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ACAS Guide Airborne Collision Avoidance

December 2017



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NOTE

This Airborne Collision Avoidance System (ACAS) Guide has been designed to support the understanding of the ACAS systems and the training of people involved in the operations of ACAS. However, it is not, per se, designed for the complete training of controllers or pilots. For a deeper knowledge, the Reader is advised to refer to documentation listed in the bibliography section.

The Guide concentrates on the ACAS II concept and technical details as well as operation principles of TCAS II version 7.1, as it is the version currently mandated in Europe. The previous TCAS II versions 6.04a and 7.0, as well as TCAS I system, are also briefly described. A preview of the forthcoming ACAS X system is also provided.

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

The original version of the Guide was partially based on the *ACAS II Brochure* that was 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
2.0	20 April 2015	Major changes.	All
2.1	18 May 2015	Correction.	Fig. 5, 6, 7
2.2	1 December 2015	Corrections and updates.	All
2.3	26 May 2016	Corrections and updates.	All
3.0	December 2017	Corrections and updates. References to version 7.0 (now obsolete) deleted or moved to the Early Versions of TCAS II section. Updated structure.	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 collisions.

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 pilots how best to regulate or adjust their vertical rate 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 civil aircraft with a maximum certified take-off mass over 5700 kg or authorised to carry more than 19 passengers, with the exception of unmanned aircraft systems.

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 description of TCAS II version 7.1; 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. The past versions of TCAS II (6.04a and 7.0) are briefly described and future airborne collision avoidance system – ACAS X, which is currently under development – is introduced to provide the Reader with a complete picture. 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 USA¹, 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’s² range and altitude.

In 1978, the collision between a light aircraft and an airliner over San Diego, California³ 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.

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. 137 people onboard plus 7 on the ground were killed.


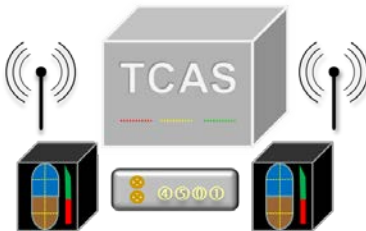
In 1986 the collision between an airliner and a light aircraft over Cerritos, California⁴ resulted in a US Congressional mandate that required some categories of US and foreign aircraft to be equipped with TCAS II for flight operations in US airspace.

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. In this Guide, the terms ACAS (the standard) and TCAS (the implementation) are used synonymously, unless specifically noted.

Table 1: ACAS and TCAS: standard and implantation

ACAS	TCAS
A irborne C ollision A voidance S ystem	T raffic alert and C ollision A voidance S ystem
Standard: ICAO Annex 10 vol. IV	The only implementation of the ICAO ACAS standard (equipment)
	

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 see each other due to the geometry of the conflict. 67 people onboard plus 15 on the ground were killed.

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. An RA will tell the pilot the range of vertical rates within which the aircraft should be flown to avoid the threat aircraft. An RA can be generated against all aircraft equipped with an altitude reporting transponder (Mode S or Mode A/C); the intruder does not need to be fitted with ACAS II. 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 II does not detect non-transponder equipped aircraft or aircraft with a non-operational transponder⁵.

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 87) 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 TAs⁶.

Although ACAS III is mentioned as a future system in ICAO Annex 10, ACAS III is unlikely to materialise due to difficulties which the conventional surveillance systems have with horizontal tracking and, consequently, issuing horizontal avoidance manoeuvres. A future collision avoidance system for Remotely Piloted Aircraft Systems (RPAS) – ACAS Xu – is being developed and will incorporate horizontal manoeuvres by utilizing modern surveillance methods, such as ADS-B (see page 21).

The latest TCAS II Minimum Operational Performance Standards (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.

⁵ On 29 September 2006 a collision between a Boeing 737-800 and Embraer Legacy occurred in Brazil. Both aircraft were TCAS II equipped. However, the Embraer crew was not aware that the transponder was no longer operating making the Embraer “invisible” to the B737 TCAS. As the transponder did not work, Embraer’s TCAS was automatically placed into Stand-by. The aircraft were flying in the opposite directions at the same altitude and collided. The B737 crashed killing 154 people on board, while the Embraer managed to land.

⁶ Sometimes referred to as TCAS IV.

ACAS equipment is available from three principle vendors, all of them based in the USA⁷. 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.

Currently, there are at least 25,000 TCAS II equipped aircraft worldwide, including passenger airline and air freight operations, business aviation, and government and military aircraft.

ACAS I

ACAS I is an airborne collision avoidance system that provides only advisories to aid visual acquisition. Unlike ACAS II, ACAS I does not issue any specific collision avoidance advice (RAs are not issued).

ACAS I provides three levels of advisories:

- Other Traffic;
- Proximate Advisories (PA);
- Traffic Advisories (TA).

TAs are issued based on either *tau*⁸ or proximity to an intruder aircraft, using two sensitivity levels⁹. Nominally, all transponder equipped intruder aircraft within five nautical miles are detected and shown on a traffic display.

The display of a TA is accompanied by an aural alert ("Traffic, traffic") to inform the crew a TA has been displayed. The aural annunciations are inhibited if own aircraft is below 400 feet AGL (on an aircraft equipped with a radio altimeter) or when the landing gear is extended (if no radio altimeter is installed). When TCAS I is installed on a fixed-gear aircraft without a radio altimeter, the aural annunciations will never be inhibited.

ACAS I advisories provide the crew with the intruder's range, bearing, and for altitude reporting intruders, relative altitude and vertical speed. The criteria for generating these advisories were chosen to provide the crew sufficient time to visually acquire the intruder aircraft prior to the closest approach of the intruder aircraft.

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 MOPS have been published by RTCA (DO-197A) in September 1994.

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

ACAS I is still mandated or allowed on some aircraft operating in US airspace. In Europe ACAS I may be found on some aircraft outside the current European mandate (i.e. either military or those falling outside the mandated weight or number of passenger seats thresholds).

ACAS I is not covered further in this Guide.

⁷ Honeywell, ACSS and Rockwell Collins.

⁸ See page 47 for more information on *tau*.

⁹ See page 41 for more information on sensitivity level.

TCAS II VERSIONS

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.

Neither version 6.02 nor 6.04a were compliant with the ICAO ACAS SARPS (Annex 10, volume IV).

Version 6.02 is longer used. Version 6.04a is still mandated or allowed on some aircraft operating in US airspace. In Europe version 6.04a may be found on aircraft outside the current European mandate (i.e. either military or those below the mandated weight or number of passenger seats thresholds).

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 brought by version 7.0 were:

- the introduction of a horizontal miss distance filter;
- 25-foot vertical tracking;
- sophisticated multi-threat logic;
- compatibility with Reduced Vertical Separation Minima (RVSM) operations¹⁰;
- the reduction of electromagnetic interference;
- allowing RA reversals in coordinated encounters;
- simplified aural annunciations.

Version 7.0 was the first TCAS II version to be compliant with the ICAO ACAS SARPS (Annex 10 volume IV).

Version 7.0 is still mandated or allowed on many aircraft operating in US airspace and other parts of the world. In Europe version 7.0 may be encountered on aircraft outside the current European mandate (i.e. either military or those below the mandated weight or number of passenger seats thresholds).

VERSION 7.1

TCAS II version 7.1 is the only ACAS version meeting the current requirements of ICAO and European mandates. It was developed based on an extensive analysis of version 7.0 performance, with two major changes implemented to improve TCAS performance.

¹⁰ The carriage and operation of TCAS II is not an RVSM requirement in itself. For equipage requirement see page 20.

New Level Off RA

Operational monitoring of version 7.0 revealed two issues with pilots' responses to Reduce Climb and Reduce Descent RAs (announced as "Adjust vertical speed, adjust"). Those were:

- **incorrect response:** the pilots increased their vertical rate instead of reducing it, consequently causing a deterioration of the situation¹¹;
- **level busts** when pilots following the Reduce Climb and Reduce Descent RAs flew through their cleared level, often causing a follow up RA for the other aircraft above or below, and disrupting ATC operations.

To address these issues, in version 7.1 the Reduce Climb/Descent RAs have been replaced with a new "Level off, level off" RA. 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 1) 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 (as illustrated in Figure 2). The aural message "Level off, level off" has the benefit of being intuitive and the associated manoeuvre corresponds to the standard levelling off manoeuvre.

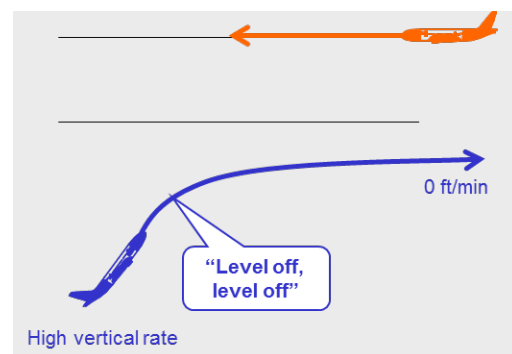


Figure 1: Level Off RA as an initial RA

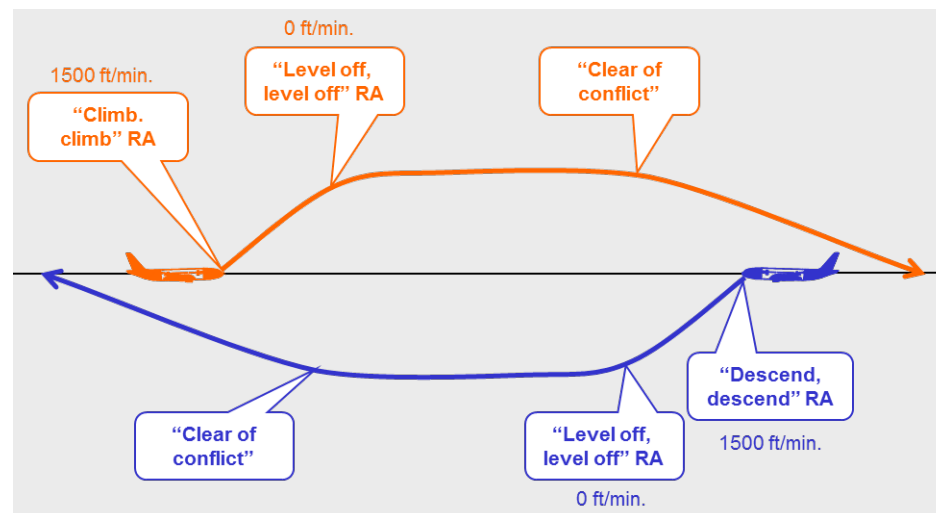


Figure 2: Level Off RA as a weakening RA.

¹¹ The aural annunciation associated with the Reduce Climb/Descent RAs ("Adjust vertical speed, adjust") did not clearly communicate what exact manoeuvre was required. That led to cases where pilots were increasing their vertical rate rather than reducing it. For instance, the SIRE+ study identified 15 opposite responses to initial Adjust Vertical Speed RAs, during 2004 and 2005 in French airspace (Source: CP115 (LOLO) Evaluation Report WP5/40/D, EUROCONTROL SIRE+ Project, May 2007).

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 (i.e. both aircraft TCAS II equipped) 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 in “vertical chase with low vertical miss distance” geometries: version 7.0 failed to reverse an RA if two aircraft converging in altitude remained within 100 feet (see Figure 3). This scenario could occur when one aircraft was not following the RA or was not TCAS II equipped, and followed an ATC instruction or performed 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 2001¹² and the Überlingen (Germany) midair collision in July 2002¹³. In 5 years following the Überlingen accident, eight other occurrences have been observed in European airspace¹⁴.

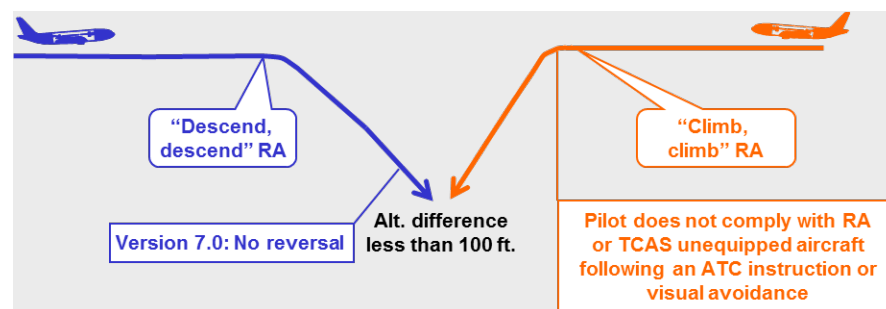


Figure 3: Geometry in which version 7.0 did not reverse an RA.

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

A feature has been added to the version 7.1 logic which monitors RA compliance in coordinated encounters. When the logic 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 RA¹⁵ (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 4). The feature will be activated only if:

- at least 4 seconds remain before CPA (because a reversal RA triggered in the last 4 seconds gives little chance for correct pilot’s response)
- and
- only if at least 10 seconds have elapsed since the initial RA, because a reversal RA triggered too early does not give the pilot enough time to comply with the initial RA.

¹² A DC-10 and a Boeing 747-400 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.

¹³ 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.

¹⁴ Source: *Decision criteria for regulatory measures on TCAS II version 7.1, EUROCONTROL SIRE+ Project WP7/69/D, July 2008.*

¹⁵ In this case, the Mode S 24-bit address priority rule (i.e. the aircraft with higher Mode S address detects the incompatibility and reverses the sense of its RA) is not applicable (see Geometric Reversals on page 55).

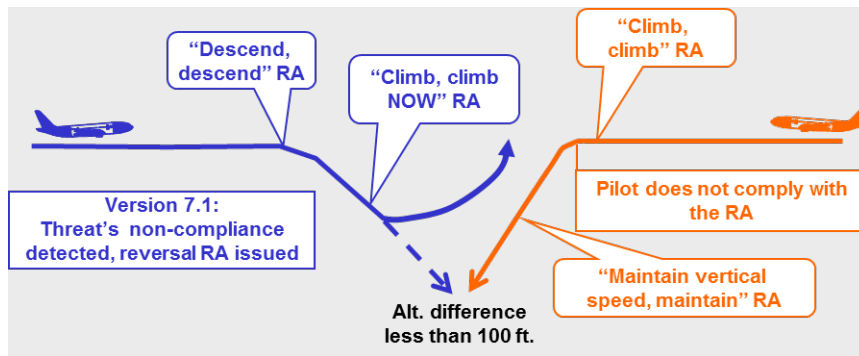


Figure 4: Improvement of reversal logic in version 7.1 (both aircraft equipped).

In single equipage encounters, version 7.1 recognises 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 5).

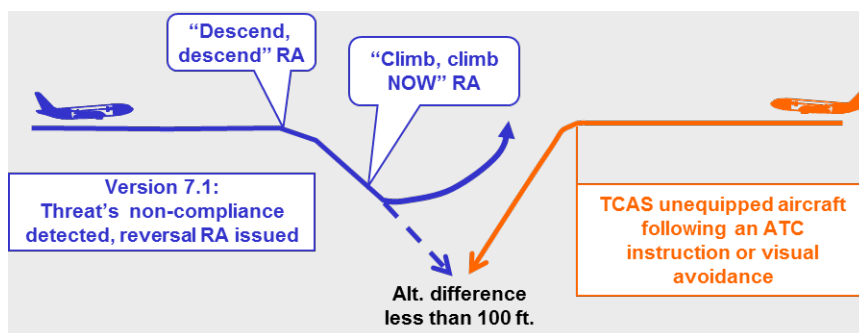


Figure 5: Improvement of reversal logic in version 7.1 (only one aircraft equipped).

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

ACAS II CARRIAGE MANDATES

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 following schedule for ACAS II implementation in Europe was adopted:

- **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)¹⁶ 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 1997¹⁷, 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.

¹⁶ An Ilyushin 76 and a Boeing 747-100 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.

¹⁷ 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.

CURRENT ICAO AND EUROPEAN TCAS II/ACAS II EQUIPAGE MANDATES

Amendment 85 to ICAO Annex 10 volume IV, published in October 2010, introduced a provision¹⁸ stating that all ACAS units shall be compliant with version 7.1 after 1 January 2017.

Version 7.1 has been mandated within European Union earlier than the dates stipulated in ICAO Annex 10. On 20 December 2011, the European Commission published an Implementing Rule¹⁹, subsequently amended on 16 April 2016²⁰, mandating the carriage of ACAS II version 7.1 within European Union airspace from 1 December 2015 by all aeroplanes with a maximum certified take-off mass exceeding 5700 kg or authorised to carry more than 19 passengers, with the exception of unmanned aircraft systems. Aircraft not referred to above but which are equipped on a voluntary basis with ACAS II, must be equipped with version 7.1.

The above mandate applies only to civil aircraft. However, the Military Authorities of the ECAC Member States have agreed on a voluntary installation programme on military (State) transport-type aircraft with ACAS II. In Germany, carriage and operation of ACAS II (i.e. TCAS II version 7.0 or 7.1) by all (German and foreign) military transport aircraft is mandatory²¹.

¹⁸ See Appendix on page 88 for the full text of ICAO Annex 10 provision.

¹⁹ 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>

²⁰ Commission Regulation (EU) No 2016/583 of 15 April 2016 amending Regulation (EU) No 1332/2011 laying down common airspace usage requirements and operating procedures for airborne collision avoidance published in the Official Journal of the European Union on 16 April 2016:
<http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0583&from=EN>

²¹ Refer to German AIC IFR 13 of 20 March 2003.

FUTURE OF COLLISION AVOIDANCE: ACAS X

The United States Federal Aviation Administration (FAA) has funded research and development of a new approach to airborne collision avoidance (known as ACAS X²²) 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.

ACAS X PRINCIPLES

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 ACAS X probabilistic model provides a statistical representation of the aircraft position in the future. It also takes into account the safety and operational objectives of the system enabling the logic to be tailored to particular procedures or airspace configurations.

This is fed into an optimisation process called dynamic programming to determine the best course of action to follow according to the context of the conflict. This employs a *rewards* versus *costs* system to determine which action would generate the greatest benefits (i.e. maintain a safe separation while implementing a cost-effective avoidance manoeuvre). Key metrics for operational suitability and pilot acceptability include minimising the frequency of alerts that result in reversals/intentional intruder altitude crossings or disruptive advisories in noncritical encounters.

The lookup table is used in real-time on-board the aircraft to resolve conflicts. ACAS X collects surveillance measurements from an array of sources (approximately every second). Various models are used (e.g. a probabilistic sensor model accounting for sensor error characteristics) to estimate a state distribution, which is a probability distribution over the current positions and velocities of the aircraft. The state distribution determines where to look in the numeric lookup table to determine the best action to take (which includes the option 'do nothing'). If deemed necessary, resolution advisories are then issued to the pilots.

ACAS X VARIANTS

- **ACAS Xa** – The general purpose ACAS X that makes active interrogations to detect intruders. ACAS Xa is the baseline system, the successor to TCAS II. The Standards are expected to be ready by 2018²³ and ACAS X may become commercially available in 2020.
- **ACAS Xo** – ACAS Xo is an extension to ACAS Xa designed for particular operations, like closely spaced parallel approaches, for which ACAS Xa is less suitable because it might generate a large number of nuisance alerts. The Standards are prepared jointly with ACAS Xa standards and also are expected to be ready by 2018; however currently it is not known when ACAS Xo will become commercially available.
- **ACAS Xu** – Designed for Remotely Piloted Aircraft Systems (RPAS), incorporating horizontal resolution manoeuvres. Work on Standards has started in 2016 and is expected to be finished in 2020.
- **ACAS Xp** – A future 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).

²² Pronounced "Ay-cas eks" rather than "Ay-cas ten".

²³ MOPS are being developed by RTCA and EUROCAE standardization working arrangements (SC-147 and WG-75 respectively).

ACAS Xa

It is envisaged that ACAS Xa will provide an improvement in safety while reducing the unnecessary alert rate. ACAS Xa will most likely be delivered together with ACAS Xo variant. The system will use the same hardware (antennas and displays) as the current TCAS II system and the same range of RAs – as in TCAS II version 7.1 – will be used. There will be no change in the way RAs are displayed and announced to the pilot with the exception of Maintain Vertical Speed and Crossing Maintain Vertical Speed RAs which will in ACAS X installation be announced using the same aural as for Descend or Climb RAs or Reversal Descend or Reversal Climb RAs (if the Maintain Vertical Speed RA is a reversal RA). 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 (versions 6.04a, 7.0 and 7.1). It is the intention that ACAS Xa will eventually replace TCAS II.

ACAS Xa will not use the Sensitivity Levels (see page 41) which are present in the TCAS II design. Also, the minimum time limits on RA duration used in TCAS II (see page 55) will not be used. However, the same low level RA inhibition (see page 56) will be applied. All ACAS X systems will include the use of hybrid surveillance (see page 40) to extend display range and limit interference.

Two of the key differences between TCAS II and the current concept for ACAS Xa 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 estimated time of closest approach and projected miss distance. This relies on a fixed set of rules, modelling the spectrum of pilots' responses (see Figure 6).

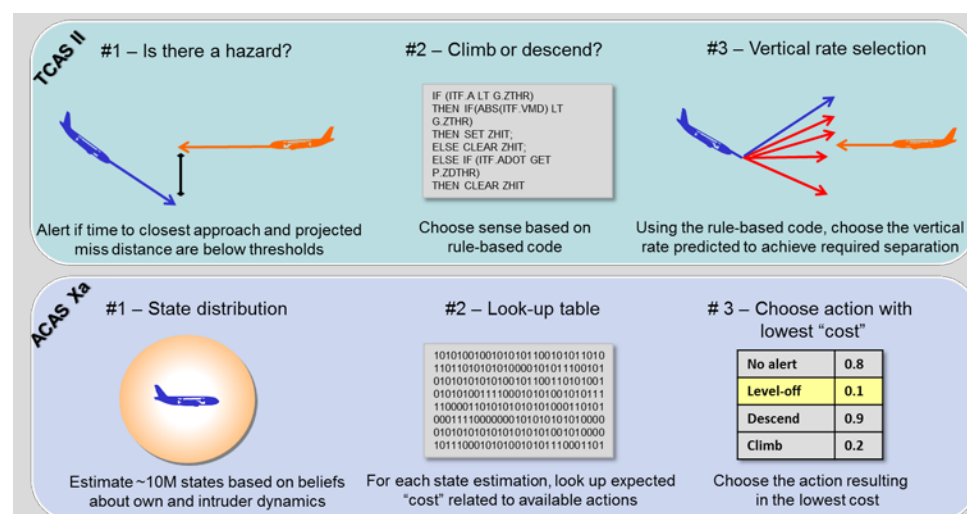


Figure 6: RA selection process: TCAS II vs. ACAS Xa.

ACAS Xo

ACAS Xo is intended for aircraft currently equipped with ACAS II and in the future with ACAS Xa. ACAS II an ACAS Xa design may reduce the effectiveness of the collision avoidance function in visual separation procedures and closely spaced parallel operations. These procedures often result in separation inside of alerting thresholds, thus resulting in nuisance alerts.

These nuisance alerts decrease the effectiveness of the collision avoidance function as flight crews may ignore RAs. ACAS Xo functionality will give the pilot an option to select a "Designated No Alerts" (DNA) mode on one intruder to suppress all alerts. DNA will operate using the ACAS Xa logic, but will suppress any TAs and RAs outputs (for the designated intruder) to the flight crew while still performing RA coordination with other aircraft. During multi-threat encounters involving the designated aircraft, DNA mode will be suspended.

Furthermore, a special mode for Closely Spaced Parallel Operations (CSPO-3000²⁴) will provide the designated traffic with modified collision avoidance logic monitoring more appropriate for parallel operations. ACAS Xa protection is maintained on all other traffic.

More modes may be developed in the future.

ACAS Xo installations will have to be integrated with an ASAS (Airborne Separation Assurance Systems) interface to allow the designation of traffic.

ACAS X BENEFITS

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.
- Safety improvement: It is envisaged that ACAS Xa will provide an improvement in safety while reducing the unnecessary alert rate.
- Adaptability to future operational concepts: Both SESAR²⁵ and NextGen²⁶ 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 2500 ft/min.), which excludes many 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.

For additional information resources on ACAS X see page 77.

²⁴ Down to 3,000-foot spacing between parallel runways.

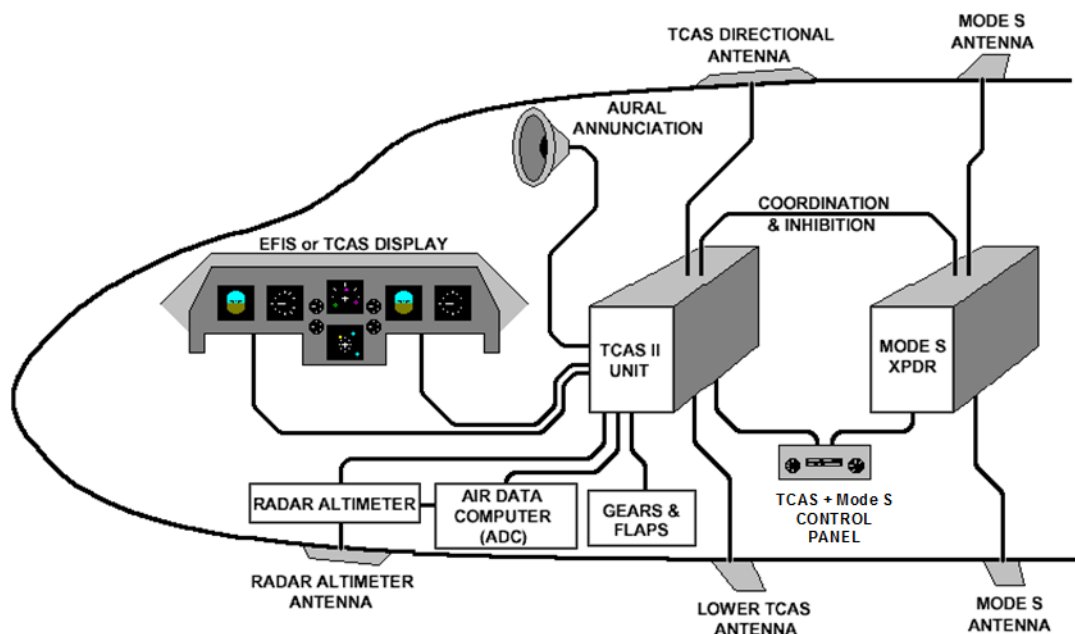
²⁵ Single European Sky ATM Research Programme (SESAR) is the European air traffic control infrastructure modernisation programme that aims at developing the new generation air traffic management system capable of ensuring the safety and fluidity of air transport worldwide over the next 30 years.

²⁶ Next Generation Transportation System (NextGen) is the name for the transformation of the National Airspace System (NAS) of the United States, planned in stages between 2012 and 2025.

SYSTEM COMPONENTS

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

- **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.



EUROCONTROL

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 autopilot²⁷, 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 II 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.

²⁷ An exception here is the Airbus AP/FD (Autopilot/Flight Director) TCAS capability. See page 65 for more information.

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 8 below and Figure 9 and in Figure 10.

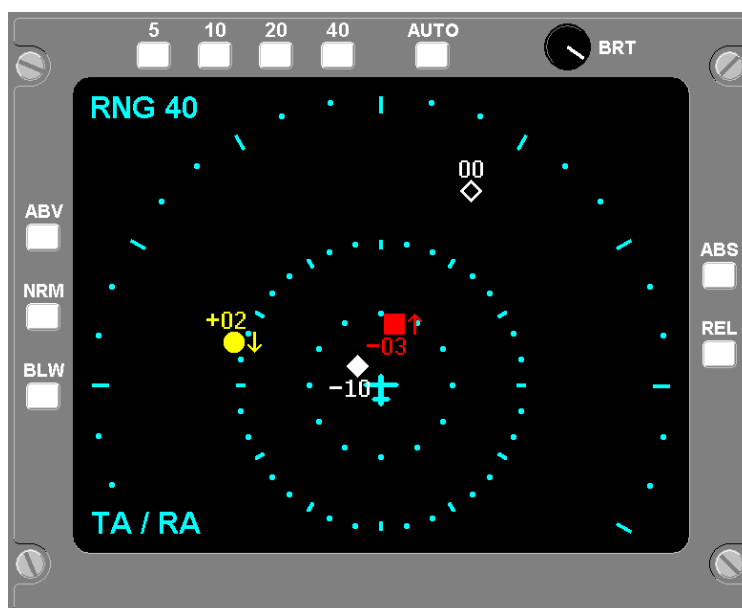


Figure 8: TCAS traffic display example - dedicated display.



Figure 9: TCAS traffic display example – IVSI combined with TCAS traffic display.



Figure 10: 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**²⁸ – 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 11.










Own aircraft		
Other aircraft		
Proximate aircraft		
Intruder aircraft		
Threat aircraft		
Vertical trend arrow and relative altitude		

Figure 11: 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.

²⁸ Typically, 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" trend 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 9 and Figure 10. 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 rates, which are to be **avoided**. When appropriate, a green arc, shown next to the red arc, indicates to the pilots that they should manoeuvre the aircraft to reach the required vertical rate, shown in the green arc. If there is more than one threat, two red arcs may flank the range of the required vertical rates.

Table 2 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 10).

There are two PFD concepts:

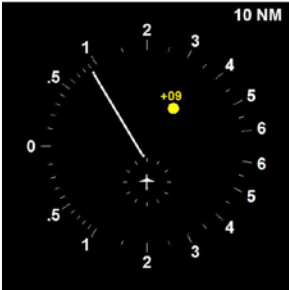
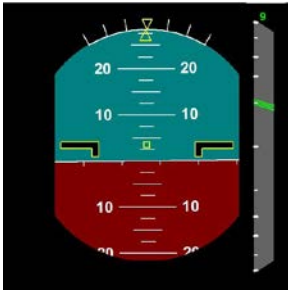

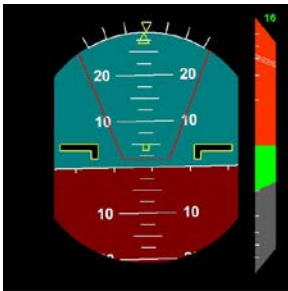
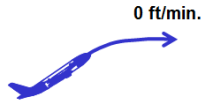

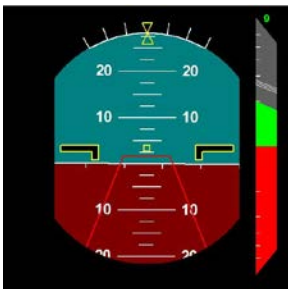
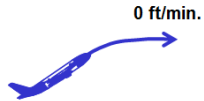
- **display on the artificial horizon** – a resolution advisory is shown by a red or orange isosceles trapezoid delineating an area showing the flight attitude values which are to be avoided. This provides direct guidance on the pitch angle to be achieved by the pilots. This form of display does not 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 rates to be avoided, a green area indicates to the pilots the required vertical rate.

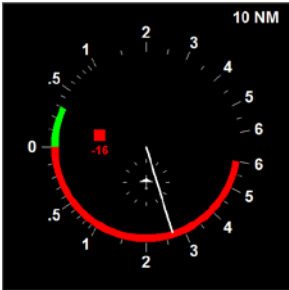
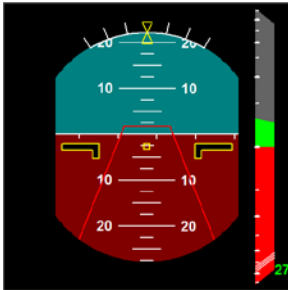
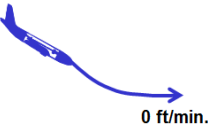

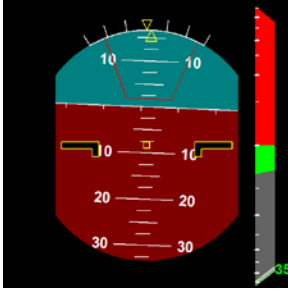
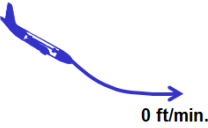

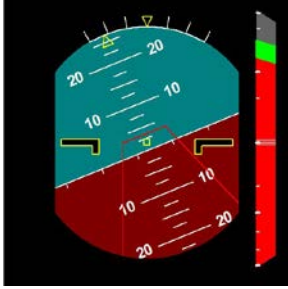
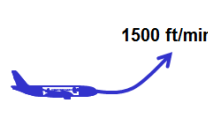
Table 2 shows examples of TCAS II advisories as shown on EFIS instrumentation.


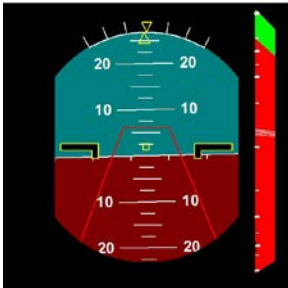
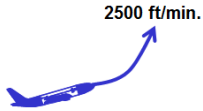

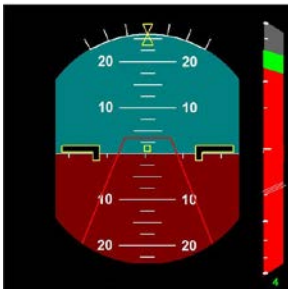
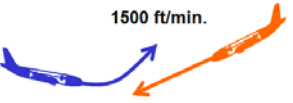

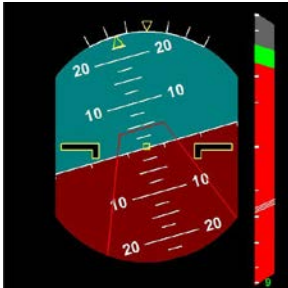
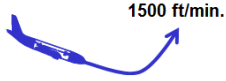
Aural annunciations

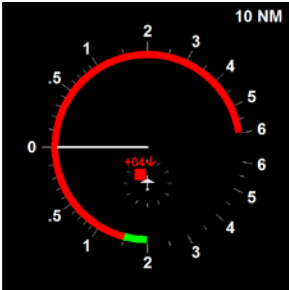
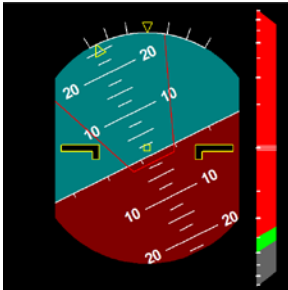
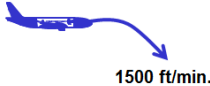

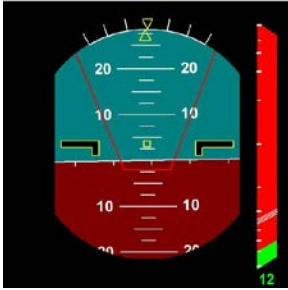
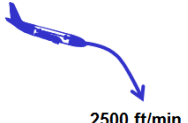

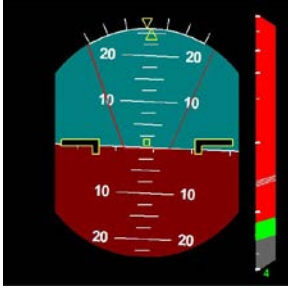
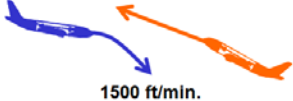
Loudspeakers located in the cockpit alert the crew, by means of aural annunciations, of TCAS II advisories. Some implementations provide aural annunciations via the crew’s headsets. All aural annunciations are inhibited below 500 feet AGL (± 100 feet) or when higher priority warning system (wind shear or GPWS) has an active warning. Additionally, an annunciation of new TA (“Traffic, traffic”) may be suppressed (implementation dependent) if an RA against another aircraft is already in progress. The version 7.1 aural messages are listed in Table 3.


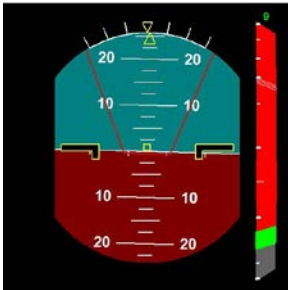
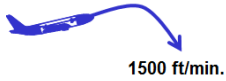

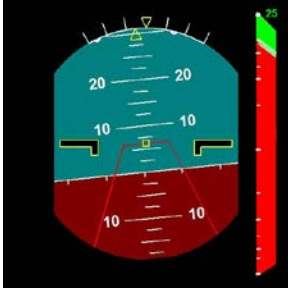


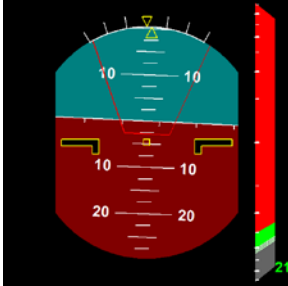

Table 2: TCAS II version 7.1 advisories as shown on (generic) IVSI and EFIS displays.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Traffic advisory	Traffic, traffic			No manoeuvring
Level Off (downward sense initial RA)	Level off, level off			
Level Off (upward sense weakening RA)	Level off, level off			

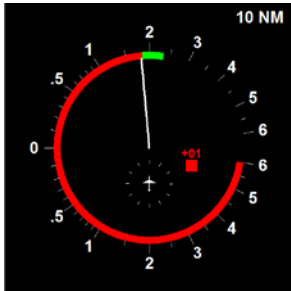
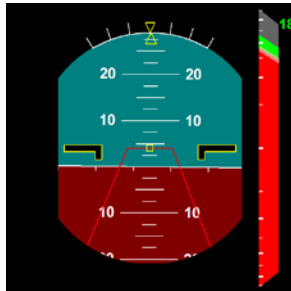


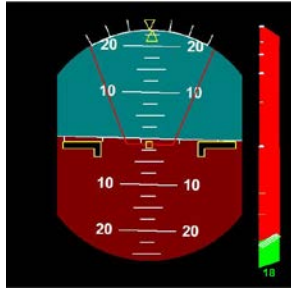
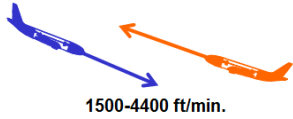

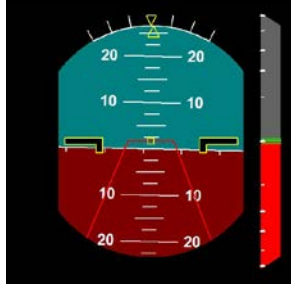

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Level Off (upward sense initial RA)	Level off, level off			
Level Off (downward sense weakening RA)	Level off, level off			
Climb	Climb, climb			

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Increase Climb	Increase climb, increase climb			
Crossing Climb	Climb, crossing climb; climb, crossing climb			
Reversal Climb	Climb, climb NOW; climb, climb NOW			

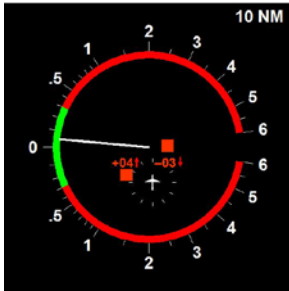
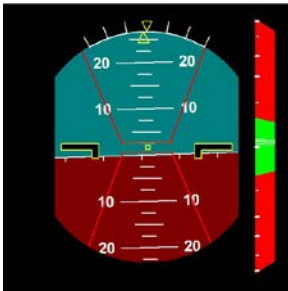
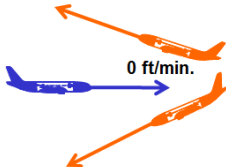

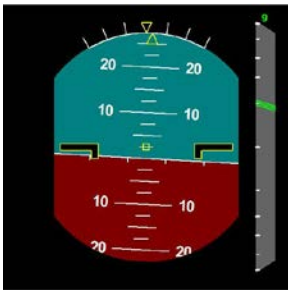
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Descend	Descend, descend			
Increase Descent	Increase descent, increase descent			
Crossing Descent	Descend, crossing descend; descend, crossing descend			

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Reversal Descent	Descend, descend NOW; descend, descend NOW			
Maintain Vertical Speed ²⁹ (upward sense)	Maintain vertical speed, maintain			
Maintain Vertical Speed ³⁰ (downward sense)	Maintain vertical speed, maintain			

²⁹ This RA only occurs when the aircraft is already climbing or descending (in the correct vertical sense) at more than 1500 ft/min. The display of the RA may be a source of confusion when the pilot is climbing but starting to descend (or vice versa): when s/he looks at the display the current vertical speed could already be in the red.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Crossing Maintain Vertical Speed ³⁰ (upward sense)	Maintain vertical speed, crossing maintain			
Crossing Maintain Vertical Speed ³⁰ (downward sense)	Maintain vertical speed, crossing maintain			
Monitor Vertical Speed	Monitor vertical speed			

³⁰ This RA only occurs when the aircraft is already climbing or descending (in the correct vertical sense) at more than 1500 ft/min. The display of the RA may be a source of confusion when the pilot is climbing but starting to descend (or vice versa): when s/he looks at the display the current vertical speed could already be in the red.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Multi-threat RA	In this example ³¹ : Level off, level off			
RA Removed	Clear of conflict			Return to the last ATC clearance.

³¹ Several other combinations of prohibited and required vertical rates are, as well as aural annunciations, possible with multi-threat RAs.

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 ³²	1500 to 4400	Maintain vertical speed, maintain	Maintain Descent ³²	– 1500 to – 4400	Maintain vertical speed, maintain
Maintain Crossing Climb ³²	1500 to 4400	Maintain vertical speed, crossing maintain	Maintain Crossing Descent ³²	– 1500 to – 4400	Maintain vertical speed, crossing maintain
Level Off	0	Level off, level off	Level Off	0	Level off, level off
Reversal Climb ³³	1500	Climb, climb NOW; climb, climb NOW	Reversal Descent ³³	– 1500	Descend, descend NOW; descend, descend NOW
Increase Climb ³³	2500	Increase climb, increase climb	Increase Descent ³³	– 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

³² This RA only occurs when the aircraft is already climbing or descending (in the correct vertical sense) at more than 1500 ft/min.

³³ Not possible as an initial RA.

TCAS II SURVEILLANCE

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. In implementations that allow for the use of the Mode S extended squitter, the normal surveillance range may be increased beyond the nominal 14 NM. However, this information is not used for collision avoidance purposes. The equipment is not intended to interrogate a target unless the altitude information indicates that it is within 10,000 feet of own altitude.

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 Mode S 24-bit address of the sender is contained within the squitter. If another aircraft has the same 24-bit address as own aircraft³⁴, the track will be ignored.

Following receipt of a squitter, TCAS II sends a Mode S interrogation to the Mode S 24-bit address contained in the message. TCAS II uses the reply received to determine range, bearing and altitude of the intruder aircraft.

If the aircraft is equipped with a Mode S transponder but does not provide altitude information this aircraft will be tracked as a non-altitude reporting target (NAR) using range and bearing information and it will be shown on the TCAS traffic display, when own aircraft is below FL155. 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 (but using reduced time thresholds which correspond to RA thresholds). 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).

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.

³⁴ Whilst that should not occur (as Mode S 24-bits addresses are assigned to individual airframes), reports suggest that there are cases of aircraft operating with an incorrect 24-bit address programmed into the transponder.

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 intruder 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, when own aircraft is below FL155. 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 24-bit 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 II 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 12).

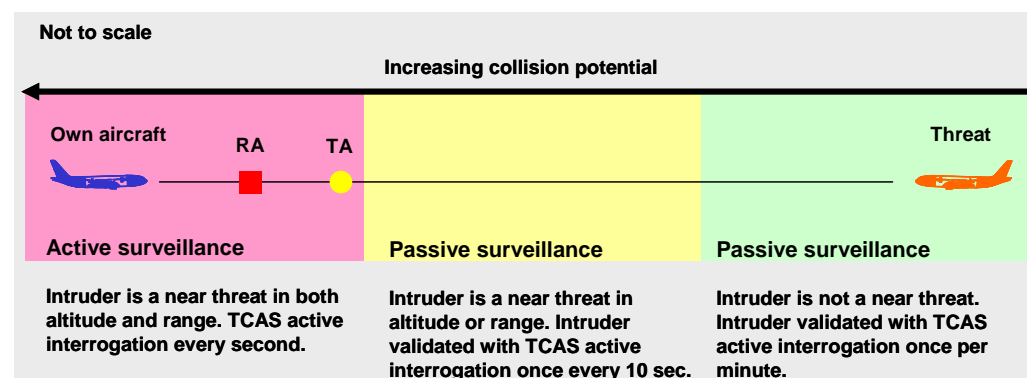


Figure 12: Hybrid surveillance - transition from passive to active surveillance.

TCAS II LOGIC AND ADVISORIES

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 13 and Figure 14) around each TCAS equipped aircraft. The sensitivity level 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 each intruder, with the higher of the two *SLs* applying to both aircraft; however, *ALIM* (the threshold for corrective RAs – see Table 6) is determined solely by each aircraft’s own altitude. If one of the two aircraft is in *SL2* (TA-only mode), it will remain in *SL2* regardless of the *SL* of the intruder. See page 47 for more information about threat detection.

Typically, the following selections of TCAS/transponder modes of operations on the transponder panel are available (Figure 15): “**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.

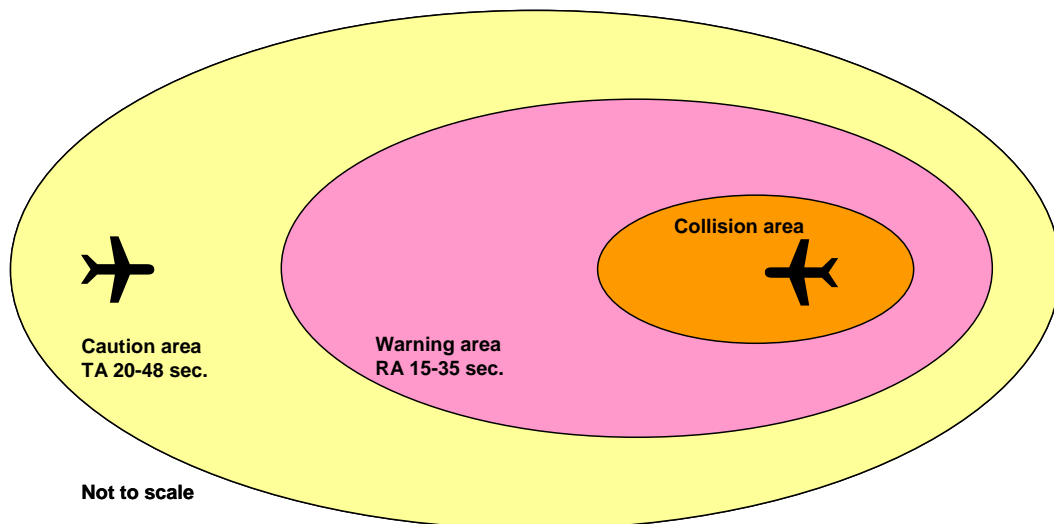


Figure 13: TCAS II protected volume (horizontal view).

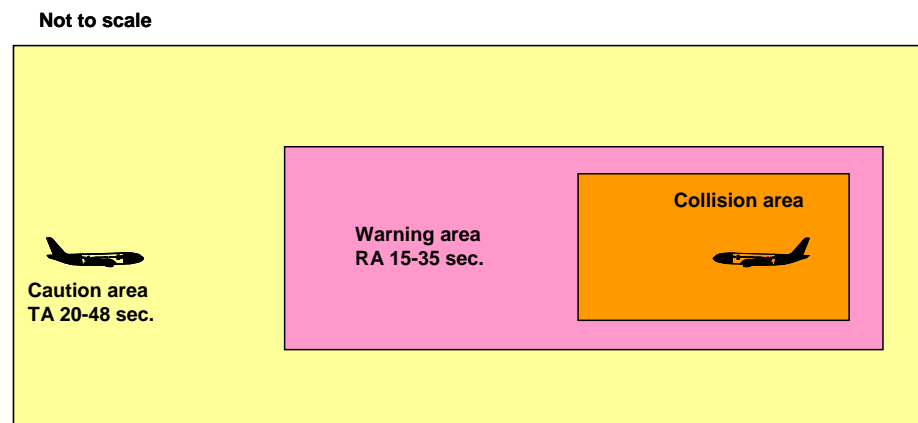


Figure 14: TCAS II protected volume (vertical view).



Figure 15: Example of TCAS/transponder panel (Boeing 737-700).

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. *SL2* is selected when the TCAS aircraft is between 0 and 1000 feet AGL (Above Ground Level) as indicated by the radar (radio) altimeter. This *SL* corresponds to **"TA-ONLY"** mode. In *SLs* 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.

Table 4: Sensitivity levels.

Own Altitude	Sensitivity levels (<i>SL</i>)
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
Above FL200	7

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 47 for more information about threat detection.

CAS FUNCTIONS

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 16. 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.

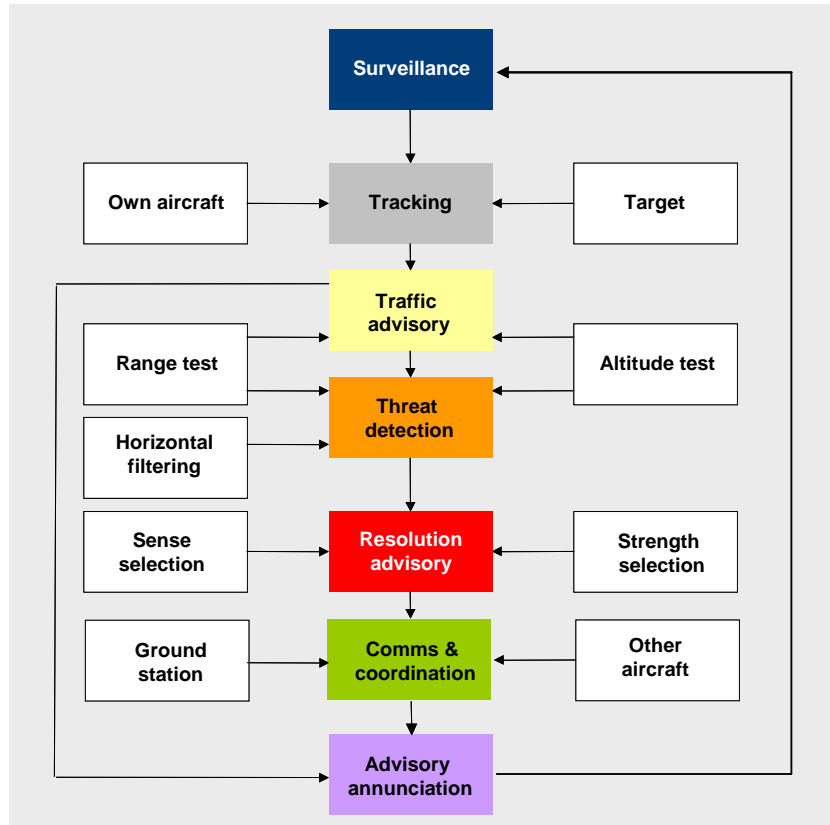


Figure 16: CAS logic functions.

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 in the USA (document DO-185B) and by EUROCAE in Europe (document ED-143).

Table 5: Transponder modes of operations.

Operating mode	Transponder	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. 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. Departure: Select XPNDR during push-back. 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. 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. Other TCAS II aircraft can generate (uncoordinated) RAs. A "TA-only" aircraft will be treated as unequipped by other TCAS II aircraft. This will allow them full freedom to choose the most effective RA. Use limited to the situations described in the Operations Manual, such as engine failure, emergency descent and other specific conditions.
TA/RA or AUTOMATIC	On	On	Yes	Yes	Own aircraft can generate RAs. RAs with other TCAS II aircraft are coordinated. Standard mode of operation.

Tracking

Using the surveillance reports (slant range, bearing³⁵ 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 rate 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. The bearing of the intruder is estimated through the use of the directional antenna.

The CAS logic uses the data from own aircraft pressure altimeter (1-foot precision)³⁶ and radar (radio) 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 (± 50 feet) AGL, the CAS logic estimates the altitude of the intruder above the ground, using own pressure altitude, own radar (radio) altimeter and the pressure altitude of the intruder. If this estimated altitude is less than 380 feet (± 20 feet), TCAS II considers the target to be on the ground, and so does not generate any TA or RA (see Figure 17). Hysteresis values ensure that the on-the-ground/airborne status does not oscillate rapidly should the aircraft be close to the nominal height boundary but periodically passing above and below that boundary. Mode S aircraft that declare that they are on the ground are not tracked by TCAS II.

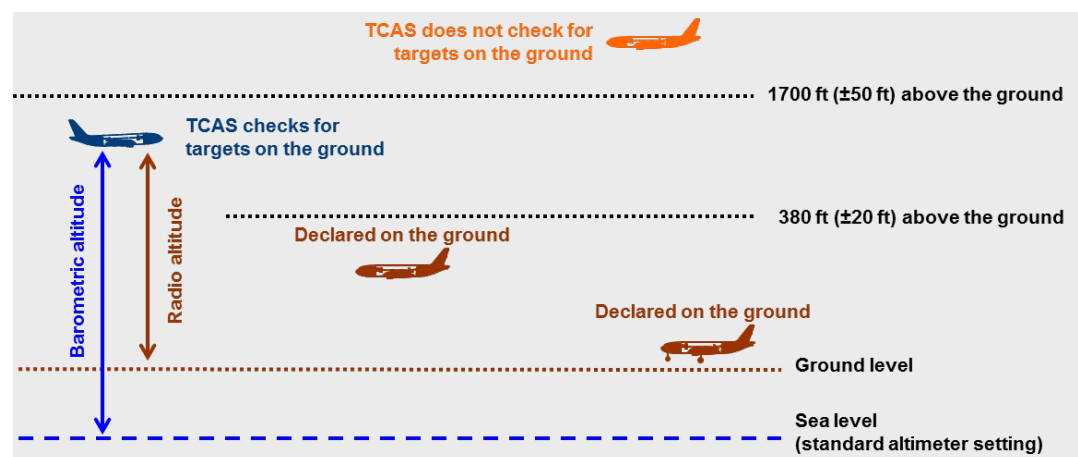


Figure 17: Target on-the-ground determination.

³⁵ 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 47).

³⁶ Some older airframes use own Mode C altitude (100-foot precision).

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 the CPA is the smallest range between the two aircraft.

In its predictions, TCAS II assumes the worst-case scenario, i.e. the aircraft are on a collision course, to estimate the time remaining until CPA. 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 τ , 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 subsequently, if the Range Test passes, an Altitude Test on every altitude-reporting target on each cycle (i.e. approximately every second). An intruder becomes a threat only if the following conditions are met in the same cycle:

- both the range and altitude tests pass; or
- the range test passes and an altitude-crossing Resolution Advisory Complement (RAC)³⁷ has been received from the threat.

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 τ : “close in range” effectively means within a distance parameter called $DMOD$ ³⁸. 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.

³⁷ See page 49 for more information on Resolution Advisory Complement.

³⁸ Distance Modification or $DMOD$ is a safety factor incorporated in range measurements to account for possible accelerations by the intruder. The value of distance modification varies with the sensitivity level (in line with the time thresholds).

Altitude Test. The Altitude Test is performed only when the Range Test passes. 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 is likely to reduce the incidence of altitude crossing RAs being selected).

Threat Declaration. If both Range Test and Altitude Test pass then the intruder is declared a threat and an RA is generated. An intruder becomes a threat when it penetrates a “protected volume” (see Figure 13 and Figure 14) enclosing own aircraft. The “protected volume” is defined by means of a Range Test (using range data only) and an Altitude Test (using altitude and range data). Application of these tests delivers a positive or a negative result (implying that the threat is inside or outside the appropriate part of the protected volume).

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.

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

TCAS II ALERTS

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 and own aircraft is below FL155, on the basis of the same *tau* values associated with the RA (in SL2 where no RAs are issued the SL3 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.

TCAS-TCAS COORDINATION

In a TCAS-TCAS encounter (i.e. an encounter between two TCAS II equipped aircraft), each aircraft, once an RA has been issued, transmits 'interrogations' to the other aircraft via the Mode S data link in the form of a Resolution Advisory Complement (RAC). The receiving aircraft notes the RAC interrogation but does not reply. RACs are sent in order to ensure the selection of complementary resolution advisories by restricting the choice of manoeuvres available to the TCAS II receiving the RAC. 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 (i.e. an RA is active).

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". The coordination interrogation also contains information as to whether the threat has selected a crossing RA or not³⁹. 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.

³⁹ Only Crossing Descend, Crossing Climb and Crossing Maintain Vertical Speed RAs annunciations contain the word "crossing". In some geometries other RAs may require that own aircraft crosses at least 100 feet below or above the threat aircraft (e.g. Level Off RA).

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. For the purpose of coordination, the aircraft with the lower Mode S 24-bit address (so called “*master aircraft*”) is given priority in coordination over the aircraft with the higher Mode S 24-bit address (so called “*slave aircraft*”). The aircraft with the higher Mode S 24-bit address (“*slave aircraft*”) will detect the incompatibility of the RA and will reverse the sense of its RA to the sense opposite to the RA generated by the other aircraft (i.e. coordination or tiebreak reversal). The aircraft with the lower Mode S 24-bit address (“*master aircraft*”) is not permitted to reverse its RA for the purpose of coordination. The reversal can occur on the cycle after the initial RA has been issued. For more information on reversals see page 53.

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 18 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 $\frac{1}{4} g$). 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.

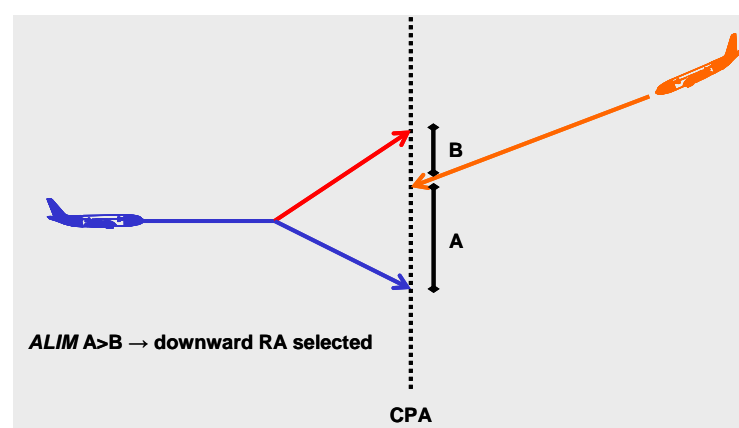


Figure 18: RA sense selection.

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 19 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 20). However, delaying mechanisms aim at reducing the incidence of crossing RAs by deferring an altitude crossing advisory if:

- one aircraft is level, or when the two aircraft have vertical rates in opposite senses and they are separated by at least 600 feet; or
- when both aircraft have a vertical rate in the same sense and they are separated by at least 850 feet.

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.

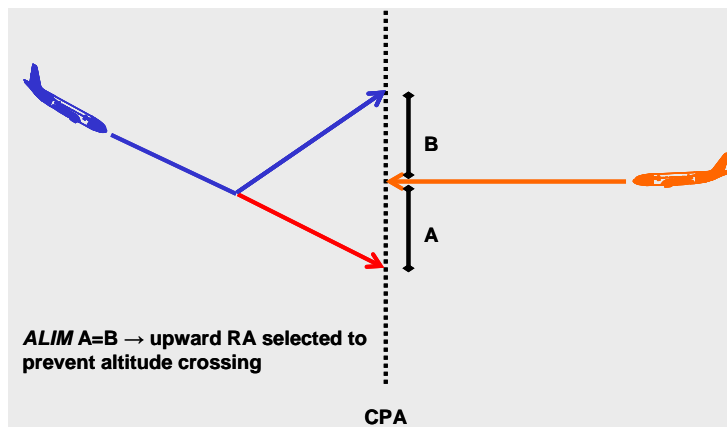


Figure 19: Non-crossing RA.

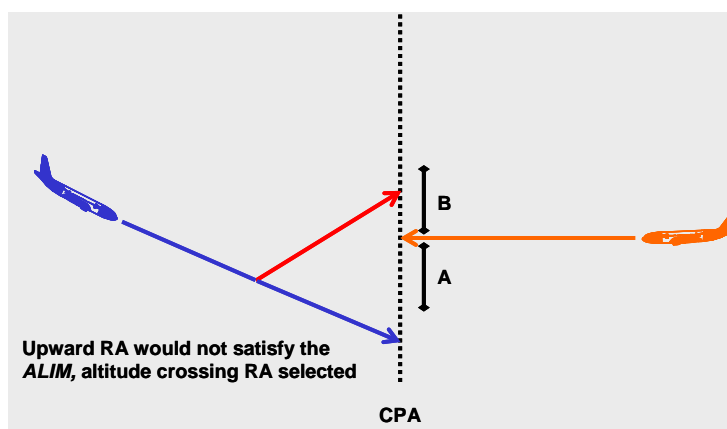


Figure 20: Crossing RA.

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 rate or requiring a modified vertical rate. 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 21, in which the vertical rate limit of 0 ft/min. would be selected as the lowest strength RA which achieves *ALIM* separation).

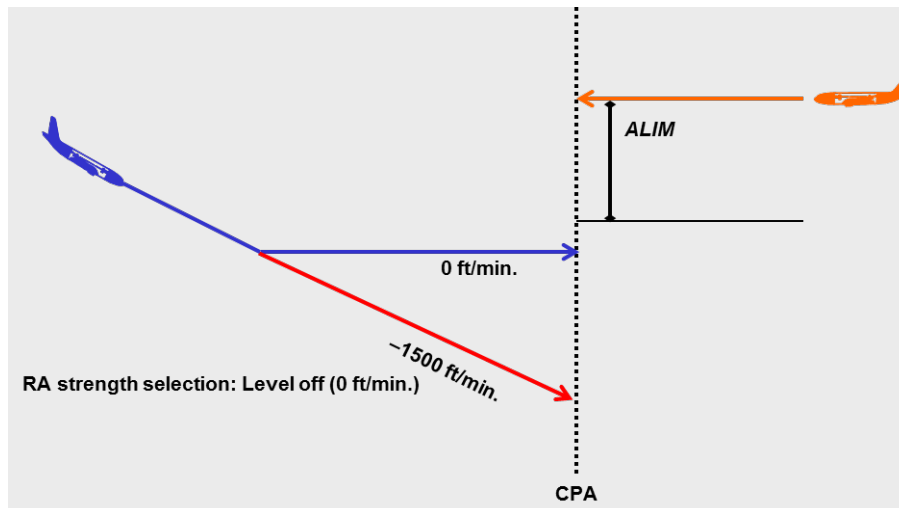


Figure 21: RA strength selection.

The Adjust Vertical Speed RA in version 7.0 required a reduction of the vertical rate to 0, 500, 1000 or 2000 ft/min. In version 7.1 the “Adjust vertical speed, adjust” RA has been replaced with a new “Level off, level off” RA. 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 15). The vertical rate reduction to 0 ft/min. is sometimes stronger than needed; however, this change was made to make the intention of the vertical rate 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 rate (i.e. “Level off, level off”) 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 for version 7.1 are listed in in Table 3.

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).

For increase and reversal RAs, the vertical speed change should be started within 2½ seconds of the RA being displayed. The change in vertical speed should be accomplished with an acceleration of approximately $\frac{1}{3} g$.

Strengthening RAs. An RA limiting the vertical rate (i.e. Monitor Vertical Speed or Level Off RAs) is strengthened by changing to a more restrictive vertical rate limit. This more restrictive RA can be a Climb or Descend RA (required vertical rate 1500 ft/min.), or it can be a Maintain Vertical Speed or Crossing Maintain Vertical Speed (required vertical rate is the current vertical rate which is in excess of 1500 ft/min.).

A positive RA (i.e. Climb, Descend, Maintain Vertical Speed or Crossing Maintain Vertical Speed RAs) is strengthened to an Increase Climb or Increase Descent RA (required increase of vertical rate from at least 1500 to 2500 ft/min.).

Figure 22 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).

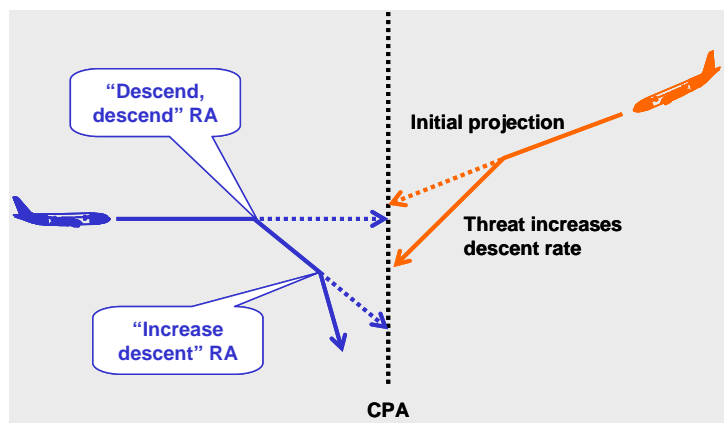


Figure 22: Increase vertical rate RA.

Reversal RAs. A reversal of RA sense is permitted in coordinated encounters (i.e. both aircraft TCAS II equipped) and in encounters with non-TCAS equipped threats. Figure 23 shows an encounter where an initial Climb RA requires reversal to a Descend RA after the threat aircraft manoeuvres.

Version 7.1 incorporates a new reversal logic that detects “vertical chase with low vertical miss distance” geometries, i.e. two aircraft converging in altitude remain within 100 feet (see Figure 3). 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 15).

Two types of reversals may occur:

- **Coordination (tiebreak) reversal** – occurs when two aircraft simultaneously declare each other as a threat and happen to both select the same RA sense. Should this occur, the aircraft with the higher Mode S 24-bit address (*"slave aircraft"*) will detect the incompatibility and will reverse the sense of its RA to the sense opposite to the RA generated by the other aircraft. The aircraft with the lower Mode S 24-bit address (*"master aircraft"*) is not permitted to reverse its RA for the purpose of coordination.
- **Geometric reversal** – can occur when one or other of the aircraft in an encounter manoeuvres, or fails to manoeuvre, in such a way as to negate the effectiveness of the RA. TCAS II equipped aircraft continuously monitor the progress of the encounter, and the effectiveness of the RA, and can reverse the sense of the RA in these circumstances. In encounters between two TCAS II equipped aircraft the reversal in RA sense will be coordinated (i.e. transmitted to the other aircraft, which will also reverse the sense of its own RA)⁴⁰. Only one geometric reversal is permitted in an encounter. Geometric reversal can still occur even if there was previously a coordination (tiebreak) reversal.

⁴⁰ Normally, the aircraft with higher Mode S 24-bit address (*"slave aircraft"*) will detect the incompatibility and will reverse the sense of its RA, with the exception of "vertical chase with low vertical miss distance" geometries (see page 17), where a special parameter is used to circumvent the Mode S address priority rule.

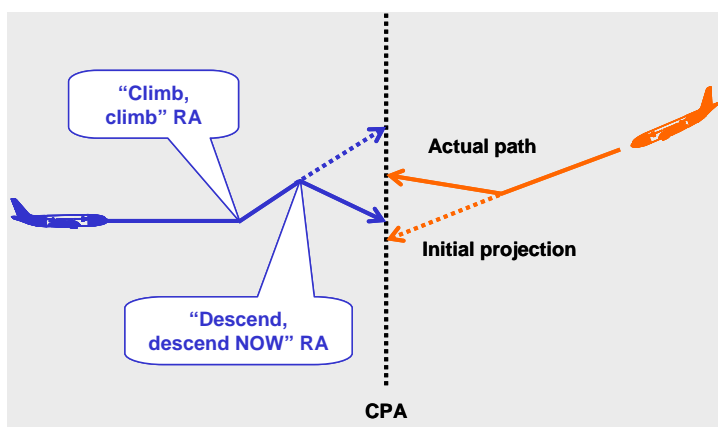


Figure 23: Sense reversal RA.

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 a “Level off, level off” RA (see Figure 24). This is done to minimise unnecessary deviations from the original altitude.

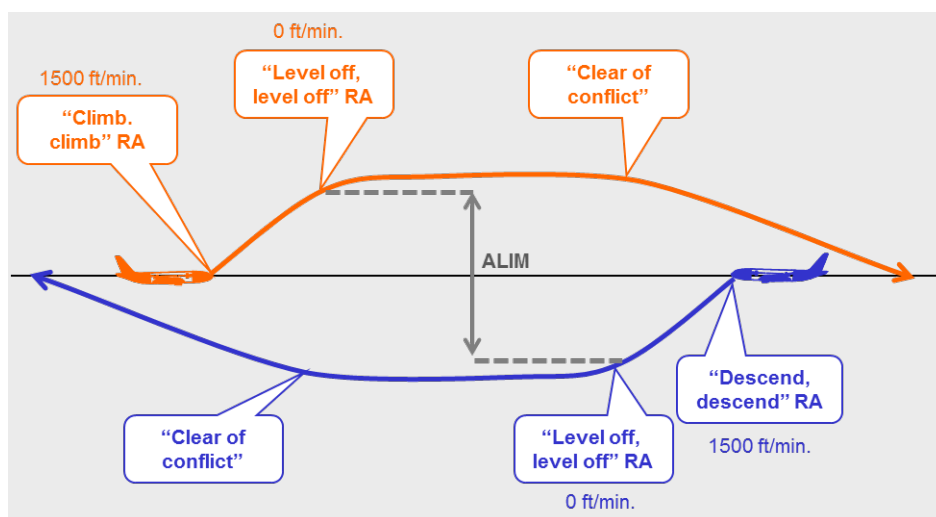


Figure 24: Weakening RAs.

RA duration

Collision avoidance logic sets the minimum time limits on RA duration as follows:

- Minimum RA duration (initial RA to Clear of Conflict) – 5 seconds;
- Minimum time before a reversal RA can be issued – 5 seconds⁴¹;
- Minimum time before weakening RA can be issued – 10 seconds.

A strengthening RA can be issued without any delay.

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).

⁴¹ Geometric reversals only: coordination (tiebreaker) reversals can be issued without any delay.

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 3 or a combination of upward and downward sense RAs. The example in Figure 25 shows a multi-threat RA (one threat above, one threat below) which will be announced "Level off, level off". The multi-threat logic is designed to utilise increase rate RAs and reversals RAs to best resolve multi-threat encounters.

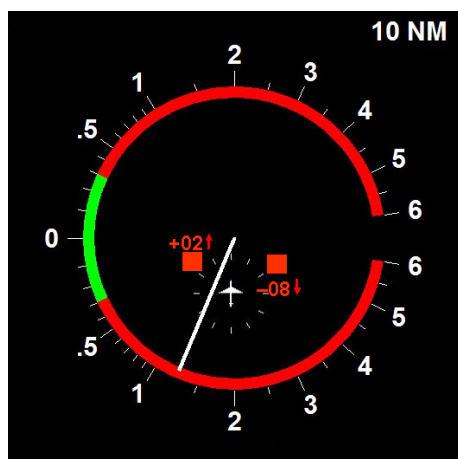


Figure 25: IVSI example showing a multi-threat encounter.

RA termination

The intruder ceases to be a threat when the range between the TCAS II aircraft and threat aircraft increases (i.e. the range test fails) or when the logic considers that the horizontal distance at CPA will be sufficient. If these conditions are met the resolution advisory is cancelled and a "Clear of conflict" annunciation is issued. The pilot then is required to return to the original 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 proximity to the ground (see Table 7 and Figure 26). RAs are inhibited based on radar (radio) altimeter reported heights. Hysteresis values of +100 feet (for climbing aircraft) and –100 feet (for descending aircraft) ensure that the inhibition state does not oscillate rapidly should the aircraft be flying close to the nominal altitude boundary but periodically passing above and below that boundary (e.g. when flying over hilly terrain).

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

Note: +100 ft values are used for climbing aircraft, –100 ft for descending aircraft.

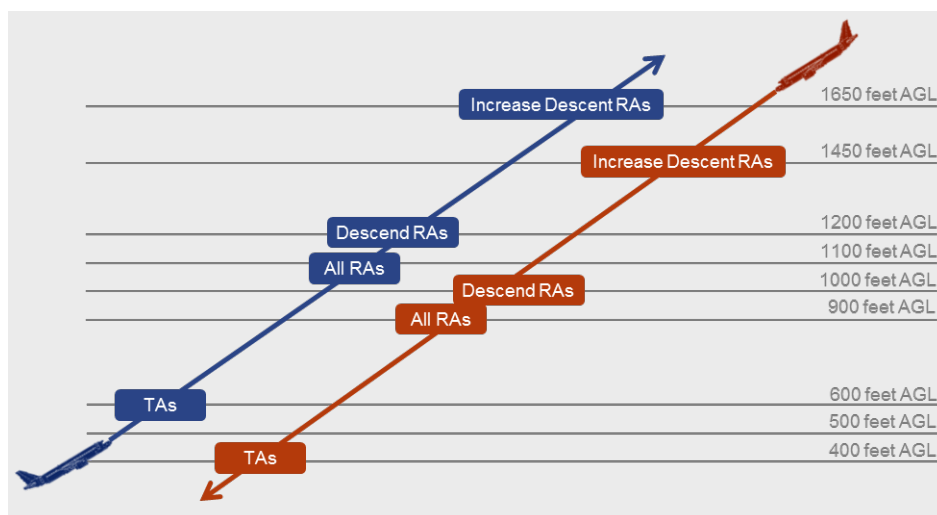


Figure 26: Illustration of TCAS alert generation inhibitions.

Moreover, when a GPWS (Ground Proximity Warning System), TAWS (Terrain Avoidance and Warning System) or wind shear detection warning have been activated, TCAS will automatically be placed into TA-only mode and TA aural annunciation is suppressed. TCAS will remain in TA-only mode for 10 seconds after the GPWS/TAWS or wind shear warning is removed. During this 10 second suppression period, the TA aural annunciation is not suppressed.

If there is no valid radar (radio) altimeter input, TCAS will set the ground level as -100,000 feet. Consequently, none of the inhibits that are activated by proximity to the ground will be set.

TCAS-TCAS encounters

In approximately half of encounters between two TCAS II equipped aircraft, an RA will only be generated by one of the aircraft while the other may or may not receive a TA. For example, in 1000-foot level off encounters, the aircraft that is climbing or descending towards another aircraft in a level flight is more likely to generate an RA first. If the RA is promptly responded to, the aircraft in level flight will not receive an RA (unless the vertical rate is very high).

Self-tracking RAs

In rare cases, an RA can be triggered as a result of self-tracking, i.e. when an aircraft tracks itself as an intruder. The pseudo-intruder is then seen at the same altitude and same position as own aircraft. Although TCAS II will not track intruders whose Mode S 24-bit address is the same as own aircraft and aircraft's suppression bus should prevent own transponder replying to interrogations, failures may occasionally occur.

Self-tracking RAs may be operationally disruptive as the pilots would follow these RAs not knowing that they result from a failure and cause large deviations from ATC clearances.

Advisory aural annunciation

The CAS logic sets the flags, which control the aural annunciations and the display of information. All aural annunciations for version 7.1 are listed in Table 3. All aural annunciations are inhibited below 500 feet (± 100 feet) AGL or when GPWS or TAWS or wind shear detection 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 once a second or every 8 seconds⁴². 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)⁴³.

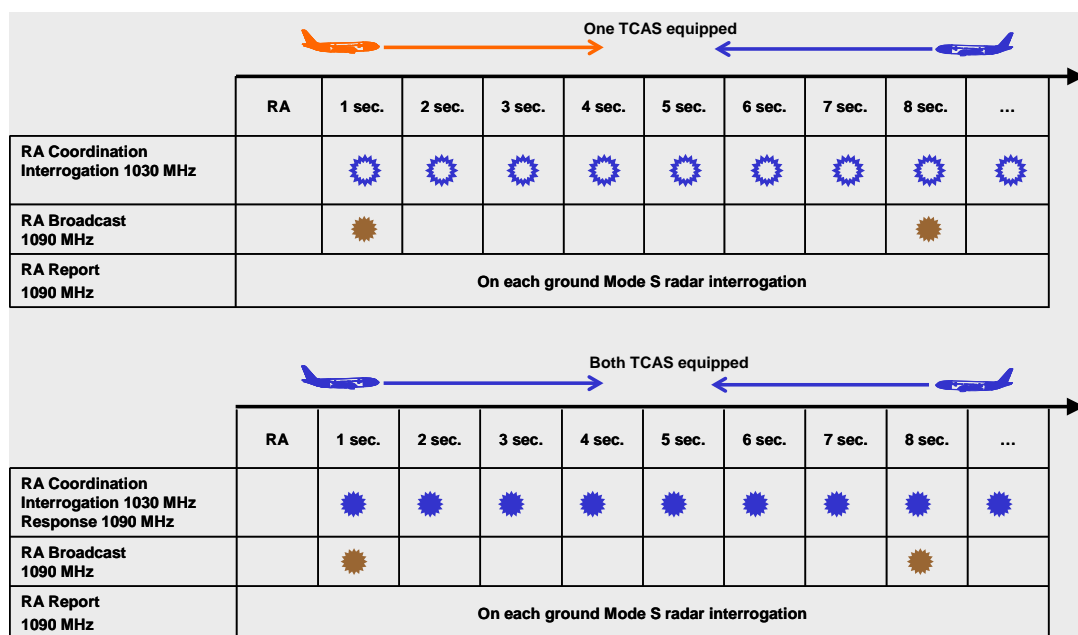


Figure 27: Air ground communications timeline.

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.

⁴² A change to TCAS II MOPS was made in 2013 to increase the frequency of rebroadcast to once every second from once every 8 seconds. As there has been no requirement to retrofit, newer equipment should transmit the RA Broadcast more frequently, while older will continue to transmit every 8 seconds.

⁴³ RA downlink display to controllers is a concept implemented only by a small number of ANSPs. ICAO has not published any provisions for operations of RA downlink.

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 or transponder is lost. If there is no valid radar (radio) altimeter input, TCAS will continue to function but is constrained to operate in SL3 or above. Additionally, none of the inhibits that are activated by proximity to the ground (see page 56) will be set.

TCAS II surveillance was designed to provide sufficient surveillance range for protection against aircraft with relative closing speeds of up to:

- 500 kts when operating in transponder-equipped aircraft densities of 0.3 aircraft per square NM; and
- 1200 kts in densities of 0.06 aircraft per square NM.

Furthermore, TCAS II will neither display nor issue alerts (RAs or TAs) against aircraft having vertical rates in excess of 10,000 ft/min.

TCAS II will generate position reports on Mode C and Mode S targets that are within ± 3000 feet and whenever possible within $\pm 10,000$ feet of the own aircraft.

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.

MINIMUM EQUIPMENT LIST

A Minimum Equipment List (MEL) is a list which provides for the operation of aircraft, subject to specified conditions, with particular equipment inoperative. MEL provisions may also allow for operations with TCAS II out of service.

The circumstances under which that is allowed vary. In most of the cases in Europe an aircraft may operate under the MEL provisions with TCAS II inoperative for up to 10 calendar days. However, 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. As these provisions are subject to change at short notice, the Reader is advised to refer to current regulation for up-to-date information.

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.

Furthermore, while discussing TCAS II safety benefits, it is not sufficient to demonstrate that TCAS II will prevent collisions that might occur in its absence. The risk that collision avoidance logic could induce a collision in otherwise safe circumstances must also be considered. Moreover, some other failures could cause TCAS II to induce a collision, e.g. an RA directing the aircraft into the flight path of an undetected third party aircraft.

Two types of collision risks influence the overall risk ratio:

- unresolved risk of collision – a situation in which TCAS II resolution fails to resolve the collision;
- induced risk of collision – a situation in which there is no risk of collision and the TCAS II resolution creates it.

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 approximately 22%)⁴⁴.

⁴⁴ The EUROCONTROL ACASA Project computed, for both the CVSM and the RVSM environments the full system ratio of 21.7% and 21.5% respectively. Source: *ACAS Safety Study: Safety Benefit of ACAS II Phase 1 and Phase 2 in the New European Airspace Environment*, ACAS/02-022, May 2002.

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 most important single factor affecting the performance of TCAS II is the response of pilots to RAs. At any time, regardless of the level of ACAS equipage by other aircraft, the risk of collision for a specific aircraft can be reduced by a factor greater than three by fitting TCAS II⁴⁵.

The operational evaluation of TCAS II performance using monitoring data and several large scale safety studies has demonstrated that it provides an overall improvement in flight safety. In many cases, RAs have prevented near mid-air collisions and mid-air collisions from taking place. However, it must be stressed that TCAS II cannot resolve every near mid-air collision and may induce a near mid-air collision if certain combinations of events occur.

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

ALTITUDE SOURCE

When feasible, pilots should use the same altitude data source used by the Pilot Flying to provide altitude information to TCAS II and the ATC transponders. Using a common altitude source limits unnecessary RAs due to differences between altitude data sources.

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.

Pilots should respond to TAs by attempting to establish visual contact with the intruder and other aircraft that may be in the vicinity. Pilots should not deviate from an assigned clearance based only on TA information nor make horizontal manoeuvres based solely on information shown on the traffic display.

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.

⁴⁵ Source: EUROCONTROL ACASA Project, Final Report on Studies on the Safety of ACAS II in Europe, WP-1.8/210D, March 2002.

In the event of an RA, pilots shall respond immediately by disconnecting the autopilot⁴⁶ and by following the RA as indicated using prompt, smooth control inputs unless doing so would jeopardise safety of the aircraft. Pilots must not manoeuvre contrary to the RA.

The aural annunciation depends on the RA issued (see Table 3). The threat aircraft symbol on the traffic displays changes to a red solid square and the ranges of the vertical rates to be avoided and the required vertical rate are displayed on appropriate instruments (implementation dependent).

If a decision is made not to respond to an RA, the flight crew negates the safety benefits provided by its own TCAS. A decision not to respond also decreases the safety benefits to all other aircraft involved in the encounter.

Pilots must not manoeuvre contrary to the RA as that could result in a collision with the threat aircraft.

For corrective RAs, the response should be initiated in the proper direction within 5 seconds of the RA being displayed. The change in vertical speed should be accomplished with an acceleration of approximately $\frac{1}{4} g$.

For increase and reversal RAs, the vertical speed change should be started within $2\frac{1}{2}$ seconds of the RA being displayed. The change in vertical speed should be accomplished with an acceleration of approximately $\frac{1}{3} g$.

Practical advice on how to achieve the required acceleration is provided in EASA's Guidance Material⁴⁷: *"An acceleration of approximately $\frac{1}{4} g$ will be achieved if the change in pitch attitude corresponding to a change in vertical speed of 1 500 ft/min is accomplished in approximately 5 seconds, and of $\frac{1}{3} g$ if the change is accomplished in approximately three seconds. The change in pitch attitude required to establish a rate of climb or descent of 1 500 ft/min from level flight will be approximately 6° when the true airspeed (TAS) is 150 kt, 4° at 250 kt, and 2° at 500 kt. (These angles are derived from the formula: 1 000 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.

If a TCAS RA manoeuvre is contrary to other critical cockpit warnings, pilots should respect those other critical warnings – responses to stall warning, wind shear, and GPWS/TAWS take precedence over an ACAS RA, particularly when the aircraft is less than 2,500 feet above ground level (AGL).

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).

⁴⁶ An exception here is the Airbus AP/FD (Autopilot/Flight Director) TCAS capability. See page 65 for more information.

⁴⁷ European Aviation Safety Agency: *Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Part-CAT, Annex to ED Decision 2012/018/R, Initial issue 25 October 2012.*

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 phraseology⁴⁸:

[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.

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).

ICAO Annex 10 states that 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 would have been simultaneously less than 2.0 NM and 750 feet (respectively) if above FL100 and 1.2 NM and 750 feet (respectively) if below FL100.

RAs are triggered if TCAS II calculates that there is a risk of impending collision between aircraft, as defined by the CAS algorithms. Most importantly, 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 87) 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. Also, the European Aviation Safety Agency (EASA) in their Safety Bulletin highlighted the fact that avoidance manoeuvres based on visual acquisition of traffic may not always provide the appropriate means of avoiding conflicting traffic⁴⁹.

⁴⁸ See Appendix page 87 for more information.

⁴⁹ EASA Safety Information Bulletin 2013-11 of 19 July 2013 (ACAS II – Manoeuvres based on Visual Acquisition of Traffic):
http://ad.easa.europa.eu/blob/SIB_201311_ACAS_II_Manoeuvres_Based_on_Visual_Acquisition_of_Traffic.pdf/SIB_2013-11_1

Avoidance manoeuvres based on visual acquisition and, especially, manoeuvres contrary to the RA may not always ensure successful collision avoidance due to:

- Traffic mis-identification;
- Traffic response to their RAs.

Closely spaced parallel approaches

As recommended by ICAO⁵⁰, when in the air TCAS II should be operated in 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 and may render the other aircraft's TCAS II less effective than if own aircraft were not TCAS II equipped.

RAs while aircraft is turning

Flying the RA is the highest priority. Therefore, if the aircraft is turning, which makes achieving the required vertical rate difficult or impossible, the turn should be stopped. It may happen that stopping the turn will put own aircraft in closer horizontal proximity to the threat aircraft but TCAS is evaluating the situation every second and it will change the RA if required. It is not required to comply with ATC instructions while responding to RAs.

ICAO ACAS Manual (Doc. 9863) recommends that *"if possible, comply with the controller's clearance, e.g. turn to intercept an airway or localizer, at the same time as responding to an RA."*

RAs at the maximum altitude

If an ACAS RA occurs when the aircraft is at the maximum altitude for its current weight, the pilots should not assume that they cannot comply with a climb RA because of that. In these cases it is acceptable and assumed that speed will be traded for height. Some aircraft types have built-in inhibits which will preclude Climb RAs at maximum altitudes.

Whether or not inhibits apply, it is still possible in some cases for an RA to exceed the capabilities of the aircraft. If a stall warning is generated, a response to stall warning takes precedence over an ACAS RA.

Pilots must respond to all RAs in a timely manner, applying the vertical rate required by the RA as accurately as possible in the circumstances and must never manoeuvre opposite to a RA.

TCAS II AND ATC OPERATIONS

The provision of air traffic services to aircraft equipped with TCAS II shall be identical to those that are not equipped. In particular, the prevention of collisions and the separation must exclude consideration of aircraft capabilities dependent on ACAS equipment⁵¹.

⁵⁰ See the quotes from ICAO PANS-OPS (Doc 8168) on page 89 and ICAO Doc. 9863 on page 90.

⁵¹ See the quote from ICAO PANS-ATM (Doc. 4444) on page 89.

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 rates when approaching the cleared flight level. ICAO Annex 6 (see page 87) recommends 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 s/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 be 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).

AIRBUS AUTOPILOT/FLIGHT DIRECTOR (AP/FD) CAPABILITY

An Airbus AP/FD TCAS capability is a guidance mode which allows the aircraft to automatically fly the RA if the autopilot is engaged or the pilot to handfly the RA by following the flight director commands⁵². The AP/FD capability is currently available for all Airbus aircraft (except A340s).

Broadly speaking, when an AP/FD aircraft receives an RA, the aircraft will automatically change its vertical speed to the vertical speed prescribed by the current RA plus 200 ft/min. (in order to help the flight crew monitoring of the RA response), unless the RA prescribes a null vertical speed (e.g. a Level Off RA), in which case the aircraft will change its vertical speed to 0 ft/min. The manoeuvre starts without delay and has been demonstrated to be equivalent to standard response delays (3 – 5 seconds) and accelerations (0.15 – 0.25 g).

When the RA is terminated, the AP/FD function will guide the aircraft to the selected altitude. All low level TCAS inhibitions are applicable (see page 56).

⁵² Specified in the Minimum Aviation System Performance Specification (MASPS) for Flight Guidance System (FGS) coupled to ACAS published by EUROCAE (ED-224).

AIRBUS TCAS ALERT PREVENTION (TCAP) FUNCTIONALITY

A TCAS Alert Prevention (TCAP) functionality has been introduced by Airbus to prevent the generation of RAs in 1000-foot level-off geometries⁵³. The functionality which is currently available for the Airbus wide body aircraft (and expected to become available on the A320 family of aircraft) uses a new altitude capture law for flight guidance computers, which decreases aircraft's vertical rate towards the selected altitude, once a TA has been generated and the auto-pilot and/or flight director are engaged (see Figure 28).

The TCAP functionality is complementary to the flight guidance computer's conventional altitude capture function.

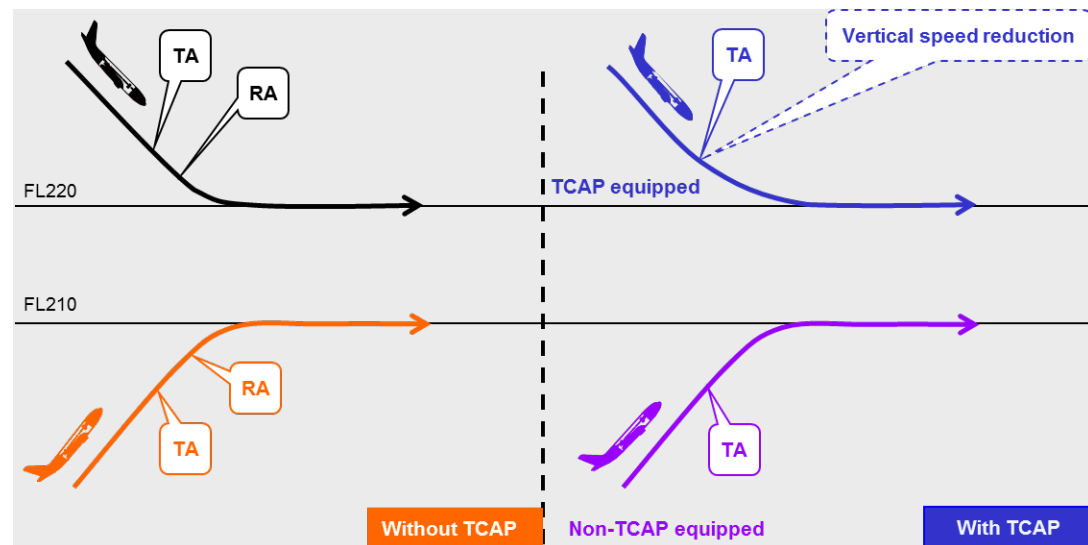


Figure 28: Illustration of an encounter without and with TCAP functionality.

⁵³ Specified in the Minimum Aviation System Performance Specification (MASPS) for Flight Guidance System (FGS) coupled to ACAS published by EUROCAE (ED-224).

RA STATISTICS

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. However, EUROCONTROL's EVAIR project⁵⁴ collects and analyses data from Mode S radars and also processes reports received from other sources (e.g. pilot or ATC reports).

In 2014, the EVAIR monitoring based on the recording from 13 Mode S radars in core European airspace found that in the vast majority of encounters only one aircraft involved in the encounter received an RA (see Figure 29)⁵⁵. Possible reasons are:

- 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 TA-only mode.

On average three RA encounters were observed each day in the area covered by the 13 radars. RAs are much more frequent in lower airspace, mainly due to higher vertical rates and more manoeuvres by aircraft.

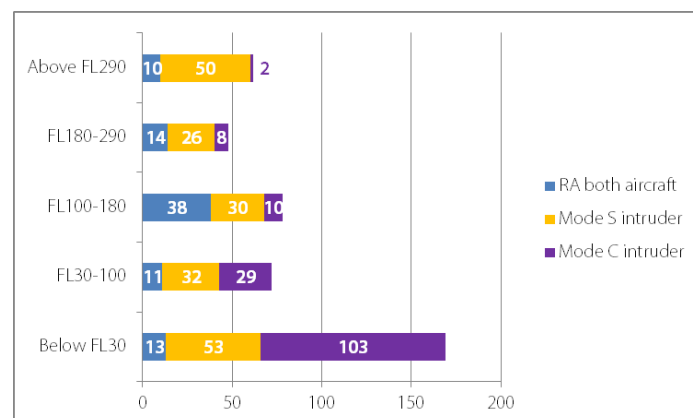


Figure 29: RA distribution by threat type.

The most common initial RA (44%) was a single Adjust Vertical Speed or Level Off RA, followed by Monitor Vertical Speed and Climb or Descend RAs (see Figure 30).

Only 20% of initial RAs resulted in a secondary RA. Here, the most common RAs were again Adjust Vertical Speed or Level Off RA (65%). Reversal RAs occurred in 6% of cases, while strengthening RAs (i.e. Increase Climb or Increase Descent) in 9% of cases (see Figure 31).

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.

⁵⁴ EUROCONTROL Voluntary ATM Incident Reporting. For more information and to access full reports go to: www.eurocontrol.int/services/evair

⁵⁵ Source: EVAIR Safety Bulletin no 14 (2010-2014).

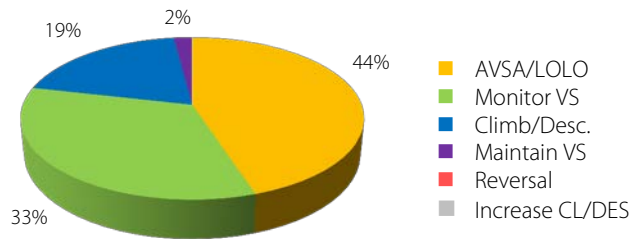


Figure 30: RA distribution by initial RA type.

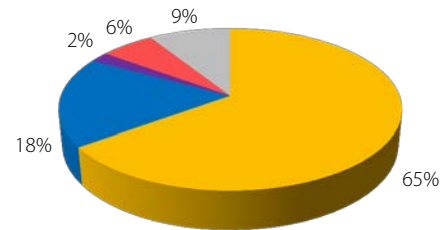


Figure 31: RA distribution by secondary RA type.

Pilot compliance

The EVAIR monitoring has also looked into pilot compliance with RAs. In 2014, 75% of initial RAs (i.e. the first RA in the encounter) were followed correctly while the remaining 25% were either excessive, too weak or opposite responses (see Figure 32). Secondary RAs (i.e. any subsequent RA in the encounter) in 2014 were followed at the desired vertical rate only in 64% of cases (see Figure 33).

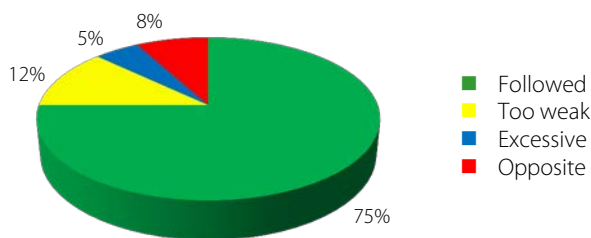


Figure 32: Pilot responses to initial RAs.

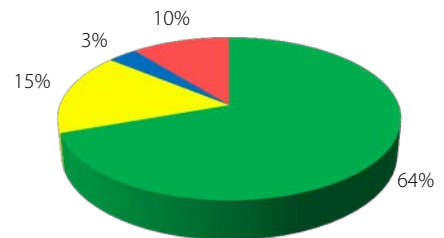


Figure 33: Pilot responses to secondary RAs.

Vertical rates

EVAIR monitoring data indicates that as much as 35% of RAs are generated due to high vertical rates and 75% of the aircraft getting an RA in the level-off geometry approach their cleared level with a rate above 1500 ft/min. These RAs are not operationally needed and can be avoided in many cases if vertical rate reductions, as recommended by ICAO (see page 87), are applied.

RAs by threat type

In 2007 a monitoring study examined the distribution of RA encounters as a function of the equipage of the threat aircraft and its TCAS status⁵⁶. The summary of the results is shown in Figure 34.

In the vast majority of encounters, only one aircraft involved in the encounter received an RA. In the equipped – equipped encounters, an RA was not generated on the TCAS-equipped threat aircraft in 47% of cases. In 32% of cases the threat aircraft was not TCAS equipped.

Only in 20% of encounters did RAs occur on both aircraft involved.

⁵⁶ Source: EUROCONTROL PASS Project Report: Analysis of RA Downlink data, Version 1.5, PASS/WA1/WP4/38, March 2009.

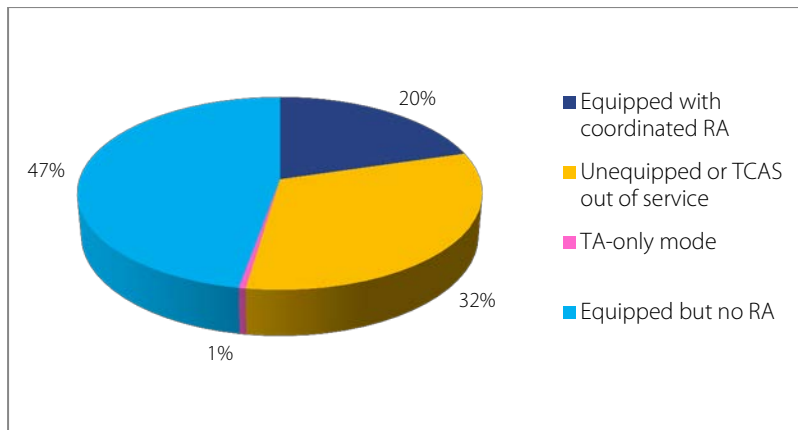


Figure 34: Distribution of RA encounters as a function of threat aircraft equipage.

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 be 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. 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-foot or 100-foot precision).	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

For the determination of collision avoidance resolution, 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 operations 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 all⁵⁷.

Additionally, below 1750 feet TCAS II also uses radar altimeter data to invoke TA/RA inhibitions due to proximity to the ground (see RA inhibition on page 56).

⁵⁷ Except some TCAS traffic displays which allow the crew to toggle between pressure corrected and standard pressure altitudes.

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 35.

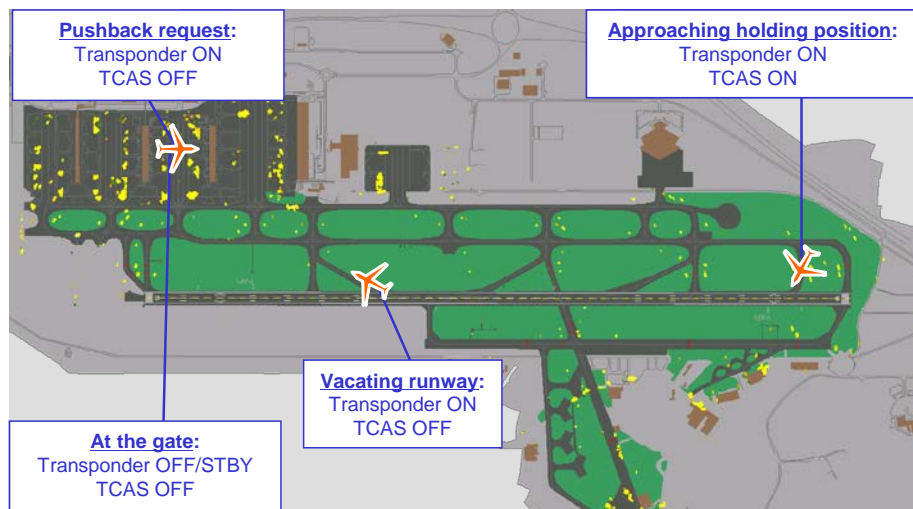


Figure 35: TCAS II/transponder operation on the ground.

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 74.

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.

At the time of writing, Light Jets (LJ) and Very Light Jets (VLJ) are not mandated to carry ACAS II as their MTOM and passenger capacity are below the thresholds specified in the current equipage mandate (see page 20). Likewise, it has not yet been determined whether UAS or RPAS will be required to be equipped with ACAS II or any other dedicated collision avoidance system.

TRANSPONDER TESTING ON THE GROUND

TCAS II interrogates, within its range, all Mode S and Mode A/C transponders. That will include ground-based transponders operated for testing or maintenance. If these transponders respond with an altitude report close to that of aircraft flying above in the vicinity, their TCAS II Traffic Display will show a 'ghost' target and could even generate TAs/RAs against such targets. These unnecessary alerts are disruptive to the flight crew and controllers.

To avoid these unnecessary alerts special caution and appropriate procedures are required during transponder testing and maintenance. In order to prevent the transmission of a virtual altitude (which could then be mistakenly used by airborne systems) effective screening or absorption devices on the antennas must be employed or the ramp test set must be physically connected to the antenna system. Where possible, the testing should be performed inside a hangar to take advantage of any shielding properties it may provide. Finally, if possible the altitude should be set to an unrealistically high (e.g. over 60,000 feet) or low value (e.g. negative 2000 feet).

CONCLUSIONS

Airborne Collision Avoidance Systems are a last resort system designed to prevent midair collisions between aircraft. Currently, this role is fulfilled by TCAS II and a new generation of Airborne Collision Avoidance Systems (ACAS X) is being developed.

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 & INFORMATION 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)

Continued overleaf

			
<u>13 - Reversing to resolve (September 2011)</u>	<u>14 - Version 7.1 is coming (January 2012)</u>	<u>15 - Not so fast... (May 2012)</u>	<u>16 - "Traffic, traffic" TCAS Traffic Advisories (December 2012)</u>
			
<u>17 - "Level off, level off" RA (August 2014)</u>	<u>18 - Notable recent operational events (May 2015)</u>	<u>19 - ATC Matters (February 2016)</u>	<u>20 - Low level events (June 2016)</u>
			
<u>21- Bizjets are amongst us (February 2017)</u>	<u>22- ATC vertical rate instructions (November 2017)</u>		

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.

	<p>SKYbrary article on ACAS with links to several other training resources</p> <p>www.skybrary.aero/index.php/Airborne_Collision_Avoidance_System_(ACAS)</p>
	<p>FAA Booklet – Introduction to TCAS II version 7.1 (February 28, 2011)</p> <p>www.faa.gov/documentLibrary/media/Advisory_Circular/TCAS%20II%20V7.1%20Intro%20booklet.pdf</p>
	<p>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)</p> <p>www.ll.mit.edu/publications/journal/pdf/vol16_no2/16_2_04Kuchar.pdf</p>

ACAS X INFORMATION RESOURCES

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

	<p>SKYbrary article on ACAS X</p> <p>www.skybrary.aero/index.php/ACAS_X</p>
	<p>Next-Generation Airborne Collision Avoidance System by Mykel J. Kochenderfer, Jessica E. Holland, and James P. Chryssanthacopoulos</p> <p>www.ll.mit.edu/publications/journal/pdf/vol19_no1/19_1_1_Kochenderfer.pdf</p>
	<p>EUROCONTROL NetAlert 17 newsletter on ACAS X</p> <p>www.skybrary.aero/bookshelf/books/2390.pdf</p>
	<p>HindSight 22 – The new kid on the block</p> <p>http://skybrary.aero/bookshelf/books/3265.pdf</p>

GLOSSARY

The glossary is provided for reference only and it has been derived from the definitions published in ICAO Annex 10, ICAO PANS-OPS (Doc. 9863), ICAO PANS-ATM (Doc 4444), and TCAS II MOPS (RTCA DO-185B and EUROCAE ED-143).

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)⁵⁸.

ACAS X – (“ay-cas eks”) – A family of new collision avoidance systems currently under development. It takes advantage of recent advances in ‘dynamic programming’ and other computer science techniques. See page 21 for more information.

Aircraft (Mode S 24-bit) address – A unique combination of 24 bits available for assignment to an aircraft for the purpose of air-ground communications, navigation and surveillance. Also known as ICAO 24-bit Aircraft Address.

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.

Bearing – The angle of the target aircraft in the horizontal plane, measure clockwise from the longitudinal axis of the own aircraft.

Closest Point of Approach (CPA) – The occurrence of minimum (slant) 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. See also: *Preventive advisory*. A Corrective advisory can be Positive or Negative. **Crossing RA** – See: *Altitude crossing RA*.

Distance Modification (DMOD) – Safety factor incorporated in range measurements to account for possible accelerations by the intruder. The value of distance modification varies with the sensitivity level (in line with the time thresholds).

Downward sense RA – Indicates that own aircraft intends to pass below the threat (the RAC tells the other aircraft “do not pass below me”). See also: Upward sense RA.

Established track – A track generated by TCAS air-to-air surveillance that is treated as the track of an actual aircraft.

⁵⁸ ACAS III is unlikely to materialize due to difficulties the conventional surveillance systems have with horizontal tracking. ACAS X will be the next generation of collision avoidance systems.

False Advisory – An advisory caused by a false track or a TCAS malfunction. See also: *Unnecessary RA* and *Nuisance RA*.

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

ICAO 24-bit Aircraft Address – see: *Aircraft (Mode S 24-bit) address*.

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.

Master aircraft – for the purpose of TCAS-TCAS coordination, an aircraft with the lower Mode S 24-bit address.

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*.

Near Midair Collision (NMAC) – Two aircraft simultaneously coming within 100 feet vertically and 500 feet (0.08 NM) horizontally.

Negative advisory – A type of RA which tells the pilot which actions should be avoided, such as do not descend (announced as Monitor Vertical Speed). See also: *Positive advisory*. A Negative advisory can be Corrective or Preventive.

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* and *False 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.

Positive advisory – An advisory that requires either a climb or a descent. . See also: *Negative advisory*.

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. See also: *Corrective advisory*. A Preventive advisory can be Positive or Negative.

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.

Relative altitude – The difference in altitude between own aircraft and a target aircraft. The value is positive when the target is higher and negative when the target is lower.

Resolution Advisory Complement (RAC) – Information provided by one ACAS to another via a Mode S interrogation in order to ensure complementary manoeuvres by restricting the choice of manoeuvres available to the ACAS receiving the RAC.

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

Risk ratio – The ratio between the risk of collision with ACAS II and the risk of collision without ACAS II.

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.

Squitter – Spontaneous transmission generated by Mode S transponders.

Slave aircraft – for the purpose of TCAS-TCAS coordination, an aircraft with the higher Mode S 24-bit address.

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.

Target – A transponder-equipped aircraft within the surveillance range of ACAS that is being tracked.

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

Track – Estimated position and velocity of a single aircraft based on correlated surveillance data reports.

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. This indication contains no suggested manoeuvre.

Transponder (Mode C) – ATC transponder that replies with both identification and altitude data.

Transponder (Mode S) – ATC transponder that replies to an interrogation containing its own, unique ICAO 24-bit aircraft address and with altitude data.

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* and *False RA*.

Upward sense RA – Indicates that own aircraft intends to pass above the threat (the RAC tells the other aircraft “do not pass above me”). See also: *Downward sense RA*.

Vertical Miss Distance (VMD) – The relative altitude between own and intruder aircraft at closest point of approach.

Vertical Resolution Advisory Complement (VRC) – Information provided by one TCAS to another via a coordination interrogation to ensure complementary manoeuvres by restricting the choice of manoeuvres available to the TCAS receiving the VRC.

Warning Time – The time interval between potential threat or threat detection and closest approach when neither aircraft accelerates.

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
AP/FD	Autopilot/Flight Director
ASAS	Airborne Separation Assurance Systems
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
BCAS	Beacon Collision Avoidance System
CAS	Collision Avoidance System
CDTI	Cockpit Display of Traffic Information
CENA	Centre d'Études de la Navigation Aérienne (France)
CPA	Closest Point of Approach
CSPO	Closely Spaced Parallel Operations
CVSM	Conventional Vertical Separation Minima
DMOD	Distance Modification
DMTL	Dynamic Minimum Triggering Level
DNA	Designated No Alerts (mode)
EASA	European Aviation Safety Agency
ECAC	European Civil Aviation Conference
EFIS	Electronic Flight Instrument System
EICAS	Engine Indication and Crew Alerting System
EUROCAE	European Organisation for Civil Aviation Equipment
EVAIR	EUROCONTROL Voluntary ATM Incident Reporting
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
g	Gravitational acceleration of 9.81 m/sec ²

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	Kilogram(s)
kts	Knots (NM/hour)
LJ	Light Jet(s)
m	Meter(s)
MASPS	Minimum Aviation System Performance Specification
MDF	Miss Distance Filtering
MEL	Minimum Equipment List
MHz	Megahertz
MOPS	Minimum Operational Performance Standards
MTOM	Maximum Take-off Mass
m/s	Meters per second
m/sec	Meters per second
n/a	Not applicable
NAR	Non-altitude reporting [target]
NAS	National Airspace System (USA)
ND	Navigation Display
NextGen	Next Generation Transportation System (USA)
NM	Nautical Mile(s)
NMAC	Near Midair Collision
PA	Proximity Alert (TCAS I)
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
RAC	Resolution Advisory Complement
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	Second(s)

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 and Warning System
TCAP	TCAS Alert Prevention
TCAS	Traffic alert and Collision Avoidance System
TVTHR	Time (Variable) Threshold – Reduced Time to Co-altitude Threshold
UAS	Unmanned Aircraft Systems
VFR	Visual Flight Rules
VLJ	Very Light Jet(s)
VMC	Visual Meteorological Conditions
VSI	Vertical Speed Indicator
XPNDR	Transponder
ZTHR	Z Threshold – Vertical Threshold for Resolution Advisory
ZTHRTA	Z Threshold – Vertical Threshold for Traffic Advisory

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RTCA Publications:

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RTCA DO-300 – Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System (TCAS II) For TCAS II Hybrid Surveillance.

EUROCAE Publications:

EUROCAE ED-143 – Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II)⁶⁰.

EUROCAE ED-221 – MOPS for TCAS II Hybrid Surveillance.

EUROCAE ED-224 – Minimum Aviation System Performance Specification (MASPS) for Flight Guidance System (FGS) coupled to ACAS.

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TSO C119C (Technical Standard Order) – Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, TCAS II With Optional Hybrid Surveillance.

⁵⁹ Superseding DO-185A (version 7.0 MOPS).

⁶⁰ Jointly published with RTCA and commensurate with DO-185B.

AC 20-131A (Advisory Circular) – Airworthiness and Operational Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders.

AC 120-55C Change 1 (Advisory Circular) – Air Carrier Operational Approval and Use of TCAS II.

Introduction to TCAS II version 7.1 – 28 February 2011

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

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APPENDIX – RELEVANT ICAO PROVISIONS

Note: Extracts from ICAO documents are provided here for reference only and are current on 1 February 2017 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.*

6.19 AEROPLANES REQUIRED TO BE EQUIPPED WITH AN AIRBORNE COLLISION AVOIDANCE SYSTEM (ACAS II)

6.19.1 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).

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

6.19.3 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.

15.7.3.4 Guidance on training of air traffic controllers in the application of ACAS events is contained in the *Airborne Collision Avoidance System (ACAS) Manual (Doc 9863)*.

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)

Chapter 3 - OPERATION OF AIRBORNE COLLISION AVOIDANCE SYSTEM (ACAS) EQUIPMENT

3.1 ACAS OVERVIEW

3.1.1 The information provided by an ACAS is intended to assist pilots in the safe operation of aircraft by providing advice on appropriate action to reduce the risk of collision. This is achieved through resolution advisories (RAs), which propose manoeuvres, and through traffic advisories (TAs), which are intended to prompt visual acquisition and to act as a warning that an RA may follow. TAs indicate the approximate positions of intruding aircraft that may later cause resolution advisories. RAs propose vertical manoeuvres that are predicted to increase or maintain separation from threatening aircraft. ACAS I equipment is only capable of providing TAs, while ACAS II is capable of providing both TAs and RAs. In this chapter, reference to ACAS means ACAS II.

3.1.2 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.

3.1.3 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.

Note 3.— ACAS Training Guidelines for Pilots are provided in the Attachment, “ACAS Training Guidelines for Pilots”.

3.2 USE OF ACAS INDICATIONS

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; and

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

1) respond immediately by following the RA as indicated, unless doing so would jeopardize 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 intruder aircraft.

4) as soon as possible, as permitted by flight crew workload, notify the appropriate ATC unit of any RA which requires a deviation from the current ATC 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.

Note 1.— Procedures in regard to ACAS-equipped aircraft and the phraseology to be used for the notification of manoeuvres in response to a resolution advisory are contained in the PANS-ATM (Doc 4444), Chapters 15 and 12 respectively.

Note 2.— Where aircraft can provide automatic following of an RA when the autopilot is engaged supported by a link between ACAS and autopilot, the operational procedures in items 4) and 8) still apply.

3.3 HIGH VERTICAL RATE (HVR) ENCOUNTERS

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 1 000 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. Some aircraft have auto-flight systems with the capability to detect the presence of such aircraft and adjust their vertical rate accordingly. These procedures are intended to avoid unnecessary 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. [...]

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.

6.3.1.5 When an RA is issued, pilots are expected to respond immediately to the RA unless doing so would jeopardize the safe operation of the flight. This means that aircraft will at times manoeuvre contrary to ATC instructions or disregard ATC instructions. The following points receive emphasis during pilot training:

- a) do not manoeuvre in a direction opposite to that indicated by the RA because this may result in a collision;
- b) inform the controller of the RA as soon as permitted by flight crew workload after responding to the RA. There is no requirement to make this notification prior to initiating the RA response;
- c) be alert for the removal of RAs or the weakening of RAs so that deviations from a cleared altitude are minimized;
- d) if possible, comply with the controller's clearance, e.g. turn to intercept an airway or localizer, at the same time as responding to an RA; and
- e) when the RA event is completed, promptly return to the previous ATC clearance or instruction or comply with a revised ATC clearance or instruction.

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.

Further information:

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www.eurocontrol.int/acas

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