the sensitivity level and the warning time. Although the CAS parameters are strictly defined, the complexity of collision avoidance logic makes prediction of exact behaviour in real-time difficult.

The sensitivity level is a function of the altitude and defines the level of protection. Sensitivity is greater (i.e. the warning time is greater) at higher altitude. The warning time is mainly based on the estimated time-to-go (and not distance-to-go) to the Closest Point of Approach (CPA). The warning time allows for additional range protection in case of low closure rates.

### Sensitivity levels

A trade-off is needed between the protection that the CAS logic must provide and the unnecessary alarms linked to the predictive nature of the logic. This balance is achieved by controlling the Sensitivity Level (*SL*), which adjusts the dimensions of a theoretical "protected volume" (see Figure 14 and Figure 15) around each TCAS equipped aircraft. The sensitivity level (*SL*) depends on the altitude of own aircraft and varies from 1 to 7 (see Table 4). The greater the *SL*, the more protection is provided. The *SL* is also coordinated with the intruder (higher *SL* applies to both aircraft). See page 37 for more information about threat detection.

Typically, the following selections of TCAS/transponder modes of operations on the transponder panel are available (Figure 16): "**STAND-BY"**, **"ALT-OFF"**, **"XPNDR"**, **"TA-ONLY"**, and **"AUTOMATIC"** or **"TA/RA"**. Note: some implementation may not have the **"ALT-REPTG-OFF"** selection. The modes of TCAS/transponder operations are explained in Table 5.

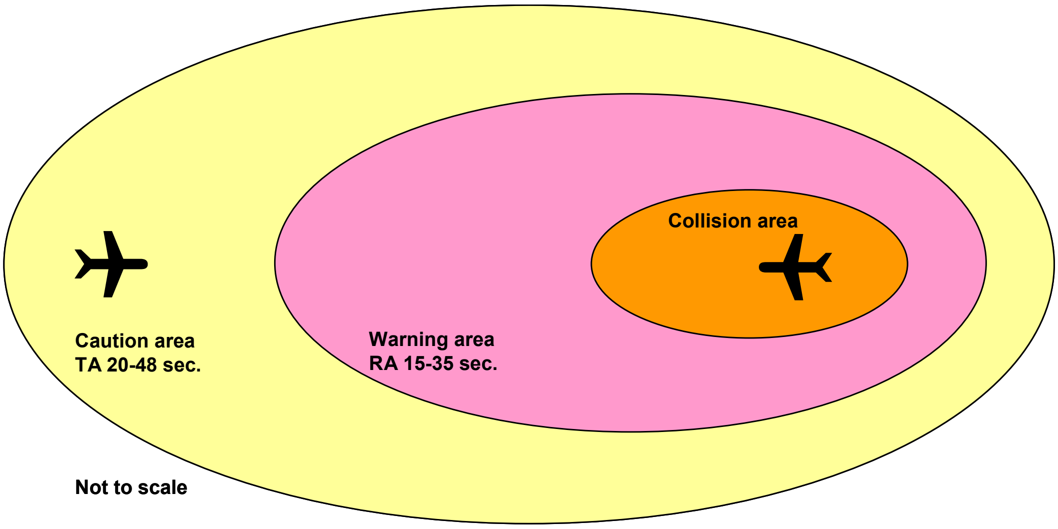



Figure 14: TCAS II protected volume (horizontal view).

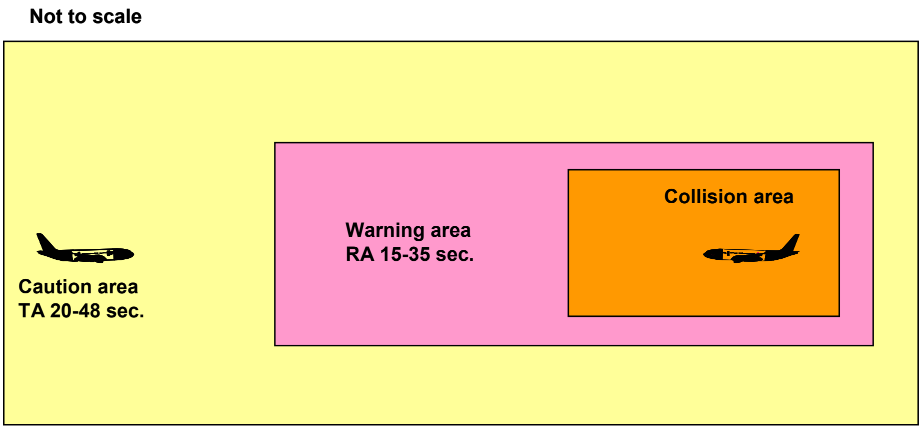



Figure 15: TCAS II protected volume (vertical view).


Figure 16: Example of TCAS/transponder panel (Boeing 737-700).

Table 4: Sensitivity levels.

| Own Altitude | Sensitivity levels (*SL*) |
|---|---|
| Stand-by mode | 1 |
| 0 – 1000 ft AGL | 2 |
| 1000 – 2350 ft AGL | 3 |
| 2350 ft AGL – FL50 | 4 |
| FL50 – FL100 | 5 |
| FL100 – FL200 | 6 |
| FL200 – FL420 | 7 |
| Above FL420 | 7 |

The CAS logic converts the modes into sensitivity levels as follows:

- When **"STAND-BY"** mode is selected by the pilot, the TCAS equipment does not transmit interrogations. Normally, this mode is used when the aircraft is on the ground or when there is a system malfunction. *SL1* is assumed.
- In **"TA-ONLY"** mode, the TCAS equipment performs the surveillance function. However, only TAs are provided. The equipment does not provide any RAs. A "TA-only" aircraft will be treated by other TCAS aircraft as unequipped. *SL2* is assumed.
- When the pilot selects **"AUTOMATIC"** or **"TA/RA"** mode, TCAS automatically selects the *SL* based on the current altitude of own aircraft. *SL*2 is selected when the TCAS aircraft is between 0 and 1000 feet AGL (Above Ground Level) as indicated by the radar altimeter. This *SL* corresponds to **"TA-ONLY"** mode. In *SL*s 3 through 7, TAs and RAs are provided. To determine the sensitivity level required above 2600 feet AGL, the logic uses the standard pressure altitude (altimeter setting 1013.25 hPa) indicated by the barometric altimeter. Table 4 provides the altitude threshold at which TCAS automatically changes *SL* and the associated *SL* for that altitude band.

#### Warning times

TCAS II operates on relatively short time scales. The nominal maximum generation time for a TA is 48 seconds before the CPA. For an RA the time is 35 seconds. The time scales are shorter at lower altitudes. Unexpected or sudden aircraft manoeuvres may cause an RA to be generated with much less lead time. It is even possible that an RA will not be preceded by a TA if a threat is imminent. See page 37 for more information about threat detection.

### CAS FUNCTIONS

TCAS II is designed to ensure collision avoidance between any two aircraft, with a closure speed of less than 1200 knots and with vertical rates of less than 10,000 ft/min.

TCAS II significantly improves flight safety. However, it cannot entirely eliminate all risks of collision. Additionally, it might itself induce a risk of collision.

In normal operation, the CAS logic works on a 1-second cycle. The CAS logic functions used to perform the collision avoidance task are shown in Figure 17. The following description provides a general understanding of these functions. There are many other parameters, notably those relating to the encounter geometry, that are beyond the scope of this document.

Table 5: Transponder modes of operations.

| Operating mode | Trans-ponder | TCAS | RAs generated against | | Mode of operation |
|---|---|---|---|---|---|
| | | | Own aircraft | Intruder | |
| Stand-by (STBY) | Off | Off | No | No | Own aircraft invisible to both ATC radars/surveillance and other TCAS II equipped aircraft.<br><br>**To be used at the gate only or while taxiing in and out.** |
| XPNDR | On | Off | No | Yes | Own aircraft visible to ATC radars/surveillance and other TCAS II equipped aircraft. Uncoordinated RAs can be generated by intruders.<br><br>**Departure: Select *XPNDR* during push-back.**<br>**Arrival: Select *XPNDR* once the runway has been vacated.** |
| ALT RPTG OFF | On, no altitude reporting | Off | No | No | Own aircraft visible to ATC radars/surveillance without altitude and other TCAS II equipped aircraft but no RAs can be generated.<br><br>**Should be selected if requested by ATC (if altitude reports are incorrect) and in other circumstances as per Operations Manual.** |
| TA-Only | On | On (TA-only) | No | Yes | Own TCAS II can generate TAs only.<br>Other TCAS II aircraft can generate (uncoordinated) RAs. A "TA-only" aircraft treated as unequipped by other TCAS II aircraft.<br><br>**Use limited to the situations described in the Operations Manual, such as engine failure, emergency descent and other specific conditions.** |
| TA/RA<br>or<br>AUTOMATIC | On | On | Yes | Yes | Own aircraft can generate RAs. RAs with other TCAS II aircraft are coordinated.<br><br>**Standard mode of operation.** |

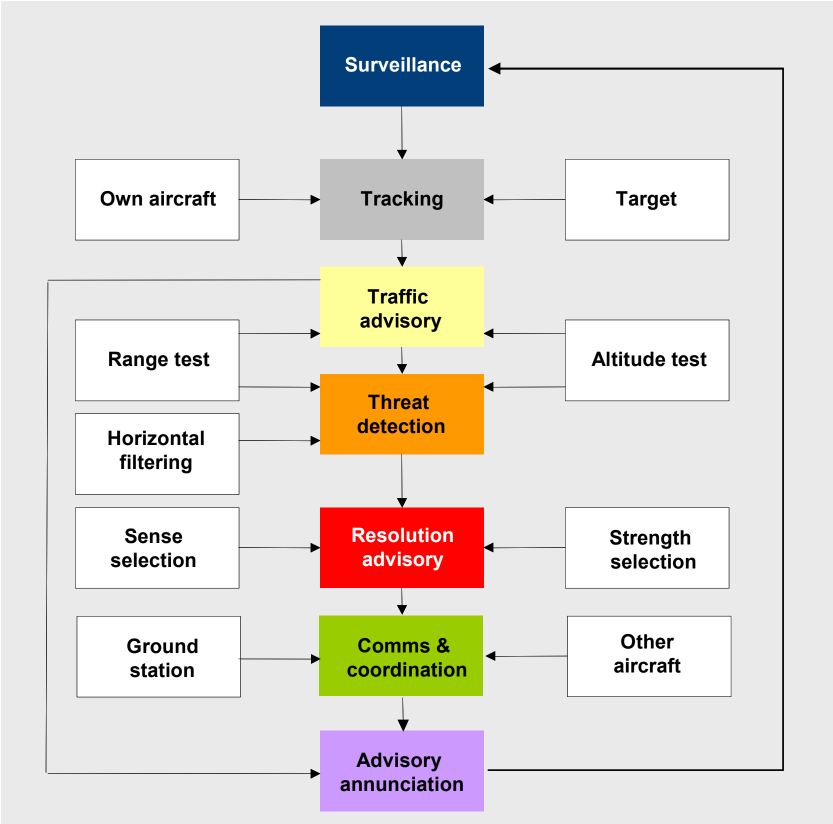



Figure 17: CAS logic functions.

A complete description of TCAS II version 7.1 logic can be found in the TCAS II MOPS (Minimum Operational Performance Standards) published by RTCA (document DO-185B) in the USA and published by EUROCAE (document ED-143) in Europe.

### Tracking

Using the surveillance reports (slant range, bearing[18] and altitude) provided each second (every five seconds in case of "reduced surveillance"), the CAS logic computes the closure rate of each target within surveillance range, in order to estimate the time in seconds to CPA, and the horizontal miss distance at CPA.

In the case of Mode C equipped intruders, their replies are correlated with known tracks (or a new track is initiated) using altitude (100-foot quantisation) and smoothed through the tracker. For Mode S equipped aircraft, their replies are correlated with tracks using aircraft address and altitude (25-foot or 100-foot quantisation, depending on the generation of the equipment) and smoothed through the tracker. The 25-foot altitude reporting results in better tracking and thus more effective RAs.

If the target aircraft is equipped with an altitude-coding transponder, the CAS logic calculates the altitude of the target at CPA. The intruder's vertical speed is obtained by measuring the time it takes to cross successive 100-foot or 25-foot altitude increments, which depends upon the type of altitude coding transponder. Bearing of intruder estimated through use of the directional antenna.

[18] Bearing is not used when generating an alert: it is used only to display positions on the traffic display and, where possible, to suppress nuisance alerts through the operation of the miss distance filter (see Threat Detection on page 37).

The CAS logic uses the data from own aircraft pressure altimeter (1-foot precision)[19] and radar altimeter at lower altitudes. In this way, it determines own aircraft altitude, vertical rate, and the relative altitude and altitude rate of each target.

The outputs from the tracking algorithm (target range, horizontal miss distance at CPA, closure rate, relative altitude and relative altitude rate of the target aircraft) are supplied to the collision avoidance algorithms.

When the aircraft is below 1700 feet AGL, the CAS logic estimates the altitude of the intruder above the ground, using own pressure altitude, own radar altimeter and the pressure altitude of the intruder. If this estimated altitude is less than 380 feet, TCAS II considers the target to be on the ground, and so does not generate any TA or RA (see Figure 18).

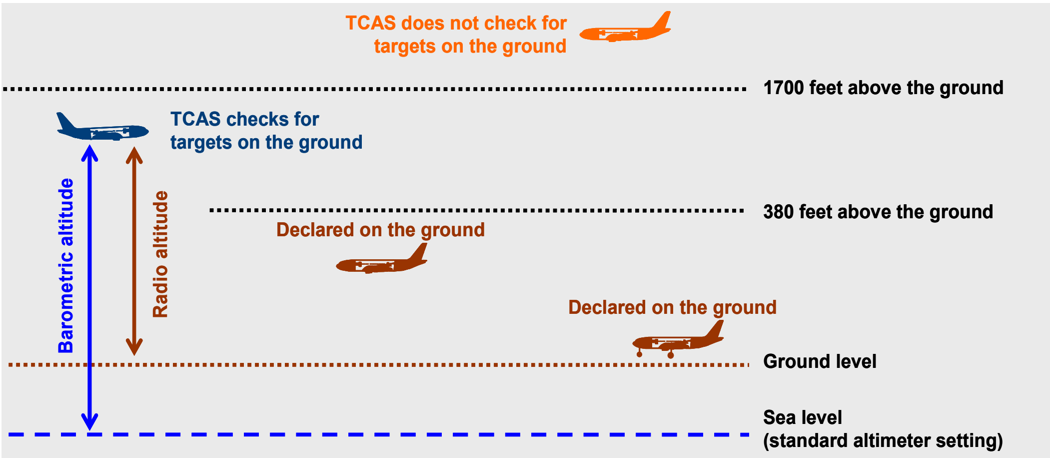


Figure 18: Target on-the-ground determination.

### Closest Point of Approach

The Closest Point of Approach (CPA) is defined as the instant at which the (slant) range between own TCAS II equipped aircraft and the intruder is at a minimum. Range at CPA is the smallest range between the two aircraft and time at CPA is the time at which it occurs.

In its predictions, TCAS II assumes the worst-case scenario, i.e. the aircraft are on a collision course. If the aircraft are indeed on a collision course then the estimate is accurate and the resulting RA will provide advice on how best to avoid an imminent collision. Otherwise – the aircraft are not on a collision course – the estimate is too large and that can lead to unnecessary RAs. From the collision avoidance perspective that does not matter because there is no risk of collision; however an unnecessary RA can be disruptive for both flight crew and ATC.

### Threat detection

In collision avoidance, time-to-go to the CPA, rather than distance-to-go to the CPA, is used. In its simplest form time-to-go to the CPA is calculated by dividing the slant range, between aircraft, by the closure rate.

The warning time, or *tau* ($\tau$), is a threshold in TCAS's threat detection logic with which time-to-go to the CPA is compared.

In order to detect threats, the TCAS II logic performs a Range Test and (if the Range Test passes) an Altitude Test on every altitude-reporting target on each cycle. Any target must pass both tests for it to be declared a threat.

[19] Some older airframes use own Mode C altitude (100-foot precision).

**Range Test.** The Range Test passes if the aircraft are currently close in range, or are projected to be close in range within the time threshold *tau*: "close in range" effectively means within a distance parameter called *DMOD*. The test is achieved by performing a single calculation of a modified time-to-go to the CPA. The modified time-to-go to the CPA is calculated by first decrementing the slant range by the parameter *DMOD* before dividing by the closure rate. This effectively provides a test on current range as well as a test on the time-to-go to the CPA. The test on current range is made in order to provide an alert in those situations when a threat would otherwise come very close in range without triggering a TA or RA (due to a slow closure encounter geometry).

In order to limit the number of operationally unnecessary RAs where the estimated horizontal miss distance (*HMD*, i.e. horizontal range, projected at CPA) is sufficient to render a collision avoidance manoeuvre unnecessary, refinements to the Range and Altitude Tests are included in the logic.

The Range Test uses a Miss Distance Filter (MDF) which is applied to suppress RAs if a reliable estimate of *HMD* is larger than the threshold *DMOD*. The MDF continually checks whether own aircraft or the threat aircraft manoeuvres, and if a manoeuvre is detected the *HMD* estimate is declared unreliable and the MDF is not used. Incidentally, this is the only case when the relative bearing of other aircraft is used in the collision avoidance logic.

**Altitude Test.** For the altitude test, separate calculations are performed to determine whether the aircraft are currently close in altitude (i.e. vertically separated by less than a threshold *ZTHR*) or are projected to be at the same altitude within a given time threshold.

The Altitude Test includes a Variable Vertical Threshold. Generally the time threshold in the Altitude Test is the time threshold *tau*. However, a reduced time threshold, the Time to Co-altitude Threshold (*TVTHR*), is used when own aircraft is deemed to be in level flight (i.e. vertical rate less than 600 ft/min.) or it is climbing or descending in the same sense as the intruder, but more slowly. The reduced time threshold allows time for any level-off manoeuvre by the intruder aircraft to be detected (which reduces the incidence of nuisance RAs) and also tends to result in any RA first being generated in a climbing/descending aircraft – rather than in the level aircraft (which tends to reduce the incidence of altitude crossing RAs being selected).

If both Range Test and Altitude Test pass then the intruder is declared a threat and an RA is generated.

The *tau*, *DMOD*, *TVTHR*, and *ZTHR* values are a function of the Sensitivity Level (*SL*) and are shown in Table 6. A further parameter, *ALIM*, (used when selecting the RA strength and direction: see below) is a function of altitude and is also shown in Table 6.

For a given intruder, the theoretical "protected volume" (see Figure 14 and Figure 15) around the TCAS equipped aircraft is generally a truncated sphere of a radius equal to the magnitude of the relative speed vector multiplied by the time *tau*. The volume is also laterally truncated by the operation of the MDF.

Generally, for a conflict geometry with a low vertical closure rate, the vertical triggering thresholds for RAs range from 600 to 800 feet, depending on the altitude of own aircraft. For a high vertical closure rate, an RA is triggered as soon as the estimated time to the moment when the threat and the own aircraft will be at co-altitude is lower than the appropriate *tau* value (see Table 6).

Depending on the geometry of the encounter, and the quality of the vertical track data, an RA may be delayed or not selected at all.

RAs cannot be generated for non-altitude reporting threats.

Table 6: Alert thresholds related to altitude.

| Own Altitude | *SL* | *tau* values (sec) | | *TVTHR* (sec) | *DMOD* values (NM) | | *ZTHR* (feet) Alt. Threshold | | *ALIM* (feet) |
|---|---|---|---|---|---|---|---|---|---|
| | | TA | RA | RA | TA | RA | TA | RA | RA |
| 0 – 1000 ft AGL | 2 | 20 | no RA | no RA | 0.30 | no RA | 850 | no RA | no RA |
| 1000 – 2350 ft AGL | 3 | 25 | 15 | 15 | 0.33 | 0.20 | 850 | 600 | 300 |
| 2350 ft AGL – FL50 | 4 | 30 | 20 | 18 | 0.48 | 0.35 | 850 | 600 | 300 |
| FL50 – FL100 | 5 | 40 | 25 | 20 | 0.75 | 0.55 | 850 | 600 | 350 |
| FL100 – FL200 | 6 | 45 | 30 | 22 | 1.00 | 0.80 | 850 | 600 | 400 |
| FL200 – FL420 | 7 | 48 | 35 | 25 | 1.30 | 1.10 | 850 | 700 | 600 |
| Above FL420 | 7 | 48 | 35 | 25 | 1.30 | 1.10 | 1200 | 800 | 700 |

## TRAFFIC ADVISORY

The traffic advisory function uses a simplified algorithm, similar to the RA generation logic but with greater alert thresholds (see Table 6). The vertical triggering thresholds for TAs are 850 feet above and below the TCAS equipped aircraft below FL420 and 1200 feet above FL420.

A non-altitude reporting target will trigger the generation of a TA if the range test is satisfied, on the basis of the same *tau* values associated with the RA (in *SL*2 where no RAs are issued the *SL*3 threshold of 15 seconds is used).

If an intruder is not the cause of a TA, but is located within 6 NM and ±1200 feet of the TCAS equipped aircraft, it will be displayed as proximate traffic.

## RESOLUTION ADVISORY

### Advisory selection

When a threat is declared, a two-step process is used to select an appropriate RA:

**Sense selection.** The first step is to select the sense (upward or downward avoidance) of the RA. Using the results of the vertical and horizontal tracking, the logic models the intruder's path to the CPA. Figure 19 shows the paths that would result if own aircraft climbed or descended at 1500 ft/min. taking into account a standard pilot response (reaction time of 5 seconds and vertical acceleration of 0.25*g*). The CAS logic computes the predicted vertical separation for each of the two cases and normally selects the sense, which provides the greater vertical distance.

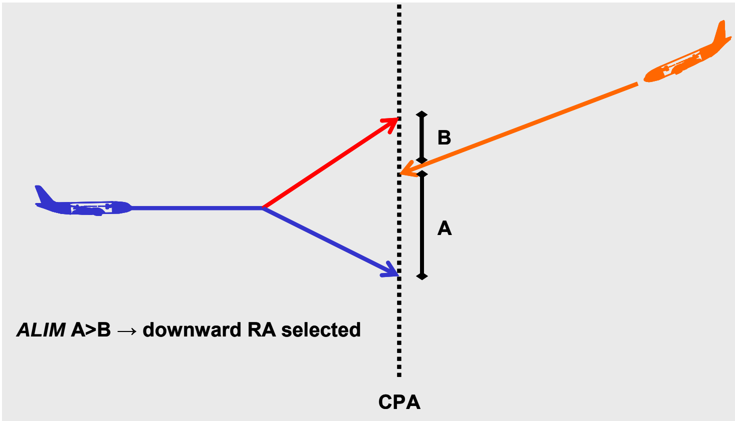



Figure 19: RA sense selection.

In the cases where an altitude crossing is projected before the CPA, the CAS logic will pick the sense that avoids crossing, provided that the resulting vertical distance at CPA is sufficient.

Figure 20 illustrates this case. The desired amount of vertical safe distance (*ALIM)*, varies from 300 to 700 feet, depending on own aircraft's altitude regime. If *ALIM* cannot be achieved, a crossing RA will be issued (see Figure 21). However, delaying mechanisms aim at reducing the incidence of crossing RAs.

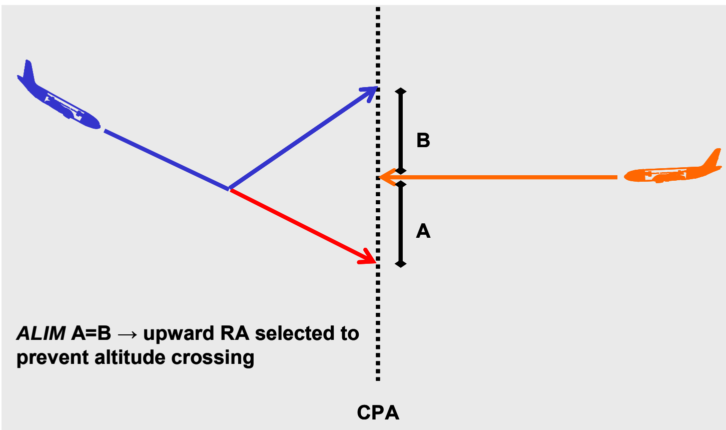



Figure 20: Non-crossing RA.

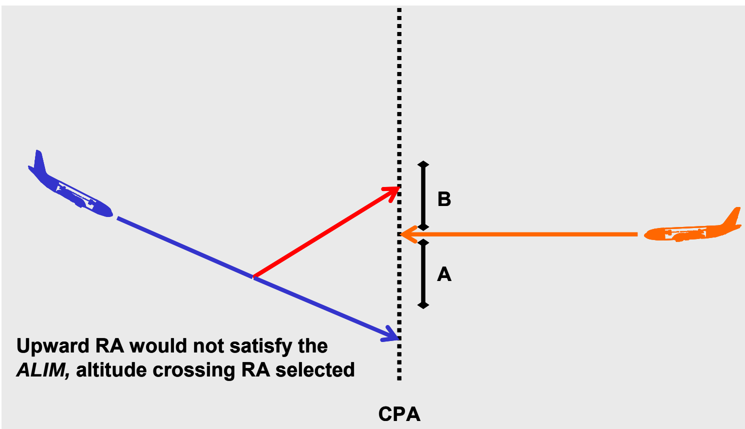



Figure 21: Crossing RA.

**Strength selection.** In the second step the strength of the RA is chosen. The strength is the degree of restriction placed on the flight path either by limiting the current vertical speed or requiring a modified vertical speed. TCAS II is designed to select the RA strength that is the least disruptive to the existing flight path, while still providing *ALIM* feet of separation (see Figure 22, in which the vertical speed limit of 500 ft/min. would be selected as the lowest strength RA which achieves *ALIM* separation in version 7.0 or 0 ft/min. in version 7.1).

An exception to the *least disruptive RA* rule was introduced in version 7.1. After version 7.0 was implemented, responses with the incorrect vertical sense to initial "Adjust vertical speed, adjust" RAs were observed. The correct response to this RA is always a reduction in vertical speed to 0, 500, 1000 or 2000 ft/min. as indicated on the cockpit instruments. Several encounters were observed where the pilot increased the vertical speed, causing further reduction in separation between own aircraft and the intruder.

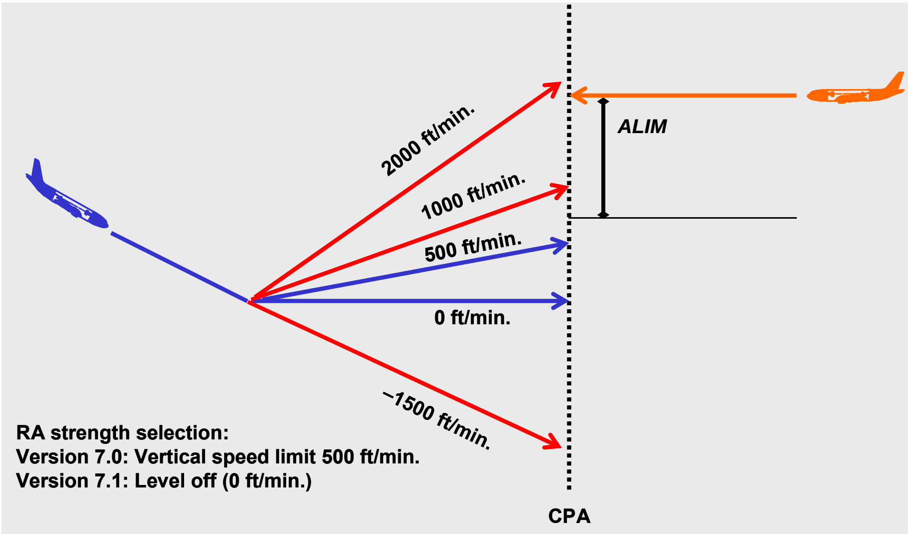


Figure 22: RA strength selection.

In version 7.1 the "Adjust vertical speed, adjust" RA has been replaced with a new "Level off, level off" RA. The Adjust Vertical Speed RA in version 7.0 requires a reduction of the vertical rate to 0, 500, 1000 or 2000 ft/min. The "Level off, level off" RA requires a reduction of vertical rate to 0 ft/min. (see also section on version 7.1 on page 12). The vertical speed reduction to 0 ft/min. is sometimes stronger than needed, however this change was made to make the intention of the vertical speed limitation, unambiguous and more intuitive (i.e. a move toward level flight).

In order to reduce the frequency of initial RAs that reverse the existing vertical rate of own aircraft, when two TCAS equipped aircraft are converging vertically with opposite rates and are currently well separated in altitude, TCAS II will first issue an RA limiting the vertical speed (i.e. "Adjust vertical speed, adjust" in version 7.0 or "Level off, level off" in version 7.1) to reinforce the pilots' likely intention to level off at adjacent standard flight levels. If no response to this initial RA is detected, or if either aircraft accelerates vertically toward the other aircraft, the initial RA will strengthen as required.

After the initial RA is selected, the CAS logic continuously monitors the vertical separation that will be provided at CPA and if necessary, the initial RA will be modified (see section below).

Advisories and associated climb/descent rates are listed in Table 2 for version 7.0 and in Table 3 for version 7.1.

**Subsequent advisories**

During the course of the encounter, the RA strength is evaluated every second. Occasionally, the threat aircraft will manoeuvre vertically in a manner that thwarts the effectiveness of the issued RA. In these cases, the initial RA will be modified to either increase the strength or reverse the sense of the initial RA (when the initially issued RA is no longer predicted to provide sufficient vertical spacing). Pilots are expected to respond within 2.5 seconds to changes to the RA and with 0.35*g* manoeuvre to increase rate or reversal RAs[20].

**Strengthening RAs.** In version 7.0 an RA limiting the vertical speed (i.e. Monitor Vertical Speed, Maintain Vertical Speed, Crossing Maintain Vertical Speed, Adjust Vertical Speed RAs) is strengthened by changing to a more restrictive vertical speed limit Adjust Vertical Speed RA or to a Climb or Descend RA (required vertical rate 1500 ft/min.).

In version 7.1 an RA limiting the vertical speed (i.e. Monitor Vertical Speed, Maintain Vertical Speed, Crossing Maintain Vertical Speed, Level Off RAs) is strengthened by changing it to a Climb or Descend RA (required vertical rate 1500 ft/min.).

In both versions, a Climb or Descend RA is strengthened to an Increase Climb or Increase Descent RA (required increase of vertical rate from 1500 to 2500 ft/min.).

Figure 23 shows an encounter where it is necessary to increase the descent rate from the 1500 ft/min. required by the initial Descend RA to 2500 ft/min. (i.e. Increase Descent RA).

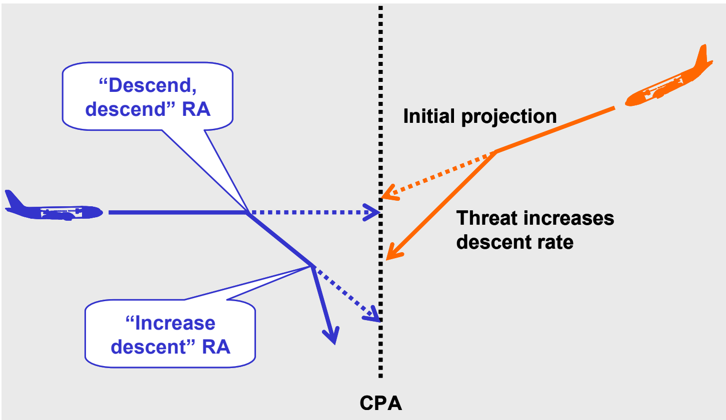


Figure 23: Increase vertical rate RA.

**Reversal RAs.** Both versions 7.0 and 7.1 permit sense reversals in coordinated encounters (both aircraft TCAS II equipped) and in encounters with non-TCAS equipped threats. Figure 24 shows an encounter where an initial Climb RA requires reversal to a Descend RA after the threat aircraft manoeuvres.

In version 7.1, new reversal logic was added to detect "vertical chase with low vertical miss distance" geometries, i.e. two aircraft converging in altitude remain within 100 feet (see Figure 5). This type of scenario can occur when one aircraft is not following the RA or is not TCAS II equipped and follows an ATC instruction or performs an avoidance manoeuvre based on visual acquisition (see section on version 7.1 on page 12).

Only one RA sense reversal can occur per encounter. In coordinated encounters (i.e. both aircraft TCAS II equipped), the aircraft with the higher Mode S address will be the one which will declare a reversal. The aircraft with the lower Mode S is not permitted to declare a reversal.

[20] E.g. Climb, Increase Climb, Reversal Climb, Descend, Increase Descent, Reversal Descent.

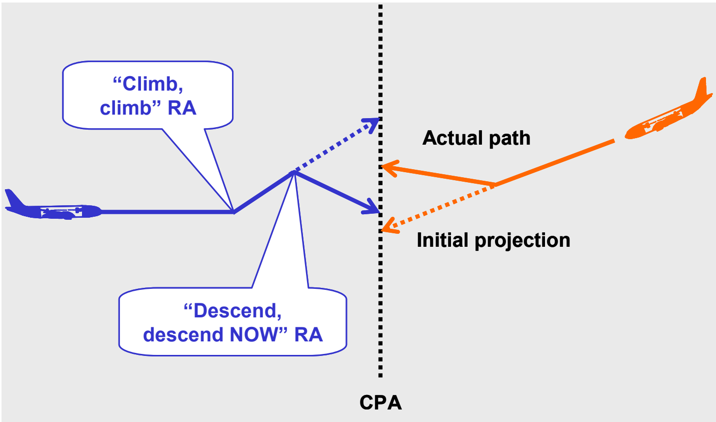



Figure 24: Sense reversal RA.

**Weakening RAs.** During an RA, if the CAS logic determines that the response to an RA has provided the vertical distance equal or greater to *ALIM* prior to CPA (i.e. the aircraft have become safely separated in altitude while not yet safely separated in range), the initial RA will be weakened to either a "Adjust vertical speed, adjust" RA in version 7.0 (vertical speed reduction 0 ft/min.) or to a "Level off, level off" RA in version 7.1 (see Figure 25). This is done to minimise unnecessary deviations from the original altitude.

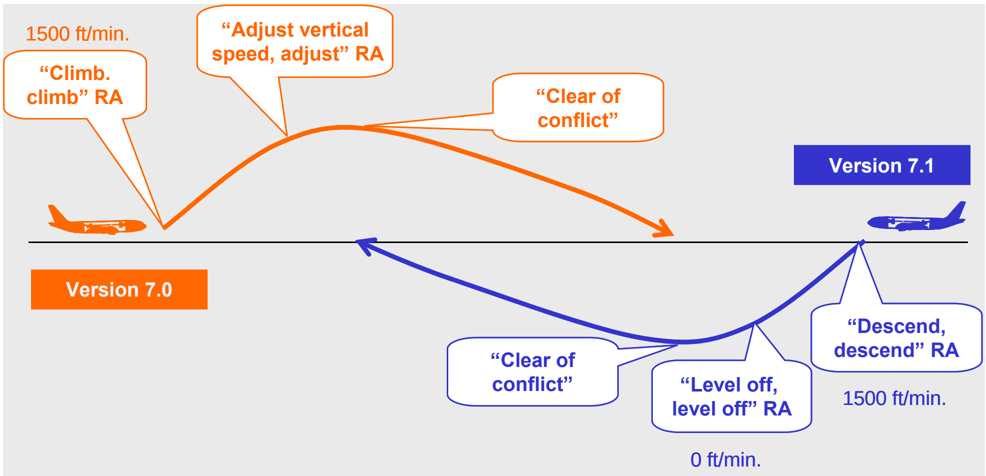



Figure 25: Comparison of weakening RAs in version 7.0 and version 7.1.

## Multi-threat logic

TCAS II is able to handle multi-threat situations either by attempting to resolve the situation with a single RA (i.e. pass above all threat aircraft or pass below all threat aircraft) which will maintain safe vertical distance from each of the threat aircraft, or by selecting an RA that is a composite of non-contradictory climb and descend restrictions (i.e. requiring own aircraft to pass below some aircraft and pass above others).

It is possible that the RA selected in such encounters may not provide *ALIM* separation from all intruders. An initial multi-threat RA can be any of the initial RAs shown in Table 2 for version 7.0 and in Table 3 for version 7.1, or a combination of upward and downward sense RAs. The example in Figure 26 shows a multi-threat RA (one threat above, one threat below) which will be announced "Adjust vertical speed, adjust" in version 7.0 or "Level off, level off" in version 7.1. The multi-threat logic is designed to utilise increase rate RAs and reversals RAs to best resolve multi-threat encounters.

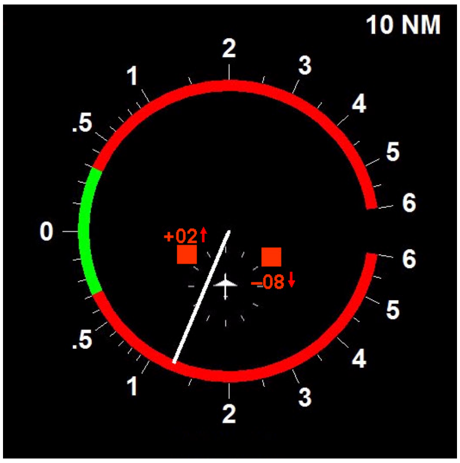


Figure 26: IVSI example showing a multi-threat encounter.

### RA termination

As soon as the intruder ceases to be a threat (when the range between the TCAS II aircraft and threat aircraft increases or when the logic considers that the horizontal distance at CPA will be sufficient), the resolution advisory is cancelled and a "Clear of conflict" annunciation is issued. The pilot then is required to return to the initial clearance, unless otherwise instructed by ATC.

When the tracking of the threat has been lost, an RA will be removed and terminated but no "Clear of conflict" annunciation made.

### RA inhibition

The CAS logic may inhibit a "Climb" or "Increase climb" RA in some cases due to aircraft climb performance limitations at high altitudes, or when the aircraft is in the landing configuration. These limitations are known by the logic, which will then choose a viable alternative RA. The limitations are set beforehand by the certification authorities according to the type of aircraft.

For all aircraft, pre-defined limitations apply at lower altitudes to prevent RAs in the proximity to the ground (see Table 7). RAs are inhibited based on radar altimeter reported heights.

Table 7: TCAS alert generation inhibitions.

| Alert type | Alert inhibited below |
|---|---|
| Increase Descent RA | 1550 ft (±100 ft) AGL |
| Descend RA | 1100 ft (±100 ft) AGL |
| All RAs | 1000 ft (±100 ft) AGL |
| All TCAS aural alerts | 500 ft (±100 ft) AGL |

TCAS II will not make any aural TA or RA annunciations when a GPWS (Ground Proximity Warning System) or TAWS (Terrain Avoidance Warning System), windshear detection, or stall warnings have been activated. Moreover, in these situations TCAS II will automatically be placed into the TA-only mode.

### TCAS-TCAS coordination

In a TCAS-TCAS encounter (i.e. an encounter between two TCAS II equipped aircraft), each aircraft transmits interrogations to the other via the Mode S data link, in order to ensure the selection of complementary resolution advisories. Coordination interrogations use the same 1030/1090 MHz channels as surveillance interrogations and are transmitted at least once per second by each aircraft for the duration of the RA. Each aircraft continues to transmit coordination interrogations to the other as long as the other is considered a threat.

Coordination interrogations contain information about an aircraft's intended manoeuvre with respect to the threat. This information is expressed in the form of a complement: e.g. if one aircraft has selected an "upward-sense" advisory, it will transmit a message to the threat, restricting the threat's selection of RAs to those in the "downward-sense". After coordinating, each TCAS II unit independently selects the RA's strength in relation to the conflict geometry.

The basic rule for sense selection in a TCAS-TCAS encounter is that before selecting a sense, each TCAS must check whether it has received a complement from the threat indicating that threat's intention. If this is so, TCAS complies with the threat aircraft expectations. If not, TCAS selects the sense, which best fits the encounter geometry.

In the vast majority of cases, the two aircraft see each other as threats at slightly different moments in time. Coordination proceeds as follows: the first aircraft selects the RA sense, based on the encounter geometry, and transmits its intent; the second aircraft then selects the opposite sense and confirms its complementary intent.

Occasionally, the two aircraft may happen to simultaneously see each other as a threat and, consequently, both select a sense based on the encounter geometry. In this case, there is a chance that both will select the same sense. Should this happen, the aircraft with the higher Mode S address will detect the incompatibility and will reverse the sense of its RA. The aircraft with the lower Mode S is not permitted to declare a reversal. The reversal can occur on the cycle after the initial RA has been issued.

**Advisory aural annunciation**

The CAS logic sets the flags, which control the aural annunciations and the display of information. All aural annunciations are listed in Table 2 for version 7.0 and in Table 3 for version 7.1. All aural annunciations are inhibited below 500 feet (±100 feet) AGL or when GPWS (Ground Proximity Warning System) or TAWS (Terrain Avoidance Warning System), windshear detection or stall warnings are active.

**Air-ground communications**

**RA Report.** Using the Mode S data link, TCAS II can downlink RA Reports to Mode S ground sensors. This information is provided in the Mode S transponder's 1090 MHz response to an interrogation from a Mode S ground sensor requesting information (see Figure 27).

**RA Broadcast Message.** TCAS II also provides an RA Broadcast Message that is transmitted automatically on 1030 MHz. The RA Broadcast Message is intended for 1030 MHz receivers on the ground. This broadcast is provided for the first time when an RA is initially displayed to the flight crew and is rebroadcast every 8 seconds. The final RA Broadcast Message is sent on RA termination.

For 18 seconds after the termination of the RA ("Clear of conflict" message), both the RA Report and RA Broadcast Message contain an RA terminated indicator (RAT), indicating that the RA is no longer being displayed to the pilot.

The air/ground communication messages allow RA activity to be detected on the ground for the purpose of RA monitoring or ATC operations (i.e. RA downlink display to controllers)[21].

[21] RA downlink display to controllers is an emerging concept. Currently, it has been implemented only by a small number of ANSPs. ICAO has not published any provisions for operations of RA downlink.

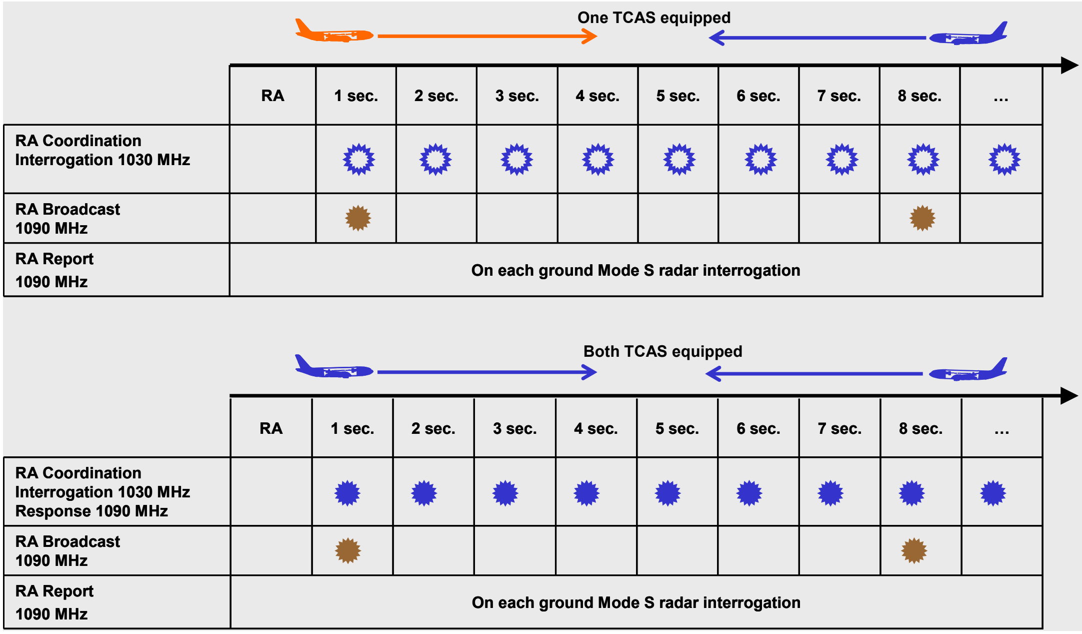



Figure 27: Air ground communications timeline.

## PERFORMANCE MONITORING

TCAS II software continuously and automatically monitors its own health and performance. The performance monitoring operates whenever power is applied to TCAS. In addition, the performance monitor includes a pilot-initiated test feature that includes expanded tests of TCAS displays and aural annunciations. The performance monitor supports expanded maintenance diagnostics that are available to maintenance personnel while the aircraft is on the ground.

The performance monitor validates many of the inputs received from other aircraft systems and validates the performance of the TCAS processor, for example own aircraft pressure altitude input or the connection of TCAS to the aircraft suppression bus.

When the performance monitor detects anomalous performance within TCAS or an invalid input from a required on-board system, the failure is enunciated to the pilot.

## TCAS II OPERATIONS

### INDEPENDENT SYSTEM

TCAS II works independently of the aircraft navigation, flight management systems, and ATC ground systems. While assessing threats it does not take into account the ATC clearance, pilot's intentions nor flight management systems inputs.

### LIMITATIONS

As TCAS II depends on the signals from the other aircraft transponders in order to assess the threat, it will not detect any non-transponder equipped aircraft, nor aircraft with an inoperative transponder. As altitude of the threat aircraft is required in order to issue an RA, RAs will not be generated against traffic without an altitude reporting transponder.

The level of protection offered by TCAS II depending on the threat type is shown in Table 8. An RA can be generated against any aircraft equipped with an altitude reporting transponder (Mode S or Mode A/C). The intruder does not need to be fitted with TCAS II. However, RAs are coordinated only between TCAS II equipped aircraft. In the majority of cases only one aircraft will receive an RA (regardless of whether the threat is equipped or not).

Table 8: TCAS II levels of protection.

| Threat aircraft equipment | Own aircraft (TCAS II) |
|---|---|
| No transponder | Not detected |
| Mode A transponder only | Not detected |
| Mode A/C transponder with no altitude reports | TA, intruder shown on TCAS traffic display without altitude |
| Mode C or Mode S transponder | TA and RA |
| TCAS I | TA and RA |
| TCAS II | TA and coordinated RA |

TCAS II will automatically fail if the input from the aircraft's barometric altimeter, radar altimeter or transponder is lost.

Due to surveillance limitations neither RAs nor TAs will be issued against any threats with a closure speed of over 1200 knots or with vertical rates over 10,000 ft/min.

RAs can be generated before ATC separation minima are violated and even when ATC separation minima will not be violated. In Europe, for about two-third of all RAs the ATC separation minima are not violated.

In Europe an aircraft may operate under the Minimum Equipment List (MEL) provisions with TCAS II inoperative for up to 10 calendar days. In German airspace the time period during which TCAS II may be inoperative is reduced to 3 days. National regulators may impose more restrictive deadlines for some operators or parts of airspace. In Europe, there is no requirement to notify ATC or to make a remark in the flight plan about TCAS II being inoperative[22].

## SAFETY BENEFITS

The safety benefits delivered by TCAS II are usually expressed in terms of the risk ratio: a comparison of the risk with and without TCAS (i.e. does TCAS II make safety better or worse?) – a risk ratio of 0% would indicate an ideal system (the risk is eliminated) and a risk of 100% would indicate an ineffective system (the risk is unaltered). Real systems have a performance somewhere between these extremes. It is important to remember that risk ratio is a relative measure expressing the improvement in safety rather than the absolute level of safety.

For Europe, TCAS II is estimated to reduce the risk of midair collision by a factor of about 5 (i.e. a risk ratio of 22%).

All other things being equal the higher the level of aircraft equipage with TCAS II and the better the level of pilot compliance with RAs the greater the reduction in risk.

The importance of correctly following RAs can be illustrated as follows: statistically, a pilot who never follows RAs faces three times the risk that is faced by a pilot who always follows RAs. The human is the weakest element in the TCAS II control loop; without "human in the loop" the risk ratio would improve by a factor of 10.

## TRAFFIC ADVISORIES

The objective of a TA is to aid visual acquisition of an intruder and prepare the crew for a possible RA. TAs are nominally generated 20 to 48 seconds prior to CPA or 10 to 13 seconds before RA, although shorter generation times are possible in some geometries. In some geometries an RA may occur without a preceding TA on one or both of the involved aircraft. The majority of TAs are not followed by RAs.

No manoeuvres shall be made in response to a TA and TAs are not required to be reported to ATC.

A TA is announced as "Traffic, traffic" and the intruder aircraft symbol on the traffic displays changes to a yellow or amber solid circle.

## RESOLUTION ADVISORIES

### Pilot actions

The objective of an RA is to achieve a safe vertical distance from a threat aircraft (between 300 and 700 feet – altitude dependent). RAs are nominally generated 15 to 35 seconds prior to the CPA, although shorter generation times are possible in some geometries.

In the event of an RA, pilots shall respond immediately by following the RA as indicated unless doing so would jeopardise safety of the aircraft. Pilots must not manoeuvre contrary to the RA.

---

[22] Note: These provisions are subject to change. Refer to current regulation for up-to-date information.

The aural annunciation depends on the RA issued (see Table 2 for aural annunciations for version 7.0 and in Table 3 for version 7.1). The threat aircraft symbol on the traffic displays changes to a red solid square and the ranges of the vertical speed to be avoid and the required vertical speed are displayed on appropriate instruments (implementation dependent).

Pilots are required to respond to first RA within 5 seconds and any subsequent RAs within 2.5 seconds. The required acceleration is 0.25*g*, or 0.35*g* for increase rate RAs and reversal of sense RAs. Pilots must not manoeuvre contrary to the RA.

Practical advice on how to achieve the required acceleration is provided in JAA-TGL 11: *"An acceleration of approximately 1/4 g will be achieved if the change in pitch attitude corresponding to a change in vertical speed of 1500 ft/min is accomplished in approximately 5 seconds, and of 1/3 g if the change is accomplished in approximately 3 seconds. The change in pitch attitude required to establish a rate of climb or descent of 1500 ft/min from level flight will be approximately 6 degrees when the True Air Speed is 150 kts, 4 degrees at 250 kts, and 2 degrees at 500 kts. (These angles are derived from the formula: 1000 divided by TAS.)"*

Pilots should avoid excessive responses to RAs – responses to RAs must be followed as indicated on the flight deck instruments. Any excessive rates increase the risk of a follow up conflict (with another aircraft) and are disruptive to ATC. Too weak a response carries a risk that the vertical spacing at CPA will not be sufficient and will cause strengthening RAs to be issued to one or both aircraft involved.

**Interaction with ATC during RA**

Pilots are required to comply with all RAs, even if the RAs are contrary to ATC clearances or instructions unless doing so would endanger the aircraft. Complying with the RA, however, will in many instances cause an aircraft to deviate from its ATC clearance. In this case, the controller is no longer responsible for separation of the aircraft involved in the RA.

On the other hand, ATC can potentially interfere with the pilot's response to RAs. If a conflicting ATC instruction coincides with an RA, the pilot might assume that ATC is fully aware of the situation and is providing the better resolution – but in reality ATC cannot be assumed to be aware of the RA until the RA is reported by the pilot. Once the RA is reported by the pilot, ATC is required not to attempt to modify the flight path of the aircraft involved in the encounter. Hence, the pilot is expected to "follow the RA" (even though this does not yet always happen in practice).

Those RAs that require a deviation from the current ATC clearance or instruction are to be reported to ATC as soon as aircrew workload permits using the following phraseology[23]:

***[callsign] TCAS RA*** *(pronounced Tee-Cas-Ar-Ay).*

After a "Clear of Conflict" message has been posted by TCAS, the crew should return to the last clearance and notify ATC or seek alternative ATC instructions using the following phraseology:

***[callsign] CLEAR OF CONFLICT (assigned clearance) RESUMED*** or
***[callsign] CLEAR OF CONFLICT, RETURNING TO (assigned clearance).***

If an ATC clearance or instruction contradictory to the TCAS RA is received, the pilot must follow the RA and inform ATC as follows:

***[callsign] UNABLE, TCAS RA.***

[23] See Appendix page 65 for more information.

Some States have implemented "RA downlink display to controller" which provides air traffic controllers automatically with information about RAs posted in the cockpit obtained via Mode S radars or other surveillance means.

### Nuisance RAs

Some RAs are perceived by pilots or controllers as a nuisance or unnecessary, as they are generated when it is believed there is no risk of a collision (see also section on TCAS II and ATC operations below).

RAs are triggered if TCAS II calculates that there is a risk of impending collision between aircraft, as defined by the CAS algorithms. The evaluation of whether the RA is *nuisance* is impossible in real-time (i.e. during the event) and it can be done reliably in hindsight only.

### RA and visual acquisition

Pilots sometimes do not follow an RA as they believe they have the threat aircraft in sight and judge there will be sufficient separation.

In this respect, ICAO provisions (see Appendix on page 65) are quite clear that in the event of an RA, the pilot must respond immediately by following the RA unless doing so would jeopardise the safety of the aircraft. That provision applies in all airspace classes and all meteorological conditions (i.e. VMC and IMC). In real-time the pilot has little chance to assess whether the traffic acquired visually is in fact the one against which the RA has been generated.

### Closely spaced parallel approaches

As recommended by ICAO, when in the air TCAS II should be operated in the TA/RA mode at all times, including during closely spaced parallel approaches. Even when closely-spaced parallel approaches procedures are correctly applied, unnecessary RAs may occasionally occur. However, the safety benefit provided by TCAS II takes precedence over an occasional unnecessary RA. Additionally, there is always a possibility that another aircraft will penetrate the approach airspace causing a real threat.

### Inappropriate pilot responses

In some instances pilots ignore RAs or respond in the opposite sense. The main causes are misinterpretation of RA display or RA aural annunciation, giving priority to ATC instruction or performing own avoidance manoeuvre (based on visual acquisition or own judgement).

Inappropriate pilot responses severely impair TCAS II's performance and create risks that can be greater than if aircraft were unequipped. For instance, a failure to follow an RA in a coordinated encounter will also restrict the performance of other aircraft's TCAS II.

## TCAS II AND ATC OPERATIONS

In some cases, RAs are perceived as disruptive by controllers, especially when the aircraft deviates from the ATC clearance, because of the possibility of an induced conflict with a third aircraft. Although concern about this possibility is understandable (and cannot be dismissed) the need for collision avoidance takes precedence. TCAS II is able to simultaneously process several intruders and provide an appropriate RA, so if the deviation from ATC clearance causes a follow-on conflict, TCAS II will respond effectively.

The most common cases which controllers find disruptive are situations when two aircraft are simultaneously levelling off at 1000 feet apart or one aircraft is levelling off 1000 feet away from a level aircraft and RAs are triggered due to aircraft's high vertical speeds when approaching the cleared flight level. ICAO PANS-OPS (see Appendix on page 65) states that the vertical rate should be reduced to 1500 ft/min. or less throughout the last 1000 feet of climb or descent to the assigned altitude when the pilot is made aware of another aircraft at or approaching an adjacent altitude or standard flight level, unless otherwise instructed by ATC. Still, in some geometries these RAs may occur. In case of non-compliance (e.g. level bust by one of the aircraft involved), these RAs provide collision avoidance protection.

For the majority of RAs which require a deviation from the ATC clearance, the vertical deviation should not exceed a few hundred feet (given correct pilot response).

TCAS II operation may not be compatible with altitude crossing clearances based upon agreed visual separation. In these situations RAs may be triggered and the provision of traffic information by the controller does not permit the pilot to ignore the RA.

RAs are often issued against VFR aircraft on the edge of controlled airspace. Even if the TCAS equipped aircraft pilot believes he has the threat aircraft in sight, these RAs must be also followed as there is no certainty that the traffic acquired visually is in fact the one against which the RA has been generated.

In the case of close aircraft proximity and in the absence of an RA report, controllers should provide horizontal avoiding instructions as they will are compatible with any RAs and may help to reduce the risk of a collision. However, controllers should be aware that when already responding to an RA, the pilot may not be able to turn the aircraft and fly the RA at the same time (and will therefore give priority to the RA).

## FREQUENCY OF RAs

It has been estimated, through various monitoring programmes and data obtained from operators, that an RA occurs approximately every 1000 flight hours on short and medium haul aircraft. The frequency decreases to an RA every 3000 hours for long haul aircraft.

Although most RAs are reported through the aircraft operator or ANSP reporting systems, there are no comprehensive European-wide statistics on the frequency of their occurrence. In order to gain an insight into the matter, EUROCONTROL undertook a 6-month RA monitoring exercise from 2007 to 2008 using six Mode S radars, covering a large portion of European core airspace.

The monitoring exercise found that in the vast majority of encounters (80%) only one aircraft involved in the encounter received an RA (see Figure 28). Reasons were:

- the geometry of the conflict was such that the RA was not generated on the TCAS II equipped threat aircraft;
- the threat aircraft was not TCAS II equipped;
- the threat's TCAS II was in the TA-only mode.

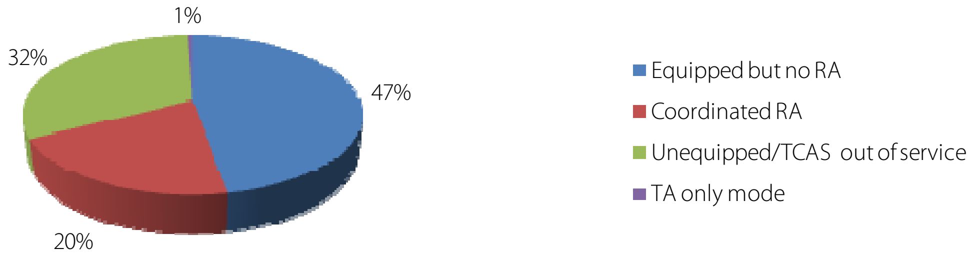



Figure 28: RA distribution by threat type.

On average three RA encounters were observed each day in the monitored area. RAs are much more frequent in TMAs than in en-route airspace, mainly due to higher vertical rates and more manoeuvres by aircraft.

The most common RA (61%) was a single "Adjust vertical speed" RA. The other most frequently occurring RAs were a sequence of "Climb" or "Descend" weakening to "Adjust vertical speed" RAs (16%), single "Monitor vertical speed" RA (10%) and single "Climb" or "Descend" RA (8%) – see Figure 29. RA reversals occurred in less than 1% of cases. In another monitoring exercise it was observed that RA crossings occur only in 2% of cases.

It can be assumed that with the introduction of version 7.1 and the replacement of the Adjust Vertical Speed RA with the Level Off RA, the latter will be the most frequently observed RA.

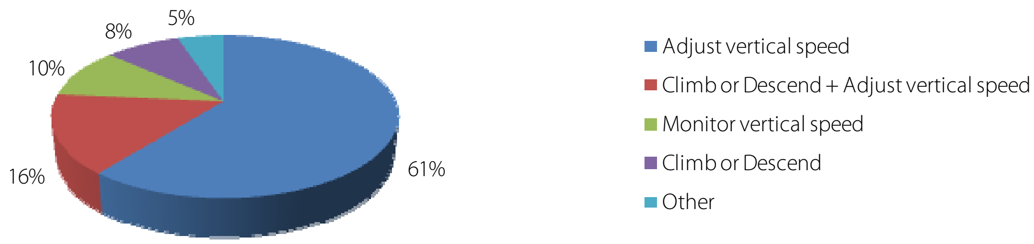



Figure 29: RA distribution by RA type.

## TCAS II AND GROUND-BASED SHORT TERM CONFLICT ALERT (STCA)

Air traffic controllers are assisted by Short Term Conflict Alert (STCA), a ground-based system that generates alerts warning of a potential or actual infringement of separation minima. TCAS II and STCA operate independently which provides redundancy and minimises single points of failure (the only common source of data is the altitude reports from aircraft transponders). TCAS II and STCA are not entirely compatible with each other. Whilst the desired behaviour is that STCA alerts at least 30 seconds before the first RA, STCA can and sometimes will trigger significantly later (sometimes even after the RA). This is a result of the differences listed in Table 9. Providing sufficient warning time is not always possible, particularly in the case of sudden, unexpected manoeuvres.

STCA and TCAS II have limited or no knowledge of controller and pilot intentions and actions. Hence, when a controller provides an instruction(s) to avoid a loss of separation, STCA and/or TCAS II alerts may still triggered, even if the pilot has already initiated a manoeuvre corresponding to the controller's instruction.

Table 9: Differences between STCA and TCAS II

| | STCA | TCAS II |
|---|---|---|
| **Performance** | Ground-based surveillance has 5 to 10 seconds update rate and good azimuth resolution.<br><br>Tracks often based on multiple data sources (TCAS tracks based on single data source). | TCAS surveillance function has 1 second update rate and poor azimuth resolution. |
| **Vertical tracking** | STCA uses tracked altitude and vertical rate based on reported altitudes (25 ft or 100 ft). | TCAS knows own altitude and vertical rate with 1-foot precision. |
| **Operation** | STCA detects imminent or actual (significant) loss of minimum separation but provides no resolution advice. | TCAS assumes collision and provides resolution advice to ensure sufficient vertical separation at CPA. |
| **Predictability** | STCA is not standardised but optimised for the operational environment to varying degrees. | TCAS is fully standardised. |
| **Communication** | Complete by providing instructions subject to read-back/hear-back. | Limited (pilot reporting not always possible in a timely manner). |
| **Effectiveness** | Only when controller immediately assesses the situation, issues an appropriate instruction to pilot and pilot follows the instruction. | Only when pilot promptly and correctly follows the RA. |

## TCAS II PRESSURE SETTING

TCAS II always utilises pressure altitude information which relates to the standard pressure (altimeter setting 1013.25 hPa or 29.92 inches of mercury). TCAS II operation are not affected if aircraft are flying Flight Levels on the standard pressure setting, altitude on QNH, or height on QFE as the same pressure setting (i.e. standard) is always used. The pressure selection by the flight crew does not affect the TCAS II system at all.

Additionally, below 1750 feet TCAS II also uses radar altimeter data.

## TCAS II/TRANSPONDER OPERATIONS ON THE GROUND

TCAS II operation on the airport surface provides no safety benefit. Routine operation of TCAS II on the ground can degrade surveillance performed by airborne TCAS II units and performance of ATC radars.

When on the ground, the pilots may turn TCAS II on for a short period of time before crossing/entering an active runway to double-check for the presence of any aircraft on short finals.

The modes of TCAS II/transponder operations are explained in and illustrated in Figure 30.

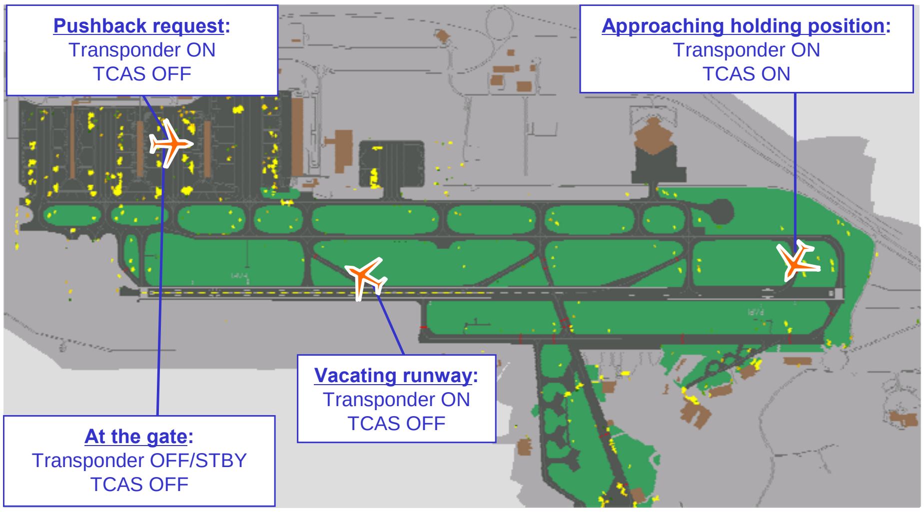



Figure 30: TCAS II/transponder operation on the ground.

## TCAS II TRAINING

### Pilots

TCAS II indications are intended to assist pilots in the avoidance of potential collisions. For the system to achieve its intended safety benefits, pilots must operate the system and respond to TCAS II advisories in a manner compatible with the system design. Many advisories involve more than one TCAS II equipped aircraft. In these coordinated encounters, it is essential that the flight crew on each aircraft respond in the expected manner. Therefore, pilot training and understanding of TCAS II operations is essential.

ICAO has recognised the importance of a suitable training programme for pilots and controllers. The guidelines for training are contained in the ICAO ACAS Manual (Doc. 9863) and ICAO PANS-OPS (Doc. 8168).

### Controllers

TCAS II training for air traffic controllers should have a different focus than pilot training. ICAO in the ACAS Manual (Doc. 9863) recommends that air traffic controllers are provided with formal ACAS II training. The objective of the training is to enable air traffic controllers to better manage situations in which TCAS RA occur by understanding how TCAS II works, and by understanding the responsibilities of pilots and air traffic controllers during a TCAS event.

### Training resources

EUROCONTROL and other organisations have produced a number of publications to support TCAS II training and awareness. The list of these publications can be found on page 57.

## INTERCEPTIONS OF TCAS II EQUIPPED AIRCRAFT

In some circumstances, like a prolonged communication loss, it is necessary that military fighters intercept a civilian aircraft in order to provide assistance or check on the safety of the flight.

If the intercepting military aircraft does not switch off its Mode C or, if equipped operate its transponder in Intercept Mode then an intercepted aircraft equipped with TCAS II may perceive the interceptor as a collision threat and might perform manoeuvres in response to an RA. Such manoeuvres might be misinterpreted by the interceptor as an indication of unfriendly intentions.

Consequently, the intercepting aircraft's Mode C should either be inhibited or Intercept Mode selected within 20 NM of the target aircraft, to prevent unnecessary RAs. This will preserve flight safety whilst still permitting the prosecution of the intercept.

## EQUIPAGE OUTSIDE THE CURRENT MANDATE

ACAS II has been design with larger commercial aircraft in mind and mandated on this class of aircraft. However, operators of several aircraft classes outside the current mandate have decided to equip their aircraft with ACAS II for various reasons. These include military transport aircraft, business jets and large helicopters. The principle of operations on the aircraft outside the mandate is the same as on the aircraft on which ACAS II is mandated.

## CONCLUSIONS

TCAS II is a last resort system designed to prevent midair collisions between aircraft. The technical features of the system provide a significant improvement in flight safety and TCAS II has attained universal recognition in the world of aviation.

TAs and RAs are relatively infrequent and are unplanned events, which call for prompt and appropriate reactions from the flight crew. Consequently, flight crew require specific and recurrent training in TCAS procedures.

TCAS II operations have an effect on ATC. It is therefore essential that controllers have a good knowledge of the TCAS II system's characteristics and of the procedures used by pilots. Controllers are also required to provide the same ATC service, especially with regard to traffic information or the maintenance of the relevant ATC separation, whether the aircraft are fitted with TCAS or not.

The implementation of TCAS II has increased the safety and reduced the possibility of midair collision. However, in order for TCAS II to continue to deliver its safety benefit, it is essential that pilots and controllers are adequately trained on TCAS II operations and followed the procedures.

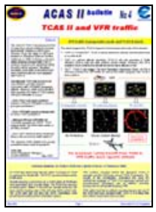
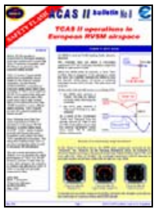
## ADDITIONAL TRAINING RESOURCES

### EUROCONTROL ACAS II BULLETINS

A series of ACAS II Bulletins has been published since 2002, each focusing on a different current operational theme of interest to both aircrews and air traffic controllers. In the Bulletins real-life examples are used to show how others reacted during RAs, what kind of mistakes were made, how correct actions improved or could have improved the situation.

Go to www.eurocontrol.int/acas or www.skybrary.aero to access all EUROCONTROL ACAS Bulletins.

*Note: The information contained in EUROCONTROL ACAS II Bulletins is accurate at the time of publishing but is subject to change.*

| | | | |
|---|---|---|---|
|  |  |  |  |
| 1 - Follow the RA! (July 2002) | 2 - RAs and 1000 ft level-off manoeuvres (March 2003) | 3 - Wrong reaction to "Adjust Vertical Speed" RAs (October 2003) | 4 - TCAS II and VFR traffic (May 2004) |
|  |  |  |  |
| 5 - Controller and Pilot ACAS regulation and training (October 2004) | 6 - Incorrect use of the TCAS traffic display (March 2005) | 7 - The Dos and Don'ts of TCAS II Operations (March 2006) | 8- TCAS II Operations in European RVSM Airspace (May 2006) |
|  |  |  |  |
| 9 - Frequently Asked Questions (July 2007) | 10 - When ATC meets TCAS II (November 2007) | 11 - ACAS world is moving on (May 2010) | 12 - Focus on pilot training (February 2011) |
|  |  |  |  |
| 13 - Reversing to resolve (September 2011) | 14 - Version 7.1 is coming (January 2012) | 15 – Not so fast… (May 2012) | 16 – "Traffic, traffic" TCAS Traffic Advisories (December 2012) |

## EUROCONTROL TRAINING PRESENTATIONS

Go to www.eurocontrol.int/acas or www.skybrary.aero to access all EUROCONTROL ACAS training publications.

| | |
|---|---|
|   | Overview of ACAS II (incorporating version 7.1) |
|   | TCAS II version 7.1 for air traffic controllers |
|   | TCAS II version 7.1 for pilots |

**For further information please contact:**
acas@eurocontrol.int
www.eurocontrol.int/acas

## OTHER TRAINING RESOURCES

Click on a link to access a specific publication or use the URL provided.

| | |
|---|---|
|   | SKYbrary article on ACAS with links to several other training resources<br><br>www.skybrary.aero/index.php/Airborne_Collision_Avoidance_System_(ACAS) |
|   | FAA Booklet – Introduction to TCAS II version 7.1 (February 28, 2011)<br><br>www.faa.gov/documentLibrary/media/Advisory_Circular/<br>TCAS%20II%20V7.1%20Intro%20booklet.pdf |
|   | The Traffic Alert and Collision Avoidance System by James K. Kuchar and Ann C. Drumm – an article from the Lincoln Laboratory Journal (Volume 16, Number 2, 2007)<br><br>www.ll.mit.edu/publications/journal/pdf/vol16_no2/<br>16_2_04Kuchar.pdf |

## GLOSSARY

*The glossary has been derived from the definitions published in ICAO Annex 10, ICAO Doc. 9863, ICAO Doc 4444, and TCAS II MOPS.*

**ACAS I** *("ay-cas one")* provides information as an aid to "see and avoid" action but does not include the capability for generating resolution advisories (RAs).

**ACAS II** *("ay-cas two")* provides vertical resolution advisories (RAs) in addition to traffic advisories (TAs).

**ACAS III** *("ay-cas three")* provides vertical and horizontal resolution advisories (RAs) in addition to traffic advisories (TAs)[24].

**ACAS X –** *("ay-cas eks")* new collision avoidance system currently under development. It takes advantage of recent advances in 'dynamic programming' and other computer science techniques. ACAS X will use the same hardware (antennas, processors, and displays) as the current TCAS II system and the same range of available RAs will be used.

**Aircraft (Mode S) address –** A unique combination of twenty-four bits available for assignment to an aircraft for the purpose of air-ground communications, navigation and surveillance.

**Altitude crossing RA –** A resolution advisory is altitude crossing if own ACAS aircraft is currently at least 100 feet below or above the threat aircraft for upward or downward sense advisories, respectively.

**Closest Point of Approach (CPA) –** The occurrence of minimum range between own ACAS aircraft and the intruder. Range at CPA is the smallest range between the two aircraft and time at CPA is the time at which it occurs.

**Collision avoidance logic –** The sub-system or part of ACAS that analyses data relating to an intruder and own aircraft, decides whether or not advisories are appropriate and, if so, generates the advisories. It includes the following functions: range and altitude tracking, threat detection and RA generation. It excludes surveillance.

**Collision Avoidance System (CAS) –** Collision avoidance logic subsystem within TCAS.

**Corrective advisory –** A resolution advisory that instructs the pilot to deviate from current vertical rate, for example a Level off RA when the aircraft is climbing.

**Crossing RA –** see: *Altitude crossing RA*.

**Horizontal Miss Distance (HMD) –** The horizontal range between two aircraft at the Closest Point of Approach.

**Increased rate RA –** A resolution advisory with a strength that recommends increasing the altitude rate to a value exceeding that recommended by a previous climb or descend RA.

**Intruder (aircraft) –** An SSR transponder-equipped aircraft within the surveillance range of ACAS for which ACAS has an established track.

**Miss Distance Filtering (MDF) –** a process in the TCAS threat detection logic which allows nuisance RAs in encounters with a significant HMD to be suppressed (in suitable encounter geometries). The process can also allow the early removal of an RA before the closest point of approach

**Mode S address –** see: *Aircraft address*.

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[24] ACAS III is unlikely to materialize due to difficulties the current surveillance systems have with horizontal tracking. ACAS X will be the next generation of collision avoidance systems.

**Nuisance RA –** in terms of compatibility with Air Traffic Management, an RA shall be considered a "nuisance" unless, at some point in the encounter in the absence of TCAS II, the horizontal separation and the vertical separation are simultaneously less than 750 feet vertically and 2 NM horizontally (if above FL100) or 1.2 NM (if below FL100). See also: *Unnecessary RA*.

**Own aircraft –** The aircraft fitted with the ACAS that is the subject of the discourse, which ACAS is to protect against possible collisions, and which may enter a manoeuvre in response to an ACAS indication.

**Potential threat (aircraft) –** An intruder that has passed the Potential Threat classification criteria for a TA and does not meet the Threat Classification criteria for an RA.

**Preventive advisory –** A resolution advisory that instructs the pilot to avoid certain deviations from current vertical rate, for example a Level off RA when the aircraft is level.

**Proximate aircraft –** Nearby aircraft within 1200 feet and 6 NM which do not meet either the threat or the potential threat classification criteria.

**RA sense –** The sense of an ACAS II RA is "upward" if it requires climb or limitation of descent rate and "downward" if it requires descent or limitation of climb rate. It can be both upward and downward simultaneously if it requires limitation of the vertical rate to a specified range.

**Resolution Advisory (RA) –** An indication given to the flight crew recommending a manoeuvre intended to provide separation from all threats; or a manoeuvre restriction intended to maintain existing separation.

**Reversed sense RA –** A resolution advisory that has had its sense reversed.

**Sensitivity Level (SL) –** An integer defining a set of parameters used by the traffic advisory (TA) and collision avoidance algorithms to control the warning time provided by the potential threat and threat detection logic, as well as the values of parameters relevant to the RA selection logic.

**Short Term Conflict Alert (STCA) –** A ground-based safety net intended to assist the controller in preventing collision between aircraft by generating, in a timely manner, an alert of a potential or actual infringement of separation minima.

**Strengthening RA –** A change in RA to another RA that is more restrictive or requires a greater vertical rate but is in the same sense as the previous RA.

**TCAS –** Traffic alert and Collision Avoidance System – an aircraft equipment that is an implementation of an ACAS.

**Threat (aircraft) –** An intruder deserving special attention either because of its close proximity to own aircraft or because successive range and altitude measurements indicate that it could be on a collision or near collision course with own aircraft. The warning time provided against a threat is sufficiently small that an RA is justified.

**Traffic Advisory (TA) –** An indication given to the flight crew that a certain intruder is a potential threat.

**Unnecessary RA –** The ACAS II system generated an advisory in accordance with its technical specifications in a situation where there was not or would not have been a risk of collision between the aircraft. See also: *Nuisance RA*.

**Weakening RA** – A resolution advisory with a strength that recommends decrease the altitude rate to a value below that recommended by a previous RA, when the initially issued RA is predicted to provide sufficient vertical spacing.

## ABBREVIATIONS

| | |
|---|---|
| **ACAS** | Airborne Collision Avoidance System |
| **ACASA** | ACAS Analysis (EUROCONTROL project in support of the mandate for the carriage of ACAS II in Europe) |
| **ADC** | Air Data Computer |
| **ADS-B** | Automatic Dependent Surveillance - Broadcast |
| **AGL** | Above Ground Level |
| **ALIM** | Altitude Limit – Vertical Threshold for Corrective Resolution Advisory |
| **ANSP** | Air Navigation Service Provider |
| **ATC** | Air Traffic Control |
| **AP/FD** | Auto pilot/flight director |
| **ATCRBS** | Air Traffic Control Radar Beacon System |
| **BCAS** | Beacon Collision Avoidance System |
| **CAS** | Collision Avoidance System |
| **CENA** | Centre d'Études de la Navigation Aérienne - France |
| **CPA** | Closest Point of Approach |
| **DMOD** | Distance Modifier – Lateral Threshold used in the Range Test and Miss Distance Filter |
| **DMTL** | Dynamic Minimum Triggering Level |
| **EATCHIP** | European Air Traffic Control Harmonisation and Integration Programme |
| **EFIS** | Electronic Flight Instrument System |
| **EICAS** | Engine Indication and Crew Alerting System |
| **EUROCAE** | European Organisation for Civil Aviation Equipment |
| **FAA** | Federal Aviation Administration (USA) |
| **FL** | Flight Level |
| **FMS** | Flight Management System |
| **FRUIT** | False Replies from Unsynchronised Interrogator Transmissions |
| **ft** | Feet |
| **ft/min.** | Feet per minute |
| **GNSS** | Global Navigation Satellite System |
| **GPWS** | Ground Proximity Warning System |
| **hPa** | Hectopascals |
| **ICAO** | International Civil Aviation Organization |
| **IMC** | Instrument Meteorological Conditions |
| **IVSI** | Instantaneous Vertical Speed Indicator |
| **kg** | Kilograms |
| **m** | Meters |
| **MDF** | Miss Distance Filtering |
| **MHz** | Megahertz |

| | |
|---|---|
| **MOPS** | Minimum Operational Performance Standards |
| **m/s** | Meters per second |
| **n/a** | Not applicable |
| **ND** | Navigation Display |
| **NextGen** | Next Generation Transportation System (USA) |
| **NM** | Nautical Miles |
| **PFD** | Primary Flight Display |
| **QFE** | Atmospheric pressure at aerodrome elevation |
| **QNH** | Altimeter sub-scale setting to obtain elevation when on the ground |
| **RA** | Resolution Advisory |
| **RPAS** | Remotely Piloted Aircraft Systems |
| **RTCA** | RTCA Inc. A USA-based non-profit organisation that develops technical standards for regulatory authorities (formerly Radio Technical Commission for Aeronautics) |
| **RVSM** | Reduced Vertical Separation Minima |
| **SARPs** | Standards and Recommended Practices |
| **sec** | Seconds |
| **SESAR** | Single European Sky ATM Research Programme |
| **SKYbrary** | A repository of safety knowledge related to ATM and aviation safety in general. |
| **SL** | Sensitivity Level |
| **SSR** | Secondary Surveillance Radar |
| **STCA** | Short Term Conflict Alert |
| **TA** | Traffic Advisory |
| **tau** | Warning Time |
| **TAWS** | Terrain Avoidance Warning System |
| **TCAP** | TCAS Alert Prevention |
| **TCAS** | Traffic alert and Collision Avoidance System |
| **TMA** | Terminal control area |
| **TVTHR** | Time (Variable) Threshold – Reduced Time to Co-altitude Threshold |
| **UAS** | Unmanned Aircraft Systems |
| **VFR** | Visual Flight Rules |
| **VMC** | Visual Meteorological Conditions |
| **VSI** | Vertical Speed Indicator |
| **XPDR** | Transponder |
| **ZTHR** | Z Threshold – Vertical Threshold for Resolution Advisory |
| **ZTHRTA** | Z Threshold – Vertical Threshold for Traffic Advisory |

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**AC 120-55C –** Air Carrier Operational Approval and Use of TCAS II.

**Introduction to TCAS II version 7.1 –** Feb. 28 2011


[25] Superseding DO-185A (version 7.0 MOPS).

[26] Jointly published with RTCA and commensurate with DO-185B.

**European publications:**

**EU-OPS-1 –** European Commission Regulation (common technical requirements and administrative procedures applicable to commercial transportation by aeroplane) – available on SKYbrary (http://www.skybrary.aero/bookshelf/books/818.pdf)

Applicable sections:

- **EU-OPS 1.668:** Airborne collision avoidance system - available on SKYbrary: www.skybrary.aero/bookshelf/books/818.pdf#search=1.668)
- **EU-OPS 1.398:** Use of airborne collision avoidance system (ACAS) - available on SKYbrary: www.skybrary.aero/bookshelf/books/818.pdf#search=1.398)

**JAA TGL-11 –** Guidance for Operators on Training Programmes for the Use of Airborne Collision Avoidance Systems (ACAS) - available on SKYbrary:

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## APPENDIX – RELEVANT ICAO PROVISIONS

***Note: Extracts from ICAO documents are provided here for reference only and are current on 1 July 2014 and are subject to change.***

### ANNEX 6 – PART I

4.4.10 Aeroplane operating procedures for rates of climb and descent

**Recommendation.**— *Unless otherwise specified in an air traffic control instruction, to avoid unnecessary airborne collision avoidance system (ACAS II) resolution advisories in aircraft at or approaching adjacent altitudes or flight levels, operators should specify procedures by which an aeroplane climbing or descending to an assigned altitude or flight level, especially with an autopilot engaged, may do so at a rate less than 8 m/sec or 1 500 ft/min (depending on the instrumentation available) throughout the last 300 m (1 000 ft) of climb or descent to the assigned level when the pilot is made aware of another aircraft at or approaching an adjacent altitude or flight level.*

**6.18 Aeroplanes required to be equipped with an airborne collision avoidance system (ACAS II)**

6.18.1 From 1 January 2003, all turbine-engined aeroplanes of a maximum certificated take-off mass in excess of 15 000 kg or authorized to carry more than 30 passengers shall be equipped with an airborne collision avoidance system (ACAS II).

6.18.2 From 1 January 2005, all turbine-engined aeroplanes of a maximum certificated take-off mass in excess of 5 700 kg or authorized to carry more than 19 passengers shall be equipped with an airborne collision avoidance system (ACAS II).

6.18.3 **Recommendation**.— *All aeroplanes should be equipped with an airborne collision avoidance system (ACAS II).*

6.18.4 An airborne collision avoidance system shall operate in accordance with the relevant provisions of Annex 10, Volume IV.

### ANNEX 10 – VOLUME IV

4.3.5.3.1 New ACAS installations after 1 January 2014 shall monitor own aircraft's vertical rate to verify compliance with the RA sense. If non-compliance is detected, ACAS shall stop assuming compliance, and instead shall assume the observed vertical rate.

*Note 1.— This overcomes the retention of an RA sense that would work only if followed. The revised vertical rate assumption is more likely to allow the logic to select the opposite sense when it is consistent with the non-complying aircraft's vertical rate.*

*Note 2.— Equipment complying with RTCA/DO-185 or DO-185A standards (also known as TCAS Version 6.04A or TCAS Version 7.0) do not comply with this requirement.*

*Note 3.— Compliance with this requirement can be achieved through the implementation of traffic alert and collision avoidance system (TCAS) Version 7.1 as specified in RTCA/DO-185B or EUROCAE/ED-143.*

4.3.5.3.2 **Recommendation.**— *All ACAS should be compliant with the requirement in 4.3.5.3.1.*

4.3.5.3.3 After 1 January 2017, all ACAS units shall comply with the requirements stated in 4.3.5.3.1.

## PANS-ATM – DOC. 4444

15.7.3.1 The procedures to be applied for the provision of air traffic services to aircraft equipped with ACAS shall be identical to those applicable to non-ACAS equipped aircraft. In particular, the prevention of collisions, the establishment of appropriate separation and the information which might be provided in relation to conflicting traffic and to possible avoiding action shall conform with the normal ATS procedures and shall exclude consideration of aircraft capabilities dependent on ACAS equipment.

15.7.3.2 When a pilot reports an ACAS resolution advisory (RA), the controller shall not attempt to modify the aircraft flight path until the pilot reports "Clear of Conflict".

15.7.3.3 Once an aircraft departs from its ATC clearance or instruction in compliance with an RA, or a pilot reports an RA, the controller ceases to be responsible for providing separation between that aircraft and any other aircraft affected as a direct consequence of the manoeuvre induced by the RA. The controller shall resume responsibility for providing separation for all the affected aircraft when:

a) the controller acknowledges a report from the flight crew that the aircraft has resumed the current clearance; or

b) the controller acknowledges a report from the flight crew that the aircraft is resuming the current clearance and issues an alternative clearance which is acknowledged by the flight crew.

*Note. — Pilots are required to report RAs which require a deviation from the current ATC clearance or instruction (see PANS-OPS, Volume I, Part III, Section 3, Chapter 3, 3.2 c) 4)). This report informs the controller that a deviation from clearance or instruction is taking place in response to an ACAS RA.*

15.7.3.5 ACAS can have a significant effect on ATC. Therefore, the performance of ACAS in the ATC environment should be monitored.

15.7.3.6 Following a significant ACAS event, pilots and controllers should complete an air traffic incident report.

*Note 1. — The ACAS capability of an aircraft may not be known to air traffic controllers.*

### Phraseology

Para. 12.3.1.2 r- y

... after a flight crew starts to deviate from any ATC clearance or instruction to comply with an ACAS resolution advisory (RA) (Pilot and controller interchange):

PILOT: TCAS RA;

ATC: ROGER;

... after the response to an ACAS RA is completed and a return to the ATC clearance or instruction is initiated (Pilot and controller interchange):

PILOT: CLEAR OF CONFLICT, RETURNING TO (assigned clearance);

ATC: ROGER (or alternative instructions);

… after the response to an ACAS RA is completed and the assigned ATC clearance or instruction has been resumed (Pilot and controller interchange):

PILOT: CLEAR OF CONFLICT (assigned clearance) RESUMED;

ATC: ROGER (or alternative instructions);

… after an ATC clearance or instruction contradictory to the ACAS RA is received, the flight crew will follow the RA and inform ATC directly (Pilot and controller interchange):

PILOT: UNABLE, TCAS RA;

ATC: ROGER;

## PANS-OPS – DOC. 8168 (VOLUME I)

Part VIII, para. 3.1.1 Airborne collision avoidance system (ACAS) indications shall be used by pilots in the avoidance of potential collisions, the enhancement of situational awareness, and the active search for, and visual acquisition of, conflicting traffic.

Part VIII, para. 3.3 Pilots should use appropriate procedures by which an aeroplane climbing or descending to an assigned altitude or flight level, especially with an autopilot engaged, may do so at a rate less than 8 m/s (or 1 500 ft/min) throughout the last 300 m (or 1000 ft) of climb or descent to the assigned altitude or flight level when the pilot is made aware of another aircraft at or approaching an adjacent altitude or flight level, unless otherwise instructed by ATC. These procedures are intended to avoid unnecessary airborne collision avoidance system (ACAS II) resolution advisories in aircraft at or approaching adjacent altitudes or flight levels. For commercial operations, these procedures should be specified by the operator.

Part VIII, para. 3.1.2 Nothing in the procedures specified in 3.2 hereunder shall prevent pilots-in-command from exercising their best judgement and full authority in the choice of the best course of action to resolve a traffic conflict or avert a potential collision.

*Note 1. — The ability of ACAS to fulfil its role of assisting pilots in the avoidance of potential collisions is dependent on the correct and timely response by pilots to ACAS indications. Operational experience has shown that the correct response by pilots is dependent on the effectiveness of the initial and recurrent training in ACAS procedures.*

*Note 2. — The normal operating mode of ACAS is TA/RA. The TA-only mode of operation is used in certain aircraft performance limiting conditions caused by in-flight failures or as otherwise promulgated by the appropriate authority.*

Part VIII para. 3.2 The indications generated by ACAS shall be used by pilots in conformity with the following safety considerations:

a) pilots shall not manoeuvre their aircraft in response to traffic advisories (TAs) only;

*Note 1. — TAs are intended to alert pilots to the possibility of a resolution advisory (RA), to enhance situational awareness, and to assist in visual acquisition of conflicting traffic. However, visually acquired traffic may not be the same traffic causing a TA. Visual perception of an encounter may be misleading, particularly at night.*

*Note 2. — The above restriction in the use of TAs is due to the limited bearing accuracy and to the difficulty in interpreting altitude rate from displayed traffic information.*

b) on receipt of a TA, pilots shall use all available information to prepare for appropriate action if an RA occurs;

c) in the event of an RA, pilots shall:

1) respond immediately by following the RA as indicated, unless doing so would jeopardise the safety of the aeroplane;

*Note 1. — Stall warning, wind shear, and ground proximity warning system alerts have precedence over ACAS*

*Note 2. — Visually acquired traffic may not be the same traffic causing an RA. Visual perception of an encounter may be misleading, particularly at night.*

2) follow the RA even if there is a conflict between the RA and an air traffic control (ATC) instruction to manoeuvre;

3) not manoeuvre in the opposite sense to an RA;

*Note.— In the case of an ACAS-ACAS coordinated encounter, the RAs complement each other in order to reduce the potential for collision. Manoeuvres, or lack of manoeuvres, that result in vertical rates opposite to the sense of an RA could result in a collision with the threat aircraft.*

4) as soon as possible, as permitted by aircrew workload, notify the appropriate ATC unit of any RA which requires a deviation from the current air traffic control instruction or clearance;

*Note.— Unless informed by the pilot, ATC does not know when ACAS issues RAs. It is possible for ATC to issue instructions that are unknowingly contrary to ACAS RA indications. Therefore, it is important that ATC be notified when an ATC instruction or clearance is not being followed because it conflicts with an RA.*

5) promptly comply with any modified RAs;

6) limit the alterations of the flight path to the minimum extent necessary to comply with the RAs;

7) promptly return to the terms of the ATC instruction or clearance when the conflict is resolved; and
8) notify ATC when returning to the current clearance.

## AIRBORNE COLLISION AVOIDANCE SYSTEM MANUAL – DOC. 9863

5.2.1.14 If an RA manoeuvre is inconsistent with the current ATC clearance, pilots shall follow the RA.

5.2.3. The following ACAS good operating practices have been identified during the use of ACAS throughout the world.

5.2.3.1 To preclude unnecessary transponder interrogations and possible interference with ground radar surveillance systems, ACAS should not be activated (TA-only or TA/RA mode) until taking the active runway for departure and should be deactivated immediately after clearing the runway after landing. To facilitate surveillance of surface movements, it is necessary to select a mode in which the Mode S transponder can nevertheless squitter and respond to discrete interrogations while taxiing to and from the gate. Operators must ensure that procedures exist for pilots and crews to be able to select the operating mode where ACAS is disabled, but the Mode S transponder remains active.

5.2.3.2 During flight, ACAS traffic displays should be used to assist in visual acquisition. Displays that have a range selection capability should be used in an appropriate range setting for the phase of flight. For example, use minimum range settings in the terminal area and longer ranges for climb/descent and cruise, as appropriate.

5.2.3.3 The normal operating mode of ACAS is TA/RA. It may be appropriate to operate ACAS in the TA-only mode only in conditions where States have approved specific procedures permitting aircraft to operate in close proximity or in the event of particular in-flight failures or performance limiting conditions as specified by the Aeroplane Flight Manual or operator. It should be noted that operating in TA-only mode eliminates the major safety benefit of ACAS.

5.2.3.3.1 Operating in TA/RA mode and then not following an RA is potentially dangerous. If an aircraft does not intend to respond to an RA and operates in the TA-only mode, other ACAS-equipped aircraft operating in TA/RA mode will have maximum flexibility in issuing RAs to resolve encounters.

A7.1.2 During a possible Air Policing Mission (hot intercept), civil aircraft might perform evasive manoeuvres, which could be interpreted as non-friendly action by the Interceptor Pilot and could lead to negative consequences stemming from the reaction of the Interceptor Pilot.

A7.1.3 From a military point of view there are two main scenarios to be discussed:
— a demonstrative intercept with a military escort mission; or
— a covert unexpected approach towards a selected target.

A7.1.4 Currently, there is no provision to distinguish between these two kinds of intercept. In addition, safe situation control on the ground can be improved in various regions of the world using capabilities implemented with Mode S.

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