ACAS Guide

Airborne Collision Avoidance Systems

April 2025

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

EUROCONTROL

NOTE

This Airborne Collison 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 focuses on both the operational principles and technical details of TCAS II version 7.1 and ACAS Xa/Xo, the only airborne collision avoidance systems currently mandated for operations in Europe. It also briefly describes previous TCAS II versions 6.04a and 7.0, as well as the TCAS I system. Additionally, the Guide covers forthcoming variants from the ACAS X family of collision avoidance systems. However, at the time of publication, none of these systems have been approved for operations in European airspace.

Other non-standardised traffic awareness systems, like FLARM, and Portable Collision Avoidance System (PCAS), intended for general aviation or military aircraft are not covered.

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 publication but is subject to change.

ACKNOWLEDGMENTS

This *ACAS Guide* has been developed by EUROCONTROL with the help of QinetiQ.

The original (2012) version of the Guide was developed in cooperation with the German Air Line Pilots' Association (Vereinigung Cockpit), and it 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* and *Introduction to ACAS X (ACAS Xa/Xo)* booklets.

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
3.0	18 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
4.0	13 December 2021	Document restructured. ACAS X Section expanded.	All
4.1	25 March 2022	Corrections and editorial changes.	All
5.0	9 April 2025	ACAS Xu/sXu Sections added. Corrections and updates.	All

Table of Contents

List of Tables

List of Figures

1. Preface

The **A**irborne **C**ollision **A**voidance **S**ystem (ACAS) II concept (realised as **T**raffic alert and **C**ollision **A**voidance **S**ystem (TCAS) II equipment and in the future as ACAS Xa equipment) is an airborne avionics system which acts independently of Air Traffic Control (ATC) as a last resort safety net to mitigate the risk of midair collisions when other safety barriers have failed.

ACAS II 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 has been mandated worldwide since the early 2000s.

Following its development in the late 2000s, TCAS II version 7.1 has been mandated in Europe since 1 December 2015 for 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.

For ACAS II 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.

The first version of the Guide was published in January 2012 (to coincide with the TCAS II version 7.1 European mandate). Since then, the Guide has been updated and significantly expanded several times to cover areas that are of interest for operational personnel. To facilitate reading and search for information, some details have been repeated.

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 and ACAS X; the system components and the presentation in the cockpit; the principles of collision avoidance systems operation and the alerts that the systems can generate; and the correct procedures for both flight crew and controllers in response to ACAS II alerts. Where appropriate, references to additional training or information resources are provided. The past versions of TCAS II (6.04a and 7.0) are briefly described. From the ACAS X family of airborne collision avoidance systems, particular attention has been given to ACAS Xa/Xo (meant for larger aircraft as a replacement for TCAS II).

Other already standardised system, namely ACAS Xu and ACAS sXu (for unmanned and small unmanned aircraft respectively) are not covered to the same extend as TCAS II and ACAS Xa due to their complexity going beyond the scope of this ACAS Guide. The coverage is limited to general description and the areas where these systems will interact with TCAS II or ACAS Xa and air traffic control.

Finally, other forthcoming collision avoidance systems from the ACAS X family (like ACAS Xr) are briefly described to provide the Reader with a complete picture.

A list of additional training resources, regulatory publications and applicable ICAO provisions are provided as well (see Sections 20 and 23).

Non-ACAS collision avoidance functions developed for Remotely Piloted Aircraft Systems (RPAS) as well as non-standardised traffic awareness systems intended for general aviation or military aircraft, like FLARM and Portable Collision Avoidance System (PCAS) are not covered in this Guide; however, some functionalities related to *detect & avoid* are briefly described for completeness.

As ACAS systems and related regulations continue to evolve, the information in this ACAS Guide is considered current as of the publication date but is subject to change.

2. INTRODUCTION

2.1 Airborne conflict management

As described in the International Civil Aviation Organization (ICAO) Global Air Traffic Management Operational Concept [1], prevention of collisions between aircraft is achieved through Conflict Management in three layers as illustrated in Figure 1 below.

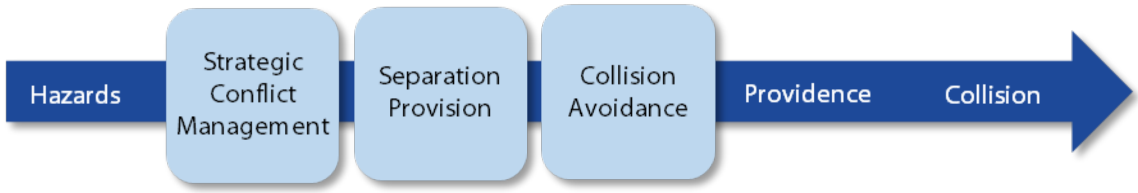


Figure 1: Conflict Management model

The three layers of conflict management can be thought of as barriers which prevent those hazards leading to an accident, and each one has a specific purpose, as follows:

The **Strategic Conflict Management** layer consists of the following main Air Traffic Management (ATM) functions:

- Airspace design to keep aircraft apart horizontally and vertically;
- Flow and capacity management to prevent any overloads in the Separation Provision layer and traffic synchronisation.

The **Separation Provision** barrier is the second layer of Conflict Management. It is the process of keeping aircraft away from each other by the appropriate separation minima by tactical intervention as the Strategic Conflict Management will not eliminate all conflicts.

Finally, the **Collision Avoidance** layer is intended to recover the situation when the two previous barriers have failed to remove a risk of collision. It can be achieved by either:

- Collision prevention actions by air traffic controllers, that can be supported by ground-based safety nets such as Short Term Conflict Alert (STCA); or
- Collision avoidance actions by pilots by the means of *see & avoid* and based on alerts from airborne safety nets such as ACAS.

Airborne collision avoidance systems covered in this ACAS Guide reside in the Collision Avoidance layer.

Ultimately, a collision can be avoided by **providence.**

2.2 See & avoid

The risk of collisions can be mitigated by pilots exercising the *see & avoid* principle. The principle is as old as aviation and is rather straightforward: weather permitting, the pilots conduct a continuous visual scan of the surrounding airspace in order to detect other traffic (and other hazards) that might constitute a threat to their own aircraft. If a threat is detected, the pilot will then undertake an avoidance manoeuvre.

[1] ICAO Doc. 9854.

The words "see" and "avoid" are habitually mentioned together. The implication is that the former leads inevitably to the latter: that a threat once seen will be successfully avoided, but this is not necessarily the case. As tragically illustrated by some midair collisions, visually acquiring a threat does not guarantee that the threat can be avoided. For example: the threat may be seen too late for any successful avoiding action to be taken; an adverse manoeuvre by the threat may hinder the avoiding action; or a misperception of the relative position and motion of the threat may result in an ineffective avoidance manoeuvre.

2.3 Detect & avoid

Following the introduction of modern Remotely Piloted Aircraft Systems (RPAS) or Unmanned Aircraft Systems (UAS), a *detect & avoid* (DAA)[2] functionality has been developed to facilitate the detection and avoidance of other aircraft, terrain and obstacles using electronic means.

The *detect & avoid* system consists of airborne and ground-based equipment that together perform the functions which allow the remote pilot to detect and avoid hazards. This includes sensors, processing units and the interface with the remote pilot. For more information about *detect & avoid* refer to Section 15.

2.4 Collision avoidance – historical background

In the early days of aviation, the separation between aircraft was solely achieved by visual means (i.e., *see & avoid*). Pilots looked outside in order to detect any other aircraft and if a threat was detected, they would then undertake an avoidance manoeuvre.

As air traffic started to increase in the 1920s, Air Traffic Control (ATC) was introduced to direct and track the movements of aircraft and keeping them adequately separated.

Over the years as air traffic has further increased, risk of collisions could not be always mitigated by pilots exercising the *see & avoid* principle or by actions of ATC. Despite technical advances in ATC systems (like the introduction of radars), there have been cases when the separation provision failed due to a human or technical error. In some cases that led to midair collisions.

To compensate for any limitations of *see & avoid* and ATC performance, an airborne collision avoidance system, **independent** of any ground systems and acting as a last resort was initiated in 1955 by the airline industry.

In 1956, an American scientist Dr John S. Morrel (1901-1974) of Bendix Aviation Corporation proposed[3] 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 (CPA)[4]. The CPA is the occurrence of minimum slant range between own aircraft and the other aircraft.

---

[2] Also referred to as *sense & avoid*.

[3] In his paper titled "Fundamental Physics of the Aircraft Collision Problem".

[4] Dr John S. Morrel holds two patents pertaining to airborne collision avoidance systems: US3181144 and US3208064, both granted in 1965.

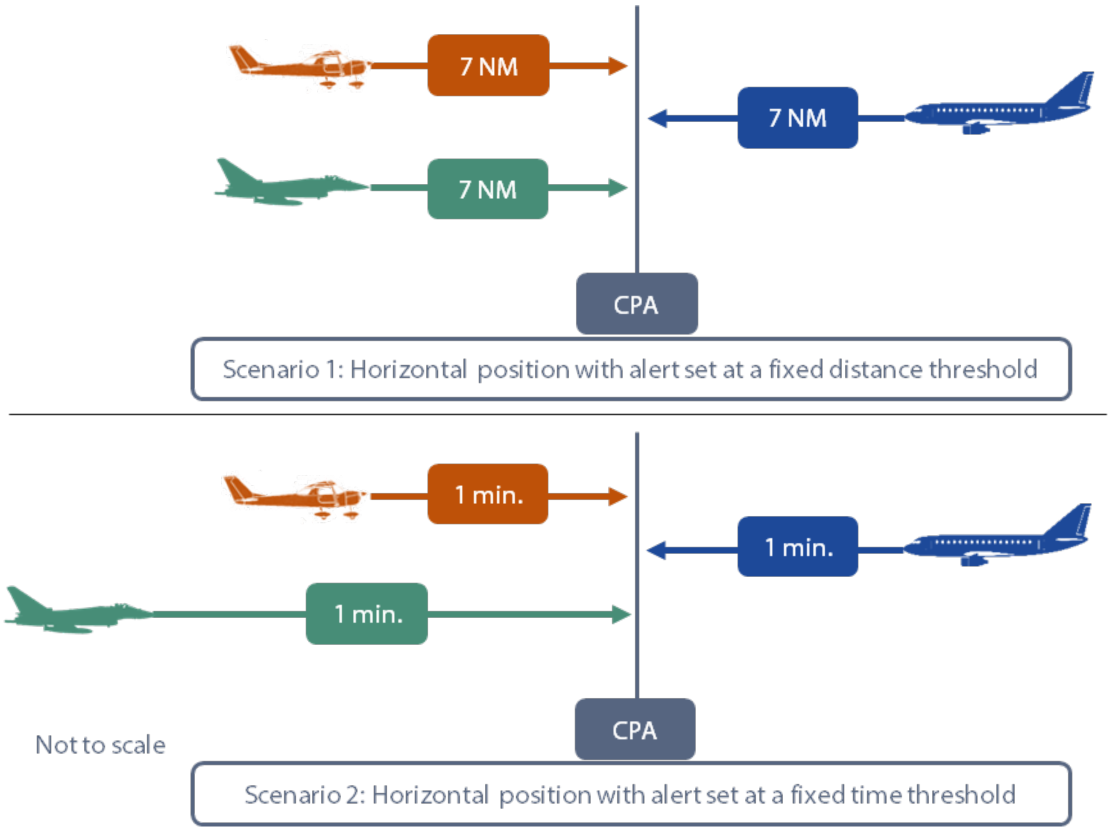


Figure 2: Alerting at fixed distance vs. alerting at fixed time to CPA.

The difference between using alerting at a fixed position threshold vs. alerting at a fixed time threshold is illustrated in Figure 2. Two scenarios of the same conflict situation are shown, each involving three aircraft: a passenger jet and two aircraft flying in the opposite direction – a slower light aircraft and a much faster military jet:

- In **Scenario 1** (depicted in the upper part of Figure 2) the alert is triggered at a specific 'distance-to-go' until estimated Closest Point of Approach. The two intruders[5] are at the same distance but because the military jet is travelling faster than the light aircraft, it will arrive at the point of closest approach earlier than the light aircraft.
- In **Scenario 2** underneath, the alert is triggered at a specific 'time-to-go' until estimated closest point of approach. The military jet is travelling faster than the light aircraft and so will be at a greater distance when the alert occurs although both will arrive at the point of closest approach at the same instant.

Today's TCAS II airborne collision avoidance system is based on the **Scenario 2** concept.

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

2.5 Collision avoidance systems – implementation driven by accidents

In 1956, just a month after Dr Morrel published his paper, the collision between two airliners, over the Grand Canyon in the USA[6], prompted both the airlines and the aviation authorities to advance the development of an airborne collision avoidance system. It was determined in the early 1960s that, due to technical limitations, the development could not be progressed beyond the overall concept.

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

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

In 1978, the collision between a light aircraft and an airliner over San Diego, California[7] led the US Federal Aviation Administration (FAA) 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.

A short time later, prototypes of TCAS II were installed on two Boeing 727 aircraft operated on regularly scheduled flights. However, the TCAS displays were located outside the view of the flight crew and seen only by trained observers. More tests on scheduled flights followed using TCAS II units manufactured by Bendix and Honeywell.

In 1986, the collision between an airliner and a light aircraft over Cerritos, California[8] 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 has developed, from the beginning of the 1980s, standards for Airborne Collision Avoidance Systems (ACAS).

2.6 ACAS and TCAS

Although terms ACAS and TCAS are often used interchangeable, there is a difference between the two terms:

- **ACAS II** is typically used when referring to the **technical standard or concept**;
- **TCAS II** is typically used when referring to a **current implementation** of the technical standards and concept, which is widely fitted throughout the world.

---

[6] A Douglas DC-7 and a Lockheed L-1049 Super Constellation were involved in this collision that occurred on 30 June 1956. 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°. 128 people were killed. More information on Aviation Safety Network.

[7] A Boeing 727-200 and a Cessna 172 were involved in this collision that occurred on 25 September 1978. 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. More information on Aviation Safety Network.

[8] A Douglas DC-9-32 and a Piper PA-28 Archer were involved in this collision that occurred on 31 August 1986. The Piper inadvertently entered 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. More information on Aviation Safety Network.

Until recently, TCAS II version 7.1 was the only implementation that fully met the ACAS ICAO Standards and Recommended Practices (SARPs)[9]. In November 2022, following the publication of amendment 91 to ICAO Annex 10, Volume IV, ACAS Xa (see Sections 3.3 and 12) became another ICAO compliant collision avoidance system. In March 2025, in addition to TCAS II version 7.1, ACAS Xa/Xo was approved for operations in European airspace[10] (see Section 4.3).

In this Guide, the following naming principles are applied:

- **ACAS II** or **ACAS** are the terms used when referring to the standard, concept and implementation, covering both TCAS II and ACAS Xa, unless specifically noted;
- **TCAS II** or **TCAS** is used when referring to the implementation of TCAS II version 7.1, unless another version is specifically noted;
- **ACAS Xa, ACAS Xo, ACAS Xu and ACAS sXu** are used when referring to the implementation of these systems respectively;
- **ACAS X** is used when referring to the ACAS X concept or ACAS X family of systems.

2.7 ACAS principles

ACAS is designed to act as a last resort safety net to prevent midair collisions. It is intended to work both autonomously and independently of the aircraft navigation equipment and any ground systems used for the provision of air traffic services.

ACAS systems detect nearby aircraft using various surveillance means and calculate if any of surrounding aircraft are a collision risk.

When a risk of collision is determined, ACAS II can issue two types of alerts[11] to the flight crew:

- **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)**[12]; the intruder does not need to be fitted with ACAS II[13]**. 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 transponder[14].

[9] ICAO Annex 10, Volume IV.

[10] In this ACAS Guide, the term *European airspace* refers to the airspace of European Union Aviation Safety Agency (EASA) states that consist of European Union member states and Iceland, Lichtenstein, Norway, and Switzerland.

[11] Other types of alerts are issued by ACAS Xu and ACAS sXu systems. See Sections 13 and 14 for more information.

[12] See Glossary for the explanation of transponder modes.

[13] In encounters with TCAS equipped aircraft, in 80% of cases an RA is issued only on one aircraft in the conflict pair, 16% for both aircraft. The remaining 4% RAs were against aircraft that were not TCAS equipped (e.g., equipped only with a Mode A/C transponder). See Section 16.2 for more information.

[14] On 29 September 2006 a collision between a Boeing 737-800 and an Embraer Legacy occurred over Mato Grosso (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 standby. The aircraft were flying in the opposite directions at the same altitude and collided. The Boeing crashed killing all 154 people on board, while the Embraer managed to land. More information on SKYbrary. A functionality that alerts a pilot if the transponder unexpectedly transition into standby mode has been introduced in ACAS Xa – see Section 12.4 for more information.

ACAS was first 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[15]. The purpose of the Manual is to provide guidance on technical and operational issues applicable to ACAS. All these publications were updated in recent years. Relevant excerpts from ICAO documents can be found in the Appendix (Section 24) of this ACAS Guide.

2.8 ACAS standards

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

- **ACAS I** provides information as an aid to *see & avoid* action but does not include the capability for generating RAs;
- **ACAS II** provides vertical RAs in addition to TAs;
- **ACAS III** provides vertical and horizontal RAs in addition to TAs[16].

Conventional surveillance systems have limited horizontal tracking capabilities and, consequently, do not provide data that is accurate enough for issuing horizontal avoidance manoeuvres. ACAS III has been mentioned as a future system in the previous editions of ICAO Annex 10[17] but there have been no comprehensive ICAO standards for ACAS III. As a recently standardised new collision avoidance system for RPAS – ACAS Xu (see Section 13) – incorporates horizontal manoeuvres by utilizing modern surveillance methods, such as Automatic Dependent Surveillance – Broadcast (ADS-B), ICAO is now developing SARPs for ACAS III.

The TCAS II, ACAS Xa/Xo and ACAS Xu Minimum Operational Performance Standards (MOPS) have been developed jointly by RTCA[18] and EUROCAE[19]. The current versions of MOPS are listed in Table 1 below and the full titles are available in Sections 23.2 and 23.3. Any ACAS equipment must meet the standards specified in the MOPS in order to be certified.

Table 1: Current RTCA and EUROCAE ACAS Minimum Operational Performance Standards.

System	RTCA		EUROCAE	
	Document	**Publication date**	**Document**	**Publication date**
TCAS II version 7.1	DO-185B	June 2008	ED-143	September 2008
ACAS Xa/Xo	DO-385A	June 2023	ED-256A	June 2023
ACAS Xu	DO-386	December 2020	ED-275	December 2020
ACAS sXu	DO-396	December 2022	No equivalent publication	

[15] Subsequently updated and published as 2nd edition in 2012 and 3rd edition in 2021.

[16] Sometimes referred to as TCAS IV.

[17] Fifth edition – July 2014, amendment 91.

[18] RTCA Inc. is a USA-based non-profit organisation that develops technical standards for regulatory authorities (formerly known as Radio Technical Commission for Aeronautics). More information on SKYbrary.

[19] EUROCAE is a non-profit organisation, created in 1963 as the European Organisation for Civil Aviation Equipment, with the objective to develop standards for European civil aviation. More information on SKYbrary.

Currently, TCAS II equipment is available from four vendors, all of them based in the USA[20]. 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 are the same, and systems are interoperable. ACAS X systems may also become available from other manufacturers.

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.

[20] ACSS, Garmin, Honeywell, and Rockwell Collins.

3. Collision Avoidance Systems

3.1 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*[21] or proximity to an intruder aircraft, using two sensitivity levels[22]. 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 (Above Ground Level) on an aircraft equipped with a radar/radio altimeter or when the landing gear is extended (if no radar/radio altimeter is installed). When TCAS I is installed on a fixed-gear aircraft without a radar/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 trend. The criteria for generating these advisories were chosen to provide the crew sufficient time to acquire visually 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; any 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 and number of passenger seats thresholds – see Section 4.3 for more information).

ACAS I is not covered further in this Guide.

[21] See Section 11.2.3 for more information on *tau*.

[22] See Section 11.1.3 for more information on sensitivity levels.

3.2 TCAS II

3.2.1 Versions 6.02, 6.04 and 6.04a

Throughout the 1980s, performance evaluations of early TCAS II versions led to gradual improvements in both hardware and software. In September 1989, the design of version 6.02 was completed, and it was introduced into operation in April 1990. Version 6.04 followed in late 1992, aiming to improve compatibility with the existing ATC system by reducing the protection volume around TCAS-equipped aircraft and raising the altitude threshold for issuing advisories.

As a result of the operational evaluation and monitoring, several improvements were proposed, leading to the development and release of version 6.04a in 1993[23], which replaced versions 6.02 and 6.04. This updated version was designed to reduce the number of nuisance alerts, particularly those occurring at low altitudes and during level-off encounters.

To assess the performance of the TCAS II system, ICAO commissioned a worldwide operational evaluation in the late 1980s, which was conducted in the early 1990s. This evaluation ultimately led to the release of ICAO ACAS SARPs (Annex 10, Volume IV) in July 1995. However, versions 6.02, 6.04, and 6.04a were not compliant with these SARPs.

Versions 6.02 and 6.04 are no 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 and number of passenger seats thresholds – see Section 4.3 for more information).

Versions 6.02, 6.04 and 6.04a are not covered further in this Guide.

3.2.2 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[24] and became available at the beginning of 1999.

Version 7.0 further improved TCAS II compatibility with the ATC 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) operations[25];
- the reduction of electromagnetic interference;
- allowing RA reversals in coordinated encounters;
- simplified aural annunciations.

Version 7.0 became the first TCAS II version to be compliant with the ICAO ACAS SARPs (Annex 10, Volume IV)[26]; however, as of 1 January 2017 only version 7.1 complies with ICAO SARPs. In November 2022, following the publication of amendment 91 to Annex 10, ACAS Xa (see Section 3.3) became the next collision avoidance system also complying with ICAO SARPs.

[23] TCAS II version 6.04a MOPS were published by RTCA as DO-185.

[24] TCAS II version 7.0 MOPS were published by RTCA as DO-185A.

[25] The carriage and operation of TCAS II is not an RVSM requirement in itself. For information about equipage mandates, see Section 4.3.

[26] First edition of Annex 10, Volume IV was published in July 1995 and has since undergone several updates.

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 and number of passenger seats thresholds – see Section 4.3 for more information).

3.2.3 Version 7.1

TCAS II version 7.1[27] is one of the two ACAS II systems meeting the current requirements of ICAO mandate[28]. Version 7.1 was developed based on an extensive analysis of version 7.0 performance, with two major improvements.

3.2.3.1 Introduction of Level Off RA

The Reduce Climb and Reduce Descent RAs (announced as "*Adjust vertical speed, adjust*") in version 7.0 required a reduction of the vertical rate to 0, 500, 1000 or 2000 ft/min. Operational monitoring revealed two issues with pilots' responses to these RAs. Those were:

- **incorrect response:** the pilots increased their vertical rate instead of reducing it, consequently causing a deterioration of the situation[29];
- **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.

> More information on Level Off RAs:
>
> ACAS Bulletin 17

To address these issues, in version 7.1 the Reduce Climb/Descent RAs have been replaced with a new Level Off RA. The Level Off RA (announced "*Level off, level off*") 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 RA may be issued as an initial RA (as illustrated in Figure 3) or as a weakening RA (following, for instance, a "*Climb, climb*" or "*Descend, descend*" RA) when the vertical distance between the aircraft increases after the initial RA has been issued (as illustrated in Figure 4). The aural annunciation "*Level off, level off*" has the benefit of being intuitive and the associated manoeuvre corresponds to the standard levelling off manoeuvre. 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).

---

[27] For more information about TCAS II version 7.1 see Section 11.

[28] The other is ACAS Xa – see Sections 3.3 and 12 for more information.

[29] 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).*

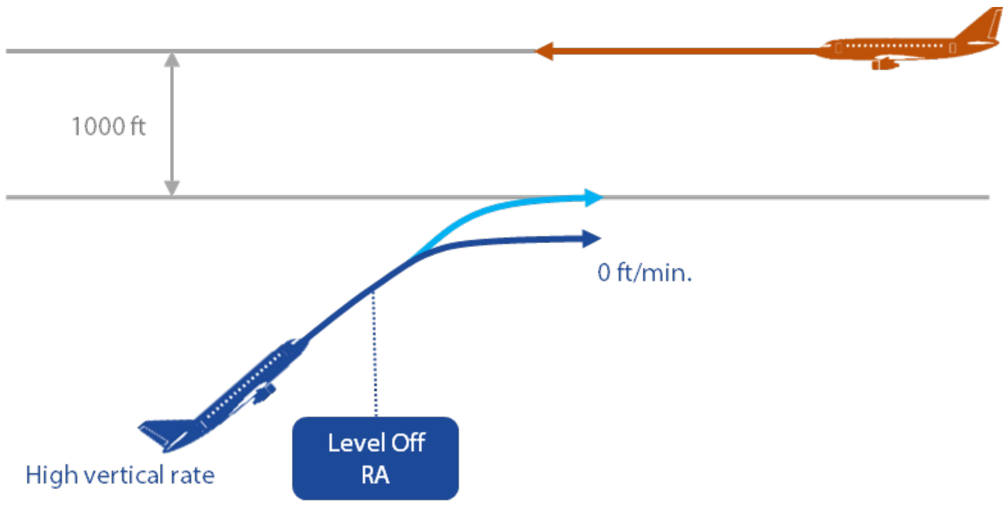


Figure 3: Level Off RA as an initial RA.

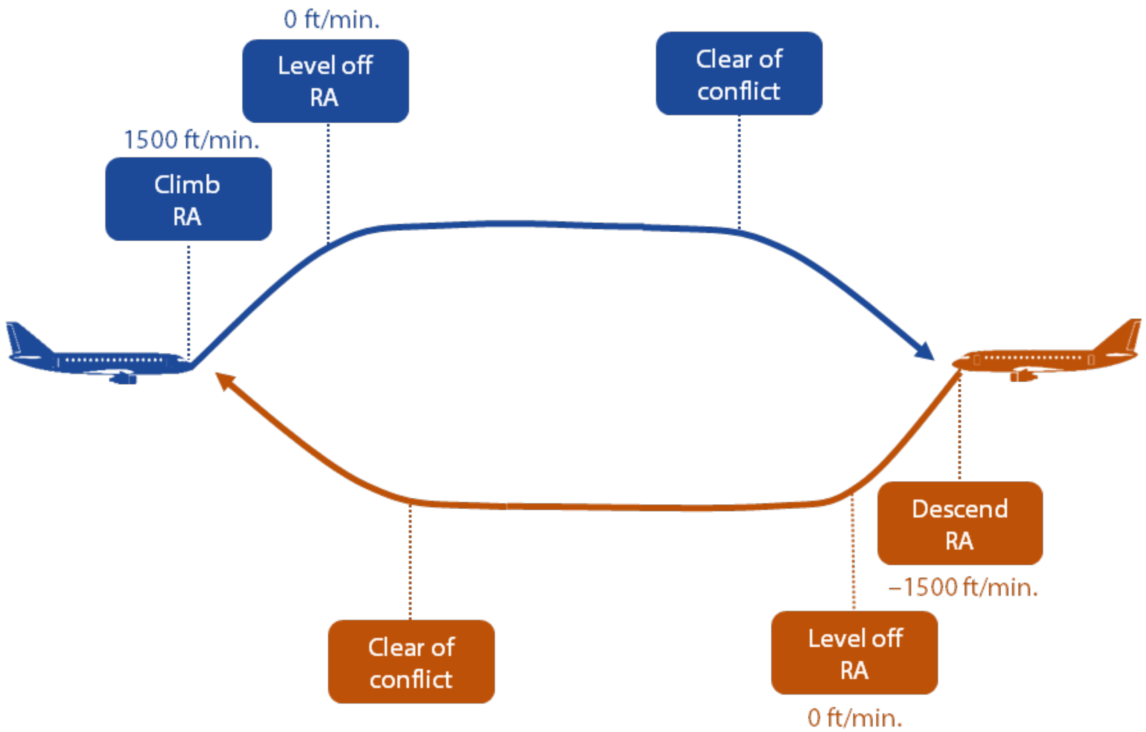


Figure 4: Level Off RA as a weakening RA.

3.2.3.2 Improved reversal logic

The design of TCAS II version 7.0 allowed for reversal RAs (i.e., Climb NOW and Descend NOW) to be issued in coordinated encounters (i.e., both aircraft ACAS 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 5). 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 in 2001[30] and the Überlingen (Germany) midair collision in 2002[31]. In 5 years following the Überlingen collision, eight other occurrences have been observed in European airspace[32].

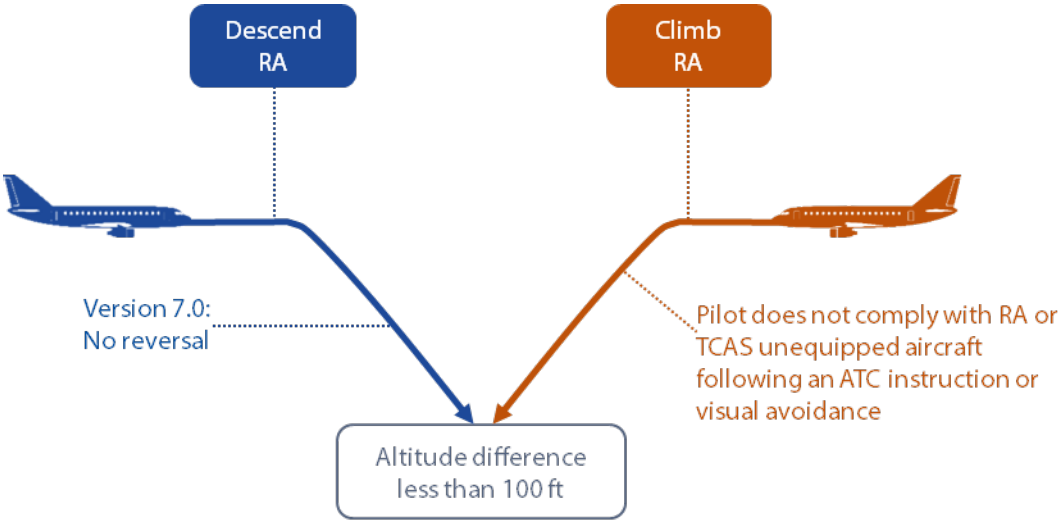


Figure 5: Geometry in which version 7.0 did not reverse an RA.

Version 7.1 brought improvements to the reversal logic by detecting situations in which, despite the RA, the aircraft continue to converge vertically. A new reversal logic has been incorporated that detects "vertical chase with low vertical miss distance" geometries, i.e., two aircraft converging in altitude remaining within 100 feet (see Figure 5). This type of scenario can occur when one aircraft is not following the RA or is not TCAS II equipped and follows an ATC instruction or performs an avoidance manoeuvre based on visual acquisition).

More information on TCAS II version 7.1:

ACAS Bulletin 14

[30] A DC-10 and a Boeing 747-400 were involved in this accident that occurred on 31 January 2001. Both aircraft were equipped with TCAS II version 6.04a. The generation of RAs on both aircraft coincided with the controller instruction for the Boeing pilot to descend. The Boeing crew complied with the ATC descent instruction, rather than the Climb RA. The DC-10 crew followed their Descend RA. Late, aggressive visual avoiding manoeuvres by both crews prevented the collision; however, 100 people on board the Boeing were injured as the result of the abrupt manoeuvre. There were a total of 677 people on board both aircraft. More information: ACAS II Bulletin no. 25 and SKYbrary.

[31] A Tupolev 154 and a Boeing 757 were involved in this collision that occurred on 1 July 2002. Both aircraft were equipped with TCAS II version 7.0. 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 crew followed their Descend RA. The aircraft collided killing 71 people. More information on SKYbrary.

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

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 RA[33] (i.e., Climb NOW or Descend NOW RAs) and will change the sense of RA issued to the aircraft that is not responding correctly to be compatible with the reversal, e.g., "*Maintain vertical speed, maintain*" RA (see Figure 6). 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.

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 7).

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

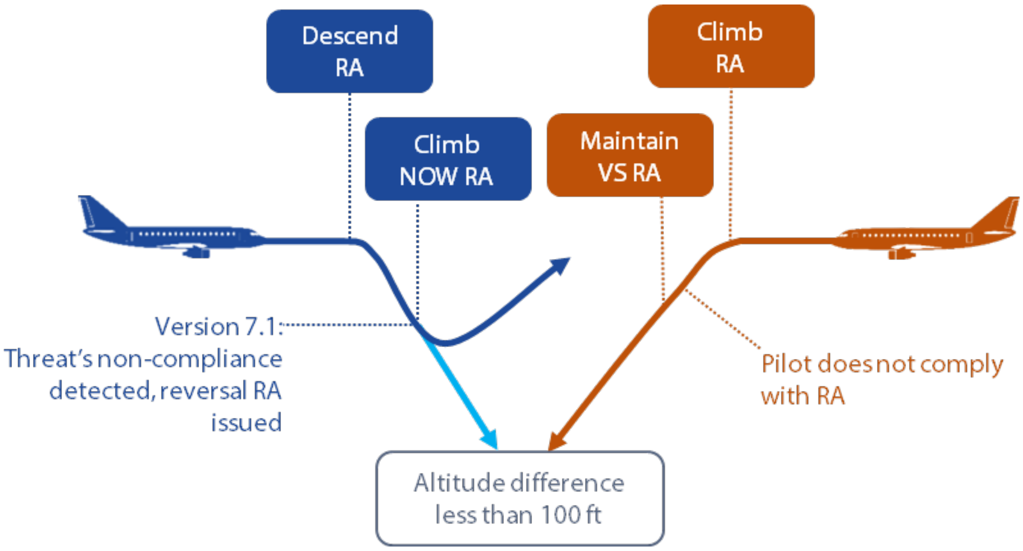


Figure 6: Improvement of reversal logic in version 7.1 (both aircraft equipped[34]).

[33] 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 in Section 6.3.2).

[34] The intruder aircraft (depicted in brown) does not necessarily have to be equipped with TCAS II version 7.1. It could be equipped with an older version of TCAS II, i.e., version 7.0 or 6.04a.

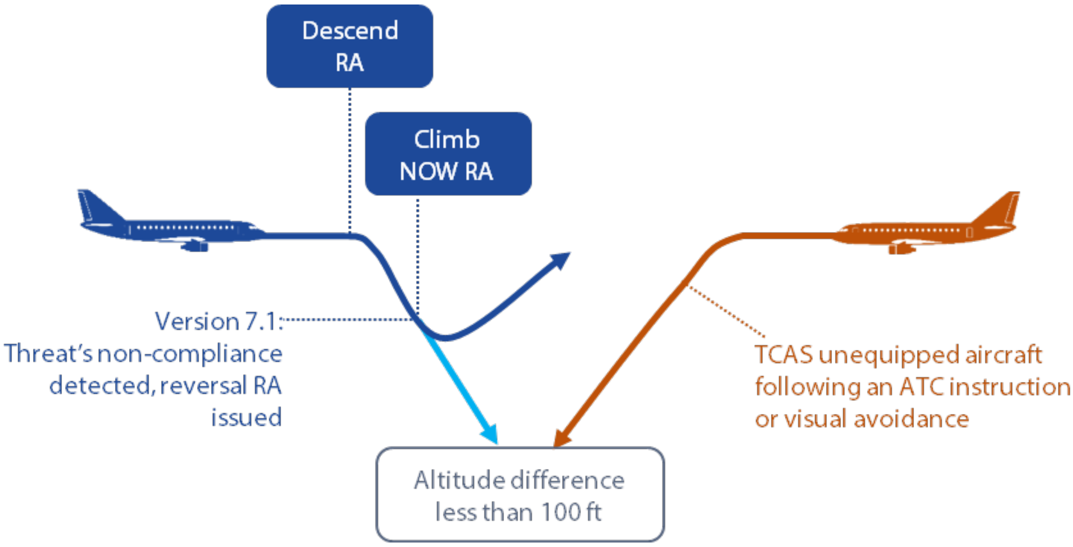


Figure 7: Improvement of reversal logic in version 7.1 (only one aircraft equipped).

3.3 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 X[35]) since 2009.

The 2012 RTCA recommendations for the future of collision avoidance systems[36] stated that the existing TCAS II system was not sufficiently flexible and adaptable to meet current challenges and future needs. It has been recommended that a new collision avoidance system is developed that will:

- Reduce the number of unnecessary RAs;
- Improve safety;
- Incorporate the use of ADS-B surveillance;
- Be flexible and adaptable for future airspace users.

These recommendations were to be achieved by taking the advantage of recent advances in 'dynamic programming' and other computer science techniques (which were not available when TCAS II was first developed).

3.3.1 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.

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

[36] RTCA DO-337 – Recommendations for Future Collision Avoidance Systems, March 2012.

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 establish the best action to take (which includes the option to 'do nothing'). If deemed necessary, RAs are then issued to the pilots.

The development of ACAS X relies mainly on encounter modelling. Encounter modelling allows developers of safety nets to generate a large number of artificial, but realistic encounters, which are rarely observed in normal operations. The safety net can then be subjected to these encounters in exercises called fast-time simulations. They allow developers to predict how the safety net will perform in real operational scenarios, within a practical timeframe.

3.3.2 ACAS X variants

Several ACAS X variants have been designed or are under consideration to extend collision avoidance protection to situations and user classes that currently do not benefit from TCAS II. The following collision avoidance systems form the ACAS X family at the time of writing (see also Table 2):

- **ACAS Xa** (**a**ctive surveillance) **–** The general purpose ACAS X that makes active interrogations to detect intruders. ACAS Xa is the baseline system, the successor to TCAS II. The MOPS were published in 2018[37]. Following the publication of amendment 91 to ICAO Annex 10 Volume IV, ACAS Xa as of November 2022 became an acceptable alternative to, and interoperable with, the existing TCAS II version 7.1. The two systems are different, mainly in areas of the collision avoidance logic and the sources of surveillance data. ACAS Xa was approved for operations in European airspace from March 2025[38]. See Section 12 for more information.
- **ACAS Xo** (**o**peration specific) **–** ACAS Xo is an optional 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 ACAS Xo MOPS were published in 2018 jointly with the ACAS Xa MOPS. ACAS Xo was approved for operations in European airspace from March 2025[39]. See Section 12.3 for more information.
- **ACAS Xu** (**u**nmanned aircraft) **–** Designed for Remotely Piloted Aircraft Systems (RPAS) with wide range of surveillance technologies and performance characteristics, incorporating horizontal resolution manoeuvres. Work on ACAS Xu Standards started in 2016 and the MOPS were published in December 2020[40]. ACAS Xu has not yet been approved for operations in European airspace. See Section 13 for more information.

[37] MOPS for ACAS Xa/Xo were jointly developed by RTCA and EUROCAE standardisation working arrangements (SC-147 and WG-75 respectively) and the current versions are published as DO-385A and ED-256A, respectively.

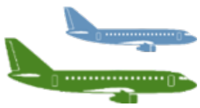
[38] Although ACAS Xa is approved for operation in Europe, it is unclear when the first equipped aircraft will begin operating in European airspace, as some avionics components of the system still require regulatory approval. Additionally, the availability of ACAS Xa equipment from manufacturers remains uncertain.

[39] At the time of writing, no European operational rules exist for the use of ACAS Xo. Additionally, the availability of ACAS Xo equipment from manufacturers remains uncertain.

[40] MOPS for ACAS Xu were jointly developed by RTCA and EUROCAE standardisation working arrangements (SC-147 and WG-75 respectively) and published as DO-386 and ED-275, respectively.

- **ACAS sXu** (small unmanned aircraft) – An extension of ACAS Xu intended for small RPAS, with wing span less than 50 feet (approximately 15 metres). ACAS sXu Standards were published in December 2022[41]. ACAS Xu has not yet been approved for operations in European airspace. See Section 14 for more information.
- **ACAS Xr** (rotorcraft) – A future version of ACAS X intended for rotorcraft (helicopters). At the time of writing, the Standards are being developed and are expected to be complete and approved by the autumn of 2025.
- **ACAS Xp** (passive surveillance) – A potential 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).

Table 2: ACAS X variants and relevant MOPS.

	ACAS X system	Purpose	RTCA MOPS	EUROCAE MOPS
	**Xa**	The general purpose ACAS X Successor to TCAS II	DO-385A	ED-256A
	**Xo**	Specific operations, e.g., closely spaced parallel approaches	DO-385A	ED-256A
	**Xu**	For unmanned aircraft	DO-386	ED-275
	**sXu**	For small unmanned aircraft (wingspan less than 15 m)	DO-396	No equivalent
	**Xr**	For rotorcraft (helicopters)	Under development (estimated completion 2025)	
	**Xp**	For general aviation (passive)	Potential future system	

[41] MOPS for ACAS sXu were developed by RTCA standardisation working arrangement (SC-147) and published as DO-396. There is no equivalent EUROCAE publication.

3.3.3 Foreseen ACAS X benefits

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

- Adaptability to future operational concepts: Both SESAR[42] and NextGen[43] 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. The design includes provisions to enable the ACAS X systems to coordinate RAs with future, yet to be designed, collision avoidance systems.
- 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 UAS or RPAS.
- Safety improvement: It is envisaged that ACAS Xa will provide an improvement in safety while reducing the unnecessary alert rate. TCAS II is an effective system operating as designed, but it can issue alerts in situations where aircraft will remain safely separated.
- 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 Section 20.4. Also, see Section 18.4 on foreseen ACAS Xa safety benefits.

3.4 Other traffic awareness and collision avoidance systems

There are several traffic awareness and collision avoidance systems for general aviation or military aircraft available on the market, for instance FLARM (Flight Alarm) or PCAS (Portable Collision Avoidance System). These systems have not been standardised and are not covered in this ACAS Guide.

These systems may detect transponders of other aircraft or, unlike TCAS II, use exclusively ADS-B data to detect the surrounding traffic and provide the pilot with the awareness of nearby aircraft and their altitude, if the nearby aircraft are suitably equipped. In some implementations, collision avoidance advice is provided but it is not coordinated between the involved aircraft. Some systems use their own proprietary technology to detect other aircraft using satellite positioning.

Collision avoidance systems for unmanned aircraft, other than ACAS Xu and ACAS sXu, are not covered in this ACAS Guide. Although a brief description of the *detect & avoid* concept and altering is provided in Section 15, *detect & avoid* systems are not covered.

[42] 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.

[43] 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.

4. ACAS CARRIAGE MANDATES

4.1 History of ACAS II carriage mandate

The carriage of TCAS II version 6.04a 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 haul 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** (Phase 1), 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** (Phase 2), 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.

Following the development of TCAS II version 7.1 in the late 2000s (to address the identified shortcomings in version 7.0, see Section 3.2.3), the carriage of TCAS II version 7.1 became mandatory in European airspace by all civil manned aeroplanes with a maximum certified take-off mass exceeding 5700 kg or authorised to carry more than 19 passengers as of 1 March 2012 (new aircraft) and 1 December 2015 (all aircraft)[44].

Worldwide, the implementation of ACAS II gradually increased due to its perceived safety benefits and the 1996 midair collision over Charkhi Dadri (India)[45]. Consequently, ICAO initiated a proposal for the worldwide mandatory carriage of ACAS II.

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 mandate 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 1997[46], urgent consideration was given to the need to equip military transport aircraft with ACAS II. Currently, many military transport aircraft have been equipped with ACAS II.

[44] 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.

[45] An Ilyushin 76 and a Boeing 747-100 were involved in this collision that occurred on 12 November 1996. 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. More information on SKYbrary.

[46] A Tupolev 154 and a C141 Starlifter were involved in this collision that occurred on 13 September 1997. 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. More information on Aviation Safety Network.

4.2 Current ICAO ACAS II equipage mandate

Amendment 91 to ICAO Annex 10 Volume IV, published in 2022, contains a provision[47] stating that all ACAS units shall be compliant with TCAS II version 7.1 or ACAS Xa/Xo **after 1 January 2017**. This provision requires that all ACAS installations monitor own aircraft's vertical rate to verify compliance with the RA sense. If non-compliance is detected, the collision avoidance system must stop assuming RA compliance, and instead assume the observed vertical rate. This allows the logic to reverse the RAs consistent with the non-complying aircraft's vertical rate[48].

States may indicate in their Aeronautical Information Publications (AIPs) if different equipage mandates are applicable in their airspace. For instance, in US airspace TCAS II version 6.04a, 7.0 and 7.1 are allowed, except for RVSM airspace where versions 7.0 or 7.1 are required[49].

4.3 Current European ACAS II equipage mandate

Effective **10 March 2025**, all aeroplanes operating in European airspace with a **maximum certificated take-off mass exceeding 5700 kg** or **authorised to carry more than 19 passengers** must be equipped with **TCAS II version 7.1** or **ACAS Xa. The above mandate applies only to civil manned aircraft.** Aircraft with a maximum certificated take-off mass under 5700 kg which are equipped on a voluntary basis with ACAS II, must have collision avoidance logic version 7.1 or ACAS Xa. Refer to European Union Implementing Regulation 2025/343[50], amending European Union Implementing Rule 1332/2011[51].

Although the above mandate applies only to civil aircraft, the Military Authorities of the European Civil Aviation Conference (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 by all (German and foreign) military transport aircraft is mandatory[52].

4.4 Equipage exemptions

The above mentioned European Union Regulation does not allow for equipage exemptions that would permit continued operations, or even a single flight, without the required ACAS II equipment. The only exception applies to aircraft correctly equipped with TCAS II version 7.1 or ACAS Xa, which may operate with the equipment temporarily unserviceable under a Minimum Equipment List (MEL) exemption (see Section 9.13)[53].

---

[47] See Section 24.3 for the full text of ICAO Annex 10 provision.

[48] See Section 3.2.3.2 for the description of version 7.1 reversal logic. The design of ACAS Xa fulfils the reversal requirement against the non-complying threat.

[49] Only versions 7.0 and above use modified alerting thresholds eliminating excessive operationally unwanted RAs.

[50] Commission Regulation (EU) No 2025/343 of 17 February 2025 amending Regulation (EU) No 1332/2011 and Implementing Regulation (EU) 2017/373 as regards airborne collision avoidance systems published in the Official Journal of the European Union on 18 February 2025.

[51] 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.

[52] Refer to German AIC IFR 13 of 20 March 2003.

[53] For more information refer to EASA website.

4.5 Equipage outside the current mandate

ACAS II has been designed 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, some fighters, 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.

The aircraft outside the current mandate that have been voluntarily equipped with TCAS II version 7.0 before 1 December 2015 (i.e., the effective date of the version 7.1 mandate) are allowed to continue to operate and do not need to upgrade to TCAS II version 7.1. However, any new voluntary installations must be TCAS II version 7.1[54].

A study of the potential safety benefits of fitting TCAS II to helicopters was conducted in 2006. The study concluded that the deployment of TCAS II on helicopters could further reduce the overall rate of collisions involving helicopters by up to a factor of between 2 and 3[55].

At the time of writing, Light Jets (LJ) and Very Light Jets (VLJ) are not mandated to carry ACAS II as neither their maximum take-off mass nor passenger capacity are within the thresholds specified in the current equipage mandate (see Section 4.2).

[54] Source: EASA website (FAQ n.20187, updated 4 December 2015).

[55] Source: EUROCONTROL Safety Benefit of ACAS II on Helicopters study.

5. System components

5.1 TCAS II system components

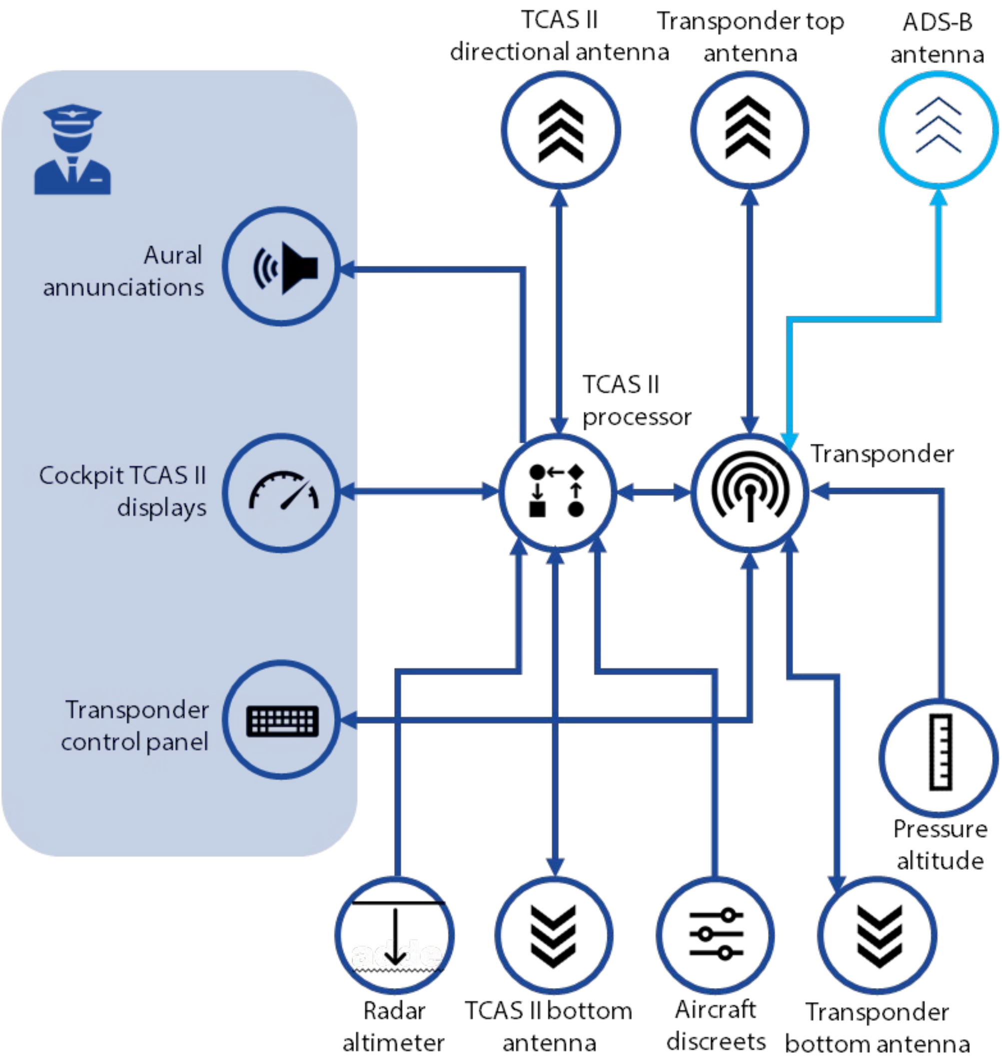


Figure 8: TCAS II installation schematic diagram.

Note: ADS-B equipage is optional.

A TCAS II installation is depicted in Figure 8 and composed of:

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

Transponder – A Mode S transponder is required to be installed and working for TCAS II to be operational. Optionally, a transponder may provide the ADS-B Out broadcast. See Section 5.3 below for more information.

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 II 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 II integrated systems only require two antennas that are shared by the transponder and TCAS II.

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.

Additionally, an optional ADS-B In antenna may be installed.

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

Pressure altitude source – connection with the altimeter is used 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 II are on the ground.

Loudspeakers – for the aural annunciations (see Section 5.6 for more information).

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) and ACAS Xa/Xo MOPS (RTCA DO-385A and EUROCAE ED-256A). See Section 5.4 for more information.

See the Sections 5.4 and 5.5 for more information concerning traffic and RA displays.

Aircraft discreets – Optionally other data relating to aircraft performance may also be taken into account, such as, landing gear and flap status, operational performance ceiling, etc.

However, TCAS II is not connected to the autopilot[56], 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.

[56] An exception here is the Airbus AP/FD (Autopilot/Flight Director) TCAS capability. See Section 9.17.1 for more information.

5.2 ACAS Xa/Xo system components

An ACAS Xa/Xo installation is depicted in Figure 9 and composed of the same elements as the TCAS II installation described in Section 5.1 above, with the following differences:

- ADS-B installation is standard for ACAS Xa/Xo;
- For ACAS Xo, a control and input panel is required[57].

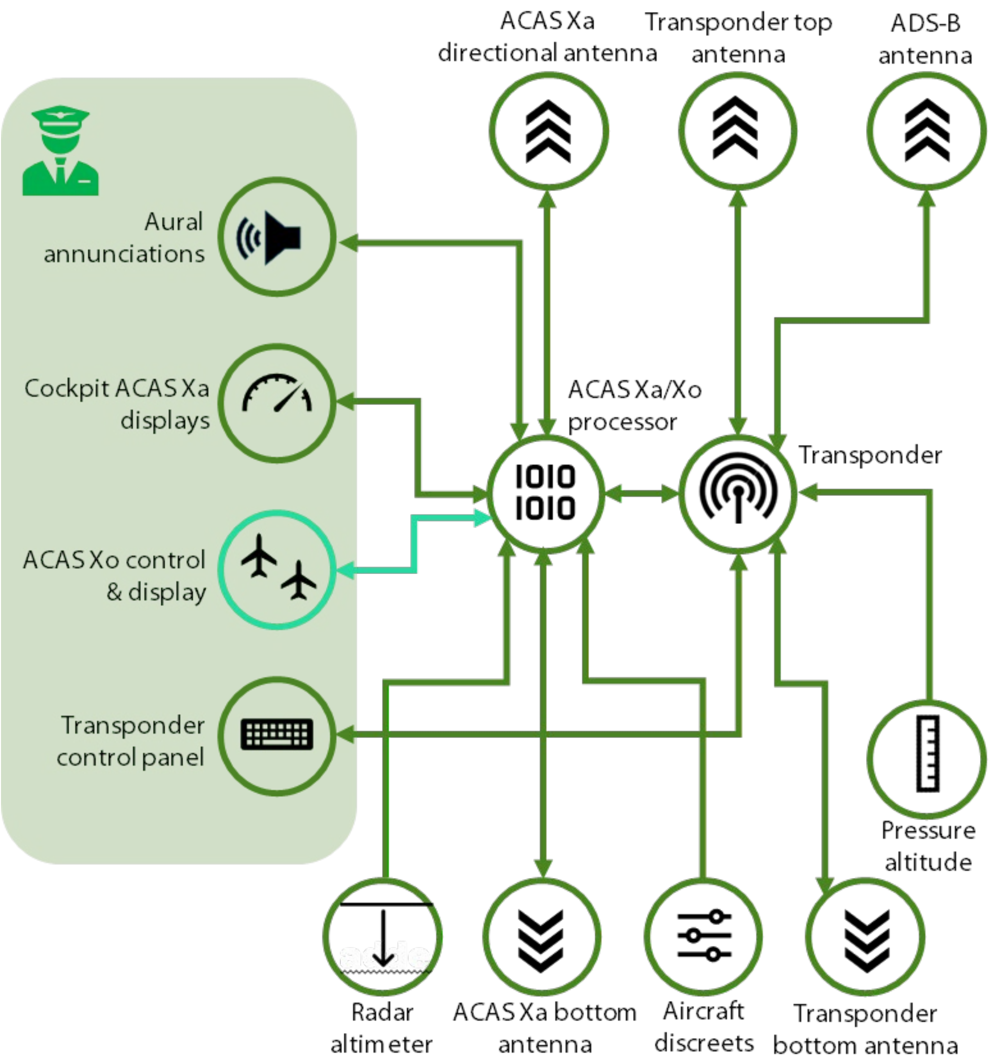


Figure 9: ACAS Xa installation schematic diagram.

Note: ACAS Xo control and display panel are optional.

5.3 Transponder

Not only does the Mode S transponder support the ground-based ATC systems, but also it is the key component of any ACAS II system. The Mode S transponder must be working for ACAS II to be functional. If the Mode S transponder fails, the ACAS Performance Monitor will detect this failure and automatically place ACAS II into standby. In ACAS Xa, aural and visual alerts will be generated if the transponder unexpectedly transitions into standby (see Section 12.4 for more information).

[57] Currently, there are no implementations of ACAS Xo control and input panel.

The Mode S transponder is used to provide air-air data exchange between ACAS II equipped aircraft so that coordinated, complementary RAs can be issued. Consequently, ACAS II cannot function without an operational Mode S transponder. Without coordination, there is a possibility that RAs in the same vertical sense are issued and induce a collision.

A transponder control panel provides the pilot with an interface for setting the operating modes of the transponder (see Figure 10 and Figure 11). Typically, the following modes are available (implementations may vary in detail):

- **STANDBY:** ACAS II is off. Power is applied to the ACAS II processor and the Mode S transponder, but ACAS II does not issue any interrogations and the Mode S transponder does not respond to any interrogations, but ACAS II does not issue or reply to any interrogations.
- **ALT-REPTG-OFF** (not all installations): Transponder is operational, but it does not provide any altitude reports.
- **XPNDR (Transponder):** The Mode S transponder is fully operational and will reply to all appropriate ground and TCAS interrogations. ACAS II remains in standby.
- **TA-ONLY:** only TAs can be issued. The Mode S transponder is fully operational. ACAS II will operate normally and issue the appropriate interrogations and perform all tracking functions. However, TCAS II will only issue TAs; RAs will be inhibited.
- **AUTOMATIC** or **TA/RA**: normal ACAS II operation. The Mode S transponder is fully operational. ACAS II will operate normally and issue the appropriate interrogations and perform all tracking functions. ACAS II will issue TAs and RAs when appropriate.
- **TFC** (not all installations): provides only a TCAS pop-up function, i.e., proximate traffic and other intruders are displayed only if a TA or RA is also present.

ACAS II and transponder modes of operations are shown in Table 3. For more information about modes of operations refer to Section 11.1.4.

See Figure 10 and Figure 11 for illustration of TCAS and transponder control panels on the Boeing 737-700 and Airbus A320.

Table 3: ACAS II and transponder modes of operations.

Operating mode	Standby (STBY)	XPNDR	ALT RPTG OFF	TA-only	TA/RA or AUTOMATIC
Transponder	Off	On	On, but no altitude reporting	On	On
ACAS II	Off	Off	Off	On	On
Own aircraft	No alerts	No alerts	No alerts	TA	TA &. RA
Intruder	No alerts	TA & RA (uncoordinated)	NAR TAs[58]	TA & RA (uncoordinated)	TA & RA
ATC	No detected	Full detection	Detected, without altitude info	Full detection	Full detection

[58] See Section 6.11 for more information regarding NAR (Non-Altitude Reporting) TAs.

Figure 10: Example of TCAS/transponder panel on a Boeing 737-700.

Figure 11: Example of TCAS/transponder panel an Airbus A320.

5.4 Traffic display

The traffic display implementation is identical for TCAS II and ACAS Xa. It depicts the position of nearby traffic on a plan position indicator, relative to own aircraft. It indicates the relative horizontal and vertical position of other aircraft based on the replies from their transponders.

> More information on traffic display:
>
> ACAS Bulletin 6
> ACAS Bulletin 32

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 respond to an RA. More information about traffic display operations can be found in Section 9.7.

5.4.1 Implementation examples

The traffic display can be implemented on either a part-time or a 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. Individual implementations details may vary.

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.

Some new traffic display implementations may also provide flight identification (callsign) as well as the traffic direction next to the traffic symbol based on ADS-B In applications.

Examples of traffic displays are shown in figures below.

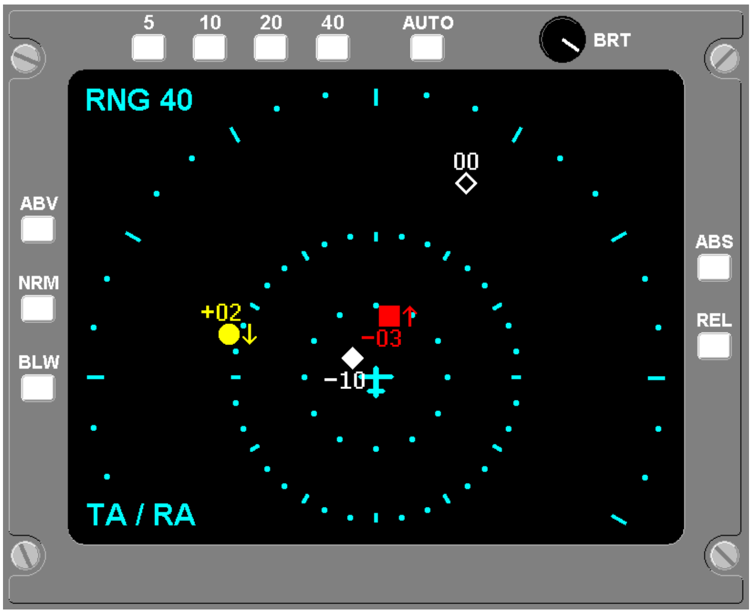


Figure 12: Traffic display example – dedicated display.

Figure 13: Traffic display example – IVSI combined with traffic display.

Figure 14: Traffic display example – Electronic Flight Instrument System (EFIS).

Figure 15: Actual traffic display implementation on Airbus A320.

Figure 16: Actual traffic display implementation on Boeing 737-800.

5.4.2 ACAS II traffic display symbology

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

The background to the display is dark. The ACAS II traffic display symbols are shown in Table 4. Targets are displayed by different symbols, according to their threat status. The ACAS Xa/Xo and ACAS Xu systems use specific symbols for certain types of traffic (implementation depended) – see Table 5 and Section 5.4.3.

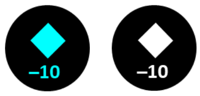
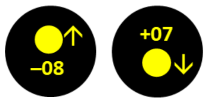
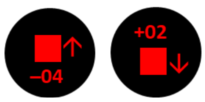
The vertical trend arrow and relative altitude will be shown next to each symbol (in the matching colour)[59]. The relative altitude is displayed in hundreds of feet, above the symbol if the intruder is above own aircraft and below the symbol in the opposite case.

Specific symbology is applied for Non-Altitude Reporting (NAR) intruders (see Section 6.11) and No-Bearing intruder (see Section 6.12).

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. Any other non-intruding traffic are called **Other Traffic** and are displayed by a hollow white or cyan (light blue) diamond. Each symbol is displayed according to its relative position to own aircraft.

[59] Except for Non-Altitude Reporting (NAR) targets. See Section 6.11 for more information.

Table 4: ACAS II traffic display symbology (except ACAS Xa/Xo specific symbols).

	White or cyan (light blue) aircraft-like symbol or a triangle	Own aircraft
	Hollow cyan (light blue) or white diamond[60]	Other traffic
	Solid cyan (light blue) or white diamond	Proximate traffic Aircraft within 6 NM and 1200 feet of own aircraft
	Solid yellow or amber circle[61]	Traffic Advisory Typically generated 20-48 seconds before CPA
	Solid red square	Resolution Advisory Typically generated 15-35 seconds before CPA

Note: In some newer implementations, other aircraft are shown as an aircraft icon in the colour corresponding to the threat level.

5.4.3 Specific ACAS Xa/Xo and ACAS Xu traffic display symbology

Generally, the display philosophy and basic symbols for the ACAS Xa/Xo (see Section 12) and ACAS Xu (see Section 13) systems are the same as for ACAS II (see Table 4). The ACAS Xa/Xo and ACAS Xu systems use different symbols for directional and non-directional traffic. Intruding traffic is considered to be non-directional if the angle accuracy calculation by own aircraft falls outside the defined limits. For directional traffic dedicated arrowhead symbols are used, while for non-directional traffic the symbols are the same as those used for ACAS II (see Table 4).

On an ACAS Xo equipped aircraft, once a pilot has designated the DNA or CSPO-3000 (see Section 12.3) function on a target, the designation will be indicated on the traffic display using a special symbol for this target.

If ACAS Xa AOTO (ADS-B Only TA Only) feature is enabled (see Section 12.2.5), then the AOTO TA symbol will differ from a standard TA symbol (as shown in Table 4).

For more information about ACAS Xa/Xo and ACAS Xu refer to Sections 12 and 13, respectively.

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

[61] In case of a TA generated against a Non-Altitude Reporting (NAR) intruder (see Section 6.11) neither altitude label nor trend arrow will be shown.

Table 5: Examples of ACAS Xa/Xo, ACAS Xu, and DAA specific traffic display symbology.

	Hollow white or cyan (light blue) diamond	Non-directional (other) traffic
	Hollow cyan (light blue) or white arrowhead	Directional (other) traffic
	Hollow white or cyan (light blue) double-border diamond	Designated non-directional (other) traffic
	Hollow cyan (light blue) or white double-border arrowhead	Designated directional (other) traffic
	Solid white or cyan (light blue) diamond	Non-directional manoeuvre guidance (proximate) traffic
	Solid cyan (light blue) or white double-border arrowhead	Directional manoeuvre guidance (proximate) traffic
	Solid white or cyan (light blue) double-border diamond	Designated non-directional manoeuvre guidance (proximate) traffic
	Solid cyan (light blue) or white double-border arrowhead	Designated directional manoeuvre guidance (proximate) traffic
	Yellow or amber hollow circle with an arrowhead	Traffic Advisory against a directional intruder or *detect & avoid* corrective alert symbol
	Yellow or amber circle with an arrowhead	Traffic Advisory against a directional intruder or *detect & avoid* preventive alert symbol
	Red square with an arrowhead[62]	Resolution Advisory against a directional intruder

Note: Implementations may vary in detail.

[62] An example of RA symbol with a directional symbol. Other implementations are possible.

5.4.4 Vertical data display

Vertical data is 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. For traffic at the same altitude, the co-altitude tag **00** will be displayed. The **00** tag is placed above the symbol if the intruder aircraft closed from above; below the symbol if the intruder aircraft closed from below (see Table 6).

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 500 ft/min. If no trend information is available, the co-altitude **00** symbol is placed below the traffic symbol.

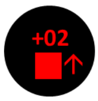
In some instances, TCAS II may not have a reliable bearing for an intruder causing a TA or RA. Bearing information is used primarily for traffic display purposes[63]: the lack of bearing information does not affect the ability of ACAS II to issue TAs and RAs. When a No-Bearing TA or RA is issued (see Section 6.12), 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. Nominally, traffic display is capable of displaying other traffic up to a maximum of ±9900 feet[64].

[63] Bearing information is also used for manoeuvre detection in the Miss-Distance Filter (see Threat Detection in Section 11.2.3).

[64] The display range is limited to ±9900 because only two digits are used to display the relative altitude (which is displayed in hundreds of feet).

Table 6: Trend arrow symbology.

	2000 feet above Level flight
	Same level (the intruder closed from above) Level flight
	Same level (the intruder closed from below) Level flight
	1500 feet below Descending
	800 feet below Climbing
	200 feet above Climbing

5.4.5 Traffic display bearing accuracy

ACAS II has limited bearing accuracy; therefore, traffic display may show positions of other aircraft inaccurately. Typically, the error is no more than 5° but it could be greater than 30° in some cases. 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° in bearing.

The bearing displayed by ACAS 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 ACAS II traffic display should not be made (see Section 9.7 for more information).

5.4.6 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 a maximum of 9900 feet above own aircraft. In the "Below" mode, tracked traffic is displayed if it is between 2700 feet above and down to a 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 or a mode which will display only threat aircraft.

5.5 RA display

5.5.1 Classical instrumentation

The traffic display is incorporated into the centre of the Instantaneous Vertical Speed Indicator (IVSI) – see Figure 13. 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**. For corrective RAs, a green arc will appear alongside the red arc, guiding pilots to manoeuvre the aircraft to achieve the required vertical rate indicated by the green arc. If there is more than one threat, two red arcs may flank the range of the required vertical rates. For preventive RAs, only a red arc will be displayed.

Table 7 and Table 8 show how ACAS II advisories are shown on an IVSI instrumentation.

5.5.2 EFIS (Electronic Flight Instrument System)

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

There are two PFD concepts:

- **display on the artificial horizon –** an RA is displayed 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 (see Figure 17). An example of implementation on a Boeing 737-800 is shown in Figure 19;
- **display on the Vertical Speed Indicator (tape) –** the RA is displayed in the same way as in "classic" cockpits (see Section 5.5.1). A red area marks the range of vertical rates to be avoided, a green area indicates to the pilots the required vertical rate (see Figure 18). An example of implementation on an Airbus A320 is shown in Figure 20.

Table 7 and Table 8 show how ACAS II advisories are shown on an EFIS instrumentation.

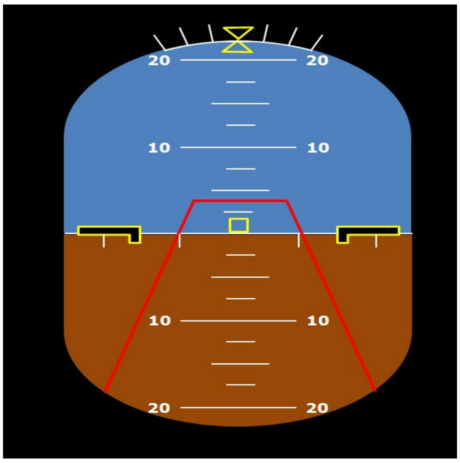


Figure 17: RA pitch cue on PFD.

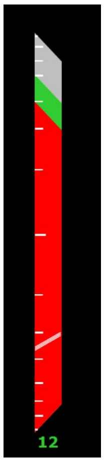


Figure 18: Vertical Speed Tape.

Figure 19: PFD with pitch cue display indicating a Climb RA on a Boeing 737-800.

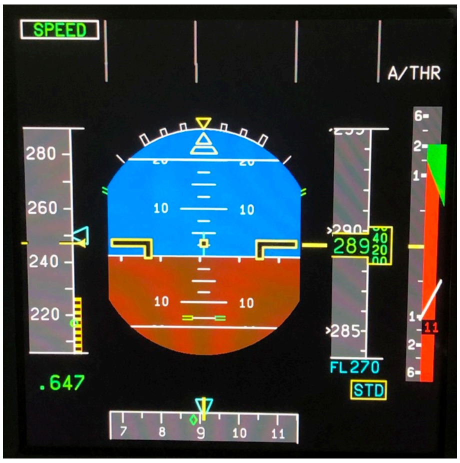


Figure 20: PFD with vertical speed tape indicating a Climb RA on an Airbus A320.

Figure 21: Primary Flight Display (left) and Navigation Display positions on Airbus A320.

5.6 Aural annunciations

Loudspeakers located in the cockpit alert the crew, by means of aural annunciations, of TAs and RAs. Some implementations provide aural annunciations via the crew's headsets.

Aural annunciations are generated by voice announcements only when a TA and when the first RA of an encounter are displayed and each time a subsequent change in the RA is displayed (strengthened, weakened or reversed). An aural annunciation is also provided when the own aircraft is clear of conflict with all threat aircraft and when the RA is cleared. No TA aural annunciation is issued when an RA against an intruder reverts to a TA at the end of an encounter. Additionally, an annunciation of new TA ("*Traffic, traffic*") may be suppressed (implementation dependent) if an RA against another aircraft is already in progress.

An aural annunciation could be interrupted before it is completed if the logic determines that a higher priority aural annunciation, e.g., "*Increase climb, increase climb*", should be announced.

All aural annunciations are inhibited below 500 feet (±100 feet) AGL or when Ground Proximity Warning System (GPWS) or Terrain Avoidance and Warning System (TAWS) or wind shear detection warnings are active (see Section 8.2).

The TCAS II version 7.1 and ACAS Xa aural annunciations are shown in Table 7 and Table 8.

5.7 Status and failure annunciations

Visual annunciations are provided to indicate the normal operating and the failure modes of TCAS II and ACAS Xa. The Traffic Display and RA display will show the following operating modes and failure conditions: TCAS/ACAS in standby or turned off, operating mode is the TA-only mode, TCAS/ACAS has failed, Traffic Display/RA display has failed, and a Self-Test is in progress. In ACAS Xa, aural and visual alerts will be generated if the transponder unexpectedly transitions into standby (see Section 12.4 for more information).

6. TCAS II and ACAS Xa Traffic and Resolution Advisories

ACAS II provides two types of advisories to the pilots:

- **Traffic Advisories (TAs)** to prepare the pilots for a potential Resolution Advisory and aid the visual acquisition of the intruder aircraft;
- **Resolution Advisories (RAs)** which provide vertical collision avoidance guidance to the pilots. An RA can be issued against a single threat or multiple threats[65].

Table 7 lists all ACAS II alerts for single threat encounters, while Table 8 provides a list of multi-threat alerts. Both Tables list the ACAS II aural annunciations and show how advisories are presented on IVSI and EFIS instrumentations. Furthermore, an indication of the required manoeuvre and the vertical speed or range of speeds that need to be achieved are provided for each advisories. In reality, these speeds cannot always be precisely achieved. The range of alerts provided by TCAS II version 7.1 and ACAS Xa is a similar but not identical – the differences are described in Section 12.2.4.

For information regarding ACAS Xu and sXu alerts see Section 13.

6.1 TAs

The objective of a TA is to aid visual acquisition of an intruder and prepare the crew for a possible RA. No manoeuvres are permitted in response to a TA.

For TCAS II, 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. For ACAS Xa, there are no predefined nominal times. The logic aims on generating TAs in the sufficient time prior to the CPA and RA. In some geometries an RA may occur without a preceding TA on one or both of the involved aircraft. It may happen if the RA criteria are already satisfied when a track is first established or a sudden manoeuvre by the intruder could cause the TA lead-time to be less than a cycle.

The majority of TAs are not followed by RAs. See Section 9.1 on pilot actions on the receipt of TA.

6.2 Initial RAs

Once the logic determines that another aircraft poses a threat, ACAS II will issue an RA. The initially issued RA's strength is evaluated every second and the logic can either strengthen, reverse, weaken or terminate the initial RA as necessary.

Some RAs cannot be issued as an initial RA, they are issued only when there is a need to strengthen or reverse the RA sense. These RAs are marked accordingly in Table 7. See Section 9.2 on pilot actions on the receipt of RA.

6.3 Reversal RAs

A reversal of RA sense is permitted in coordinated encounters (i.e., both aircraft ACAS II equipped) and in encounters with non-ACAS equipped threats. For example, an initial Climb RA can be reversed to a Descend NOW RA. If an aircraft does not respond to the initial Climb or Descend RA and continues descending or climbing, respectively, a reversal RA may be issued as Maintain Vertical Speed or Crossing Maintain Vertical Speed (not applicable to ACAS Xa, as it does not use Maintain Vertical Speed RAs).

> More information on reversal RAs:
>
> ACAS Bulletin 13

[65] RAs are generated except where it is not possible to select an RA that can be predicted to provide adequate separation either because of uncertainty in the diagnosis of the intruder's flight path or because there is a high risk that a manoeuvre by the threat will negate the RA.

A reversal is an indication that the previous RA is failing to resolve the encounter. Therefore, a change in the RA sense is urgently needed. To draw pilot's attention to the change, the word "*NOW*" (spoken with a sense of urgency) is added to the aural annunciation (except Maintain Vertical Speed or Crossing Maintain Vertical Speed RAs).

However, there is a special case where an RA can be reversed to a Maintain Vertical Speed RA, in which the word "*NOW*" is not used.

This occurs when there is a delayed or no response to a Climb or Descend RA, and the aircraft has a high vertical rate (greater than 2500 ft/min.) in the direction opposite to the original RA. In such cases, TCAS II may reverse the Climb or Descend RA to a Maintain Vertical Speed RA. The reversal will be announced as "*Maintain vertical speed, maintain*" (or possibly "*Maintain vertical speed, crossing maintain*" if the intruder's altitude is to be crossed). Unlike other RA reversals, this type of reversal does not include a specific aural annunciation to indicate it is a reversal – meaning the word "*NOW*" will not be used. In such cases, ACAS Xa will announce the reversal RAs as "*Climb, climb NOW*" or "*Descend, descend NOW*", as applicable.

A reversal to a Maintain Vertical Speed RA requires the pilot to maintain the current vertical speed. However, this can be a source of confusion if the pilot is in the process of transitioning from a climb to a descent (or vice versa). By the time the pilot looks at the display, their current vertical speed may already be in the red zone.

When the reversal does not require a climb or descend manoeuvre, the RA will be announced as either "*Level off, level off*" or "*Monitor vertical speed*" depending on the advisory sense and the current vertical speed of the aircraft. Reversals to Level Off or Monitor Vertical Speed RAs are rare and can only occur in a multi-threat encounter or when own aircraft inhibits are active at low altitudes (see Section 8.2.1).

Two types of reversals may occur as described below.

6.3.1 Coordination (tiebreak) reversal

A 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, i.e., the *"slave aircraft"* will change its initial RA from, for instance, a Climb RA to a Reversal Descent RA (see Figure 22). The aircraft with the lower Mode S 24-bit address ("*master aircraft*") is not permitted to reverse its RA for the purpose of coordination and will retain its initial RA.

6.3.2 Geometric reversal

Occasionally, the threat aircraft manoeuvres (or fails to manoeuvre) in such a way as to negate the effectiveness of the initial RA. When sufficient vertical spacing is no longer predicted, a geometric reversal will take place and the initial RA will be modified to the opposite sense (vertical direction). In these cases, the initial RA can also be strengthened (see Section 6.4 below) if that is deemed by the logic as more effective. ACAS 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 (see Figure 23).

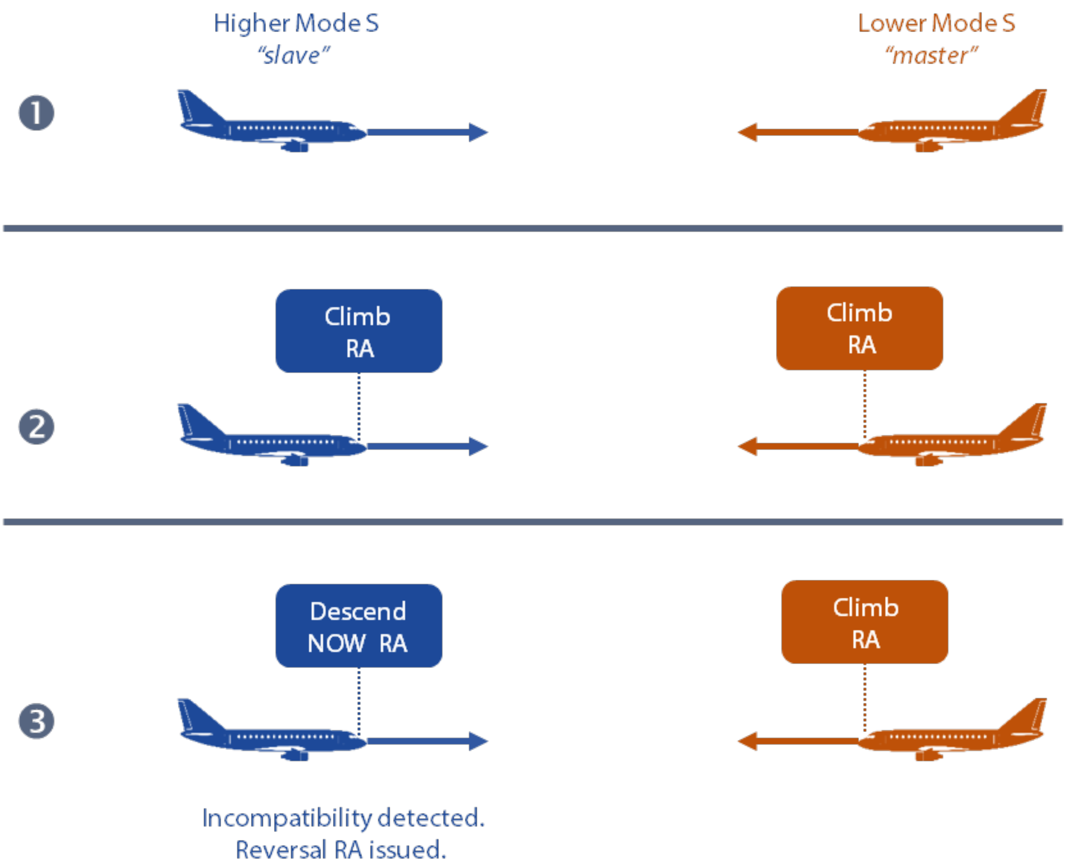


Figure 22: Coordination (tie-break) reversal in case of simultaneous threat declaration.

Both in TCAS II and ACAS Xa, an aircraft with the lower Mode S address ("*master aircraft*") is permitted to initiate a geometric reversal: Each cycle, this aircraft reassesses its RA and can reverse it if it is deemed ineffective. The lower Mode S aircraft is limited to one geometric reversal per intruder per encounter. If it declares a reversal, then the aircraft with the higher Mode S address ("*slave aircraft*") is forced to reverse its RA, so the RAs stay compatible[66].

An aircraft with the higher Mode S address can only reverse to comply with an RAC received from an aircraft with a lower address ("*master aircraft*"). Generally, only one geometric reversal is permitted in an encounter. However, an ACAS Xa higher Mode S address aircraft (*"slave"*) can issue a geometric reversal if the lower Mode S address aircraft ("*master*") has not yet issued an RA. Consequently, on rare occasions there can be two geometric reversals in one encounter in ACAS Xa equipped aircraft.

The reversal logic is complex and it requires that several conditions are met in order for a reversal to be issued. A detailed description can be found in the ICAO ACAS Manual[67].

Geometric reversal can still occur even if there was previously a coordination (tiebreak) reversal.

See Section 9.2 on pilot actions on the receipt of a reversal RA.

---

[66] 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 Section 3.2.3.2), where a special parameter is used to circumvent the Mode S address priority rule.

[67] ICAO Doc 9863 Section 3.15.14.3.

6.4 Strengthening RAs

If the logic determines that the initially issued RA will not provide sufficient vertical spacing, the strength of the RA will be increased. 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, in TCAS II, 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 (in TCAS II), including crossing RAs is strengthened to an Increase Climb or Increase Descent RA (required increase of vertical rate from at least 1500 to 2500 ft/min.). Aural annunciations containing the word "*increase*" are spoken with a sense of urgency.

See Section 9.2 on pilot actions on the receipt of a strengthening RA.

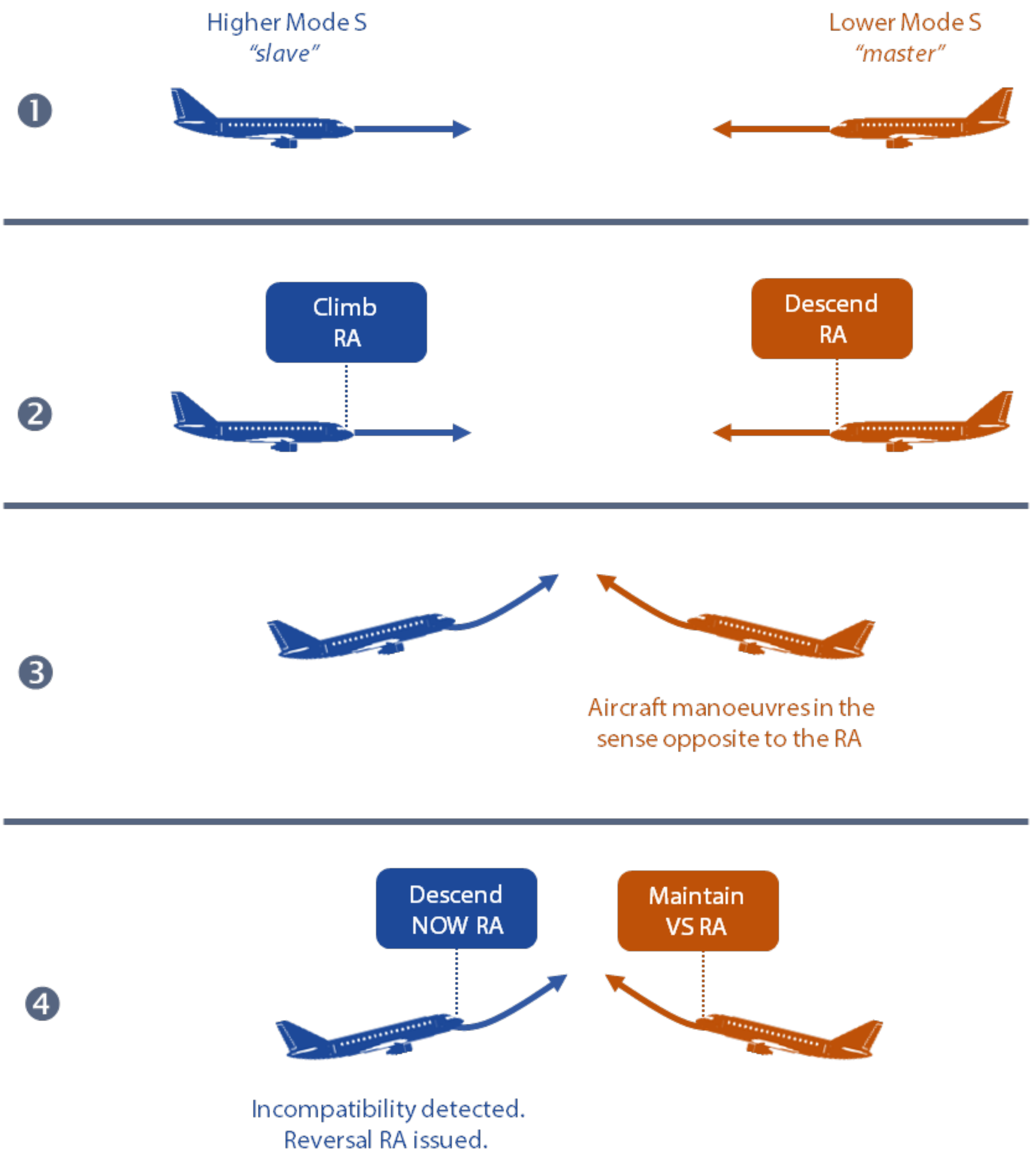


Figure 23: Geometric reversal.

6.5 Weakening RAs

During an RA, if the logic determines that the response to an RA has provided the sufficient spacing, the initial RA will be weakened, for instance a Descend RA will be weakened to a Level off RA. This is done to minimise unnecessary deviations from the original altitude The weakening RAs will show required, as well as vertical speeds to be avoided (in green and red respectively).

6.6 Crossing RAs

An RA is considered crossing if own aircraft is expected to cross the altitude of the intruder before closest approach, e.g., pass above a threat currently above own aircraft. An RA can be considered crossing regardless of whether the word "*crossing*" is included in the aural annunciation.

More information on crossing RAs:

ACAS Bulletin 31

An RA is altitude crossing if own ACAS II aircraft is currently at least 100 feet below or above the threat aircraft for upward or downward sense advisories, respectively. ACAS II is designed to prefer non-altitude crossing RAs if these provide the adequate collision resolution.

Crossing reversal RAs will not be issued if the vertical spacing between own and threat aircraft is more than 150 feet for TCAS II and 500 feet for ACAS Xa. Only when it is estimated that sufficient vertical separation at CPA cannot be achieved will an RA with altitude crossing be posted. Crossing RAs are less intuitive than other RAs as they may give the pilots the impression that they are being wrongly directed towards the other aircraft.

6.7 Preventive RAs

A Preventive RA is issued when no change in the aircraft's vertical rate is required. It may restrict the aircraft from descending or climbing and is announced as "*Monitor Vertical Speed*."

Unlike other RAs, Preventive RAs only display prohibited vertical speed ranges (in red) and do not indicate required vertical speeds (in green). Pilots are not required to take any action as long as the aircraft remains outside the restricted vertical speed ranges.

6.8 Classification of RAs

Each RA can be classified as follows:

- **RA sense –** An RA with an **upward** sense is issued to ensure that own aircraft will pass above the threat, while a **downward** sense RA ensures that own aircraft will pass below the threat.
- **RA strength –** Upward RAs strengths include **Do Not Descend** (announced "*Monitor Vertical Speed*") or **Climb** advisories. The equivalent downwards RAs will be **Do Not Climb** (announced "*Monitor Vertical Speed*") or **Descend** advisories.
- **Positive/negative RAs –** A **positive** RA requires a climb or a descent at a particular rate; while a **negative** (or vertical speed limit) RA requires that a prescribed range of vertical rates must be avoided.
- **Corrective/preventive RAs –** A **corrective** advisory requires a change in own aircraft's vertical rate, while a **preventive** advisory does not.

6.9 Multi-threat RAs

Multi-threat encounters are rare (less than 1% of all RAs). ACAS II is able to handle multi-threat encounters 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). Examples of multi-threat RAs are shown in Table 8.

6.10 RA termination or removal

When the intruder ceases to be a threat, the RA is cancelled, and a Clear of Conflict annunciation is made.

An RA will be removed (i.e., no longer displayed) but no Clear of Conflict annunciation will be made if:

- the tracking of the threat has been lost;
- the flight crew on the threat aircraft selected TA-only mode;
- a higher priority alert (e.g., GPWS/TAWS)[68] has been issued on own aircraft;
- own aircraft has passed below the RA inhibition altitude, i.e., 1000 feet (±100 feet) AGL (see Section 8.2 information about RA inhibitions).

If an RA is removed without a Clear of Conflict annunciation, the collision risk may still be present, so flight crews are advised to continue monitoring surrounding traffic visually.

6.11 Non-Altitude Reporting intruders

If the intruder aircraft is equipped with a Mode S or Mode A/C transponder but does not provide altitude information[69] this aircraft will be tracked as a Non-Altitude Reporting target (NAR) using range and bearing information and it will be shown on the traffic display, only when own aircraft is below FL155 (i.e., 15,500 feet). Neither an altitude data tag nor a trend arrow will be shown with the traffic symbol for an intruder that is not reporting altitude (see Figure 24).

Figure 24: Illustration of a NAR TA.

TCAS II will generate TAs against Non-Altitude Reporting aircraft when the Range Test[70] for TA generation is satisfied (but using reduced time thresholds which correspond to RA thresholds). Non-Altitude Reporting aircraft are deemed to be at the same altitude as own aircraft (i.e., the worst-case scenario).

A NAR 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; see Section 11.1.3). Nominal TCAS II TA generation times against NAR intruders are shown in Figure 25.

[68] See Section 8.2.2.

[69] The lack of altitude information could be caused by pilot's failure to select the altitude transmission function on the transponder or due to a technical fault.

[70] See Section 11.2.3.1 for more information.

No RAs will ever be generated against NAR intruders. A NAR TA will alert the crew to the presence of another aircraft in the vicinity and should prompt the crew to attempt the visual acquisition of the intruder aircraft[71].

If a NAR aircraft selects altitude transmission while being tracked by another aircraft, it will then be treated as a normal target with RAs being generated if required.

ACAS Xa will also generate TAs against Non-Altitude Reporting aircraft below FL155 using the dedicated algorithm for this type of intruders[72].

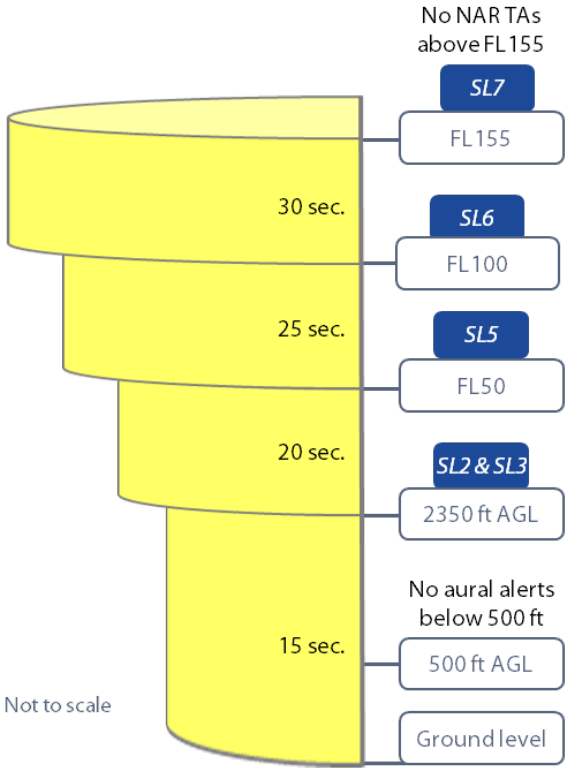


Figure 25: Nominal NAR TA generation times.

[71] See SKYbrary article on an incident involving a NAR aircraft.

[72] The algorithm can be found in the ACAS Xa MOPS. The description of this complex algorithm is beyond the scope of this ACAS Guide.

6.12 No-Bearing intruders

In some cases, ACAS II may not have a reliable bearing for an intruder causing a TA or RA. Since bearing information is required for display purposes only, the lack of bearing information does not affect the ability of TCAS II to issue TAs and RAs[73].

The No-Bearing (or bearingless) advisories are shown on the traffic display as an alphanumerical string in the colour corresponding to the alert (yellow for TAs and red for RAs) as follows:

- threat level (TA or RA);
- range in NM;
- relative altitude (hundreds of feet);
- the intruder vertical trend arrow.

Each piece of information is separated by a space or a slash (/). The use of the range units (NM) is optional. In the example shown in Figure 26, an intruder generating a TA is at the range of 5.1 NM, 800 feet below and climbing. In Figure 27, an intruder generating an RA is at the range of 3.9 NM, 400 feet above and descending. The position on the traffic display where the No-Bearing advisories are shown is implementation dependent.

Figure 26: No-Bearing TA display.

Figure 27: No-Bearing RA display.

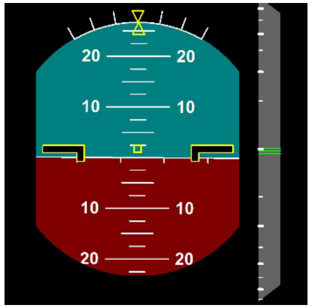
[73] Where possible, bearing is also used to suppress nuisance alerts through the operation of the Miss Distance Filter (see Threat Detection in Section 11.2.3).

7. TCAS II AND ACAS XA ALERT AURAL ANNUNCIATIONS AND DISPLAY

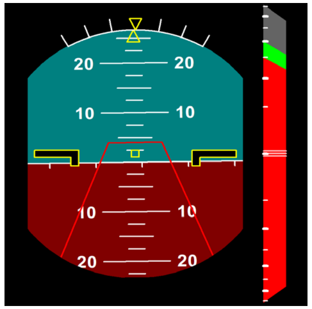
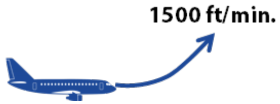
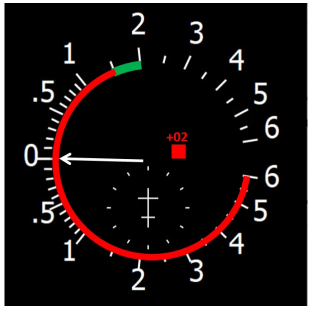
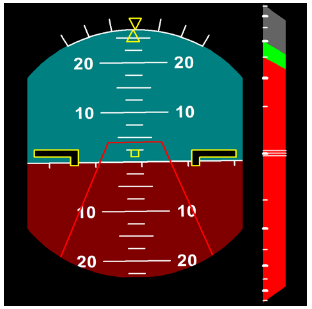
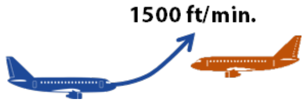
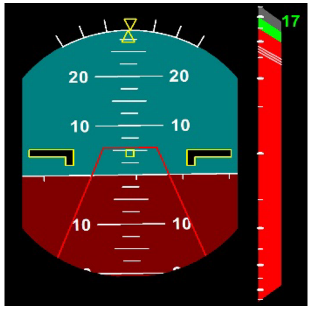
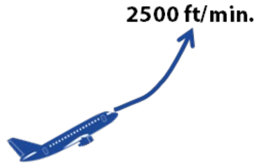
7.1 TA, single threat RAs, and RA termination

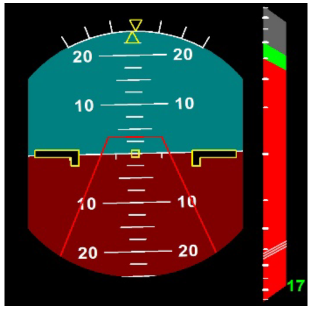
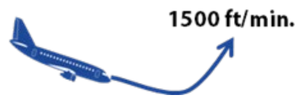
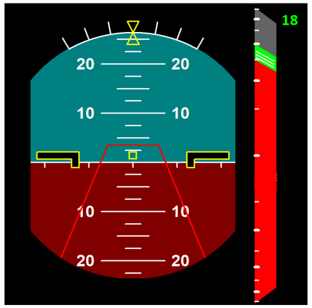
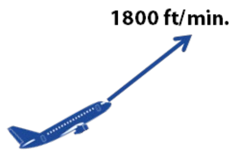
TCAS II version 7.1 and ACAS Xa advisories in single threat encounters and associated aural annunciations are shown in Table 7 below. Generic IVSI and EFIS displays depict how an advisory will be presented to the pilot (individual implementations may vary in detail). The required manoeuvre while responding to an advisory is shown in the last column. For information regarding ACAS Xu and ACAS sXu RAs see Sections 13.4 and 14.2 respectively.

Table 7: TCAS II version 7.1 and ACAS Xa single threat advisories.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Traffic Advisory[74]	Traffic, traffic (TCAS II ver. 7.1) Traffic, traffic (ACAS Xa)			No manoeuvring

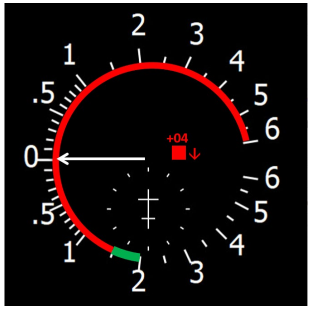
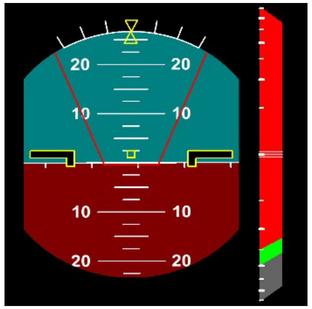
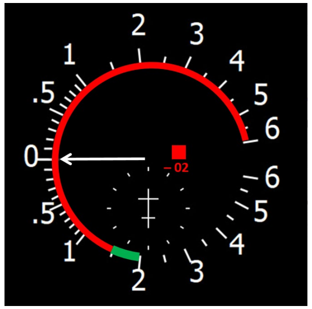
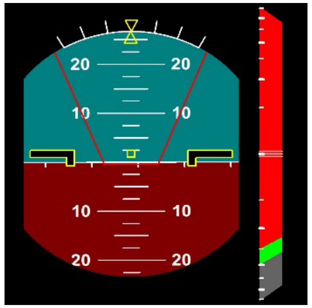
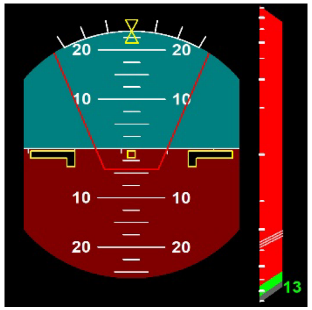
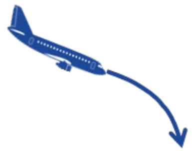
[74] In case of a TA generated against a Non-Altitude Reporting (NAR) intruder (see Section 6.11) neither altitude label nor trend arrow will be shown (see Figure 24). A dedicated TA symbol will be used if the TA is generated against an ADS-B only track (AOTO mode, see Section 12.2.5).

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Climb	Climb, climb TCAS II ver. 7.1			
	Climb, climb ACAS Xa			
Crossing Climb	Climb, crossing climb; climb crossing climb TCAS II ver. 7.1			
	Climb, crossing climb; climb crossing climb ACAS Xa			
Increase Climb Not possible as an initial RA	Increase climb, increase climb TCAS II ver. 7.1			
	Increase climb, increase climb ACAS Xa			

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Reversal Climb Not possible as an initial RA	Climb, climb NOW; climb, climb NOW **TCAS II ver. 7.1** Climb, climb NOW; climb, climb NOW **ACAS Xa**			
Reversal Climb Issued while climbing, i.e., Maintain Climb[75] Not possible as an initial RA	Maintain vertical speed, maintain[76] **TCAS II ver. 7.1** Climb, climb NOW; climb, climb NOW **ACAS Xa**			

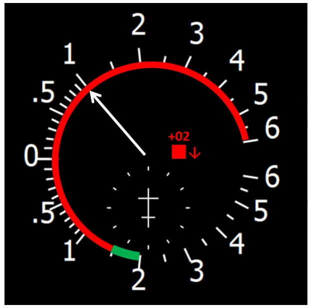
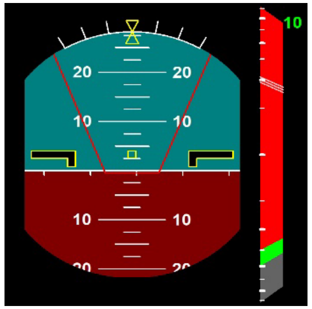
[75] An RA can reverse to climb while the aircraft is climbing, if the pilot has not yet responded to the previous downwards RA. The word "*NOW*" is not used. This RA only occurs when the aircraft is already climbing at 1500 ft/min. or more. The green arc will span around the current vertical rate.

[76] The aural annunciation could also be "*Maintain vertical speed, crossing maintain*" if the altitude of the intruder is to be crossed.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Descend	Descend, descend **TCAS II ver. 7.1**			 1500 ft/min.
	Descend, descend **ACAS Xa**			
Crossing Descend	Descend, crossing descend; descend crossing descend **TCAS II ver. 7.1**			 1500 ft/min.
	Descend, crossing descend; descend crossing descend **ACAS Xa**			
Increase Descent Not possible as an initial RA	Increase descent, increase descent **TCAS II ver. 7.1**			 2500 ft/min.
	Increase descent, increase descent **ACAS Xa**			

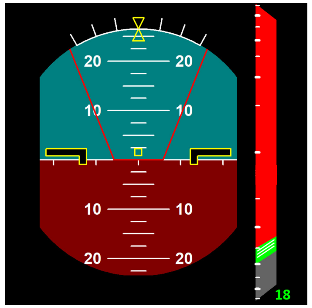
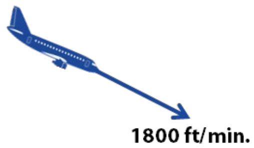
<table>
<tr><th>Advisory</th><th>Aural annunciation</th><th>IVSI</th><th>EFIS</th><th>Manoeuvre</th></tr>
<tr><td rowspan="2">Reversal Descent
Issued while climbing

Not possible as an initial RA</td><td>Descend, descend NOW;
descend, descend NOW

TCAS II ver. 7.1</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Descend, descend NOW;
descend, descend NOW

ACAS Xa</td></tr>
<tr><td rowspan="2">Reversal Descent
Issued while descending, i.e., Maintain Descent[77]

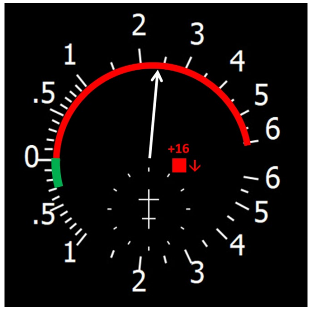
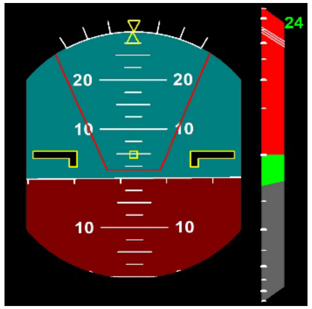
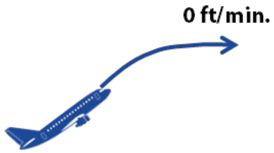
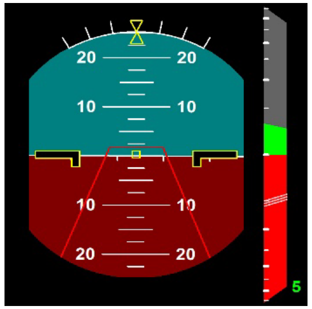
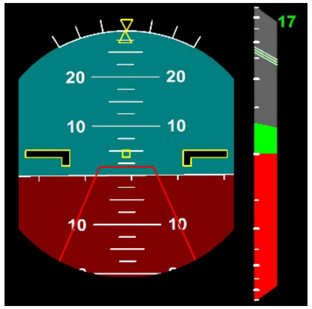
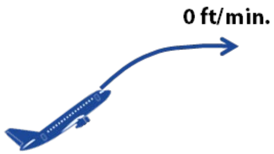
Not possible as an initial RA</td><td>Maintain vertical speed, maintain[78]

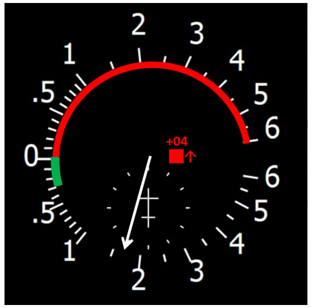
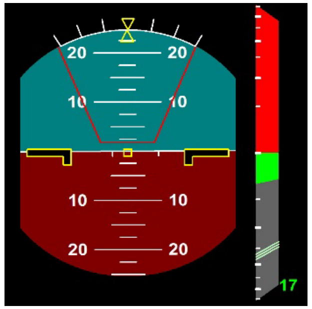
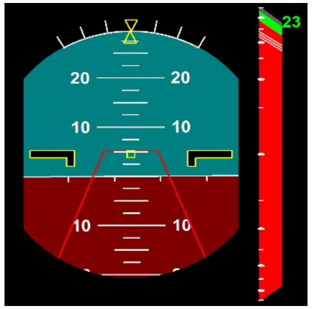
TCAS II ver. 7.1</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Descend, descend NOW;
descend, descend NOW

ACAS Xa</td></tr>
</table>

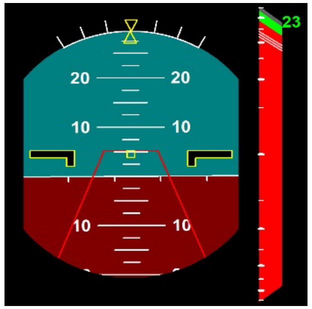
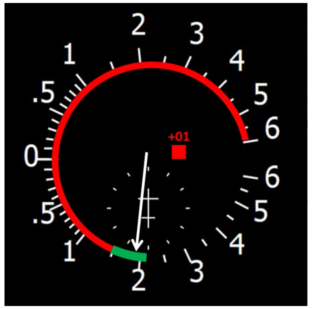
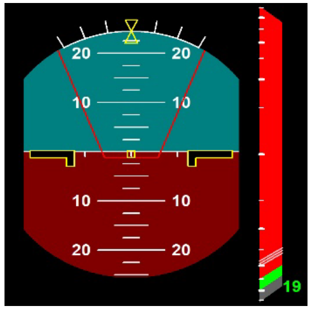
[77] An RA can reverse to descent while the aircraft is descending, if the pilot has not yet responded to the previous upwards RA. The word "*NOW*" is not used. This RA only occurs when the aircraft is already descending at 1500 ft/min. or more. The green arc will span around the current vertical rate.

[78] The aural annunciation could also be "*Maintain vertical speed, crossing maintain*" if the altitude of the intruder is to be crossed.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Level Off (Do Not Climb) Initial downward RA issued while climbing	Level off, level off **TCAS II ver. 7.1** Level off, level off **ACAS Xa**			
Level Off (Do Not Descend) Initial upward RA issued while descending	Level off, level off **TCAS II ver. 7.1** Level off, level off **ACAS Xa**			
Level Off (Do Not Climb) Weakening downward RA issued after climb Not possible as an initial RA	Level off, level off **TCAS II ver. 7.1** Level off, level off **ACAS Xa**			

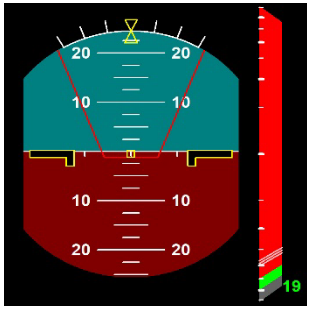
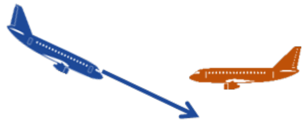
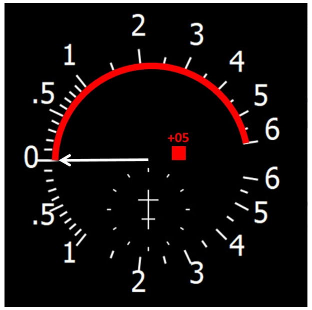
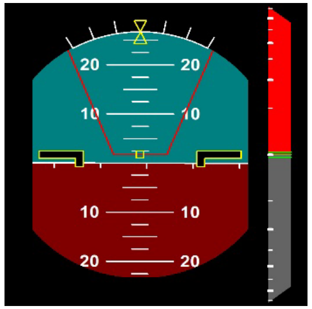
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Level Off (Do Not Descend) Weakening upward RA issued after descent Not possible as an initial RA	Level off, level off **TCAS II ver. 7.1** Level off, level off **ACAS Xa**			 **0 ft/min.**
Maintain Vertical Speed Issued while climbing (upward), i.e., Maintain Climb[79]	Maintain vertical speed, maintain **TCAS II ver. 7.1** Climb, climb **ACAS Xa**			**1500-4400 ft/min.** 

[79] This RA only occurs when the aircraft is already climbing at 1500 ft/min. or more. The green arc will span around the current vertical rate.

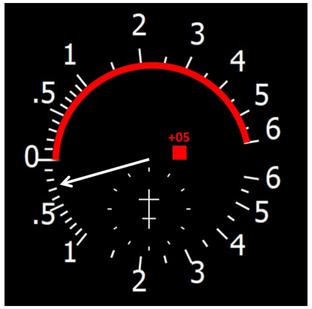
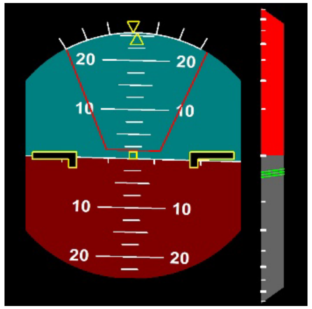
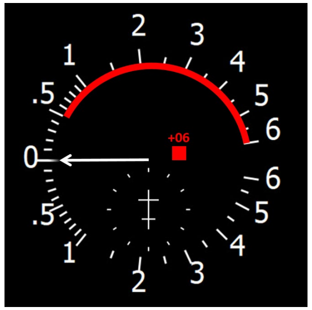
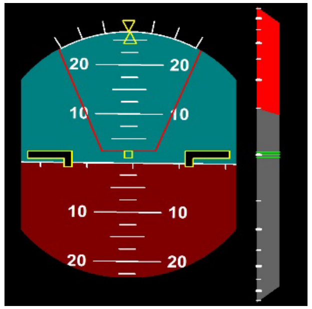
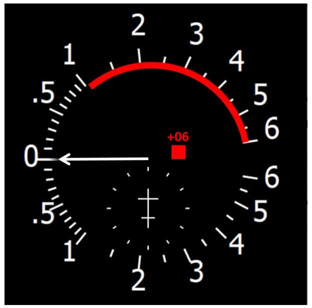
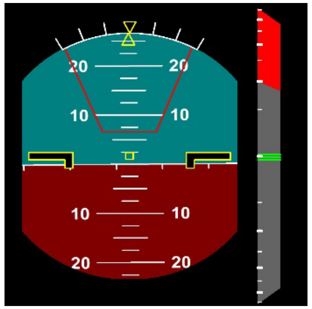
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Crossing Maintain Vertical Speed Issued while climbing (upward), i.e., Maintain Crossing Climb[80]	Maintain vertical speed, crossing maintain **TCAS II ver. 7.1** Climb, crossing climb; climb crossing climb **ACAS Xa**			 **1500-4400 ft/min.**
Maintain Vertical Speed Issued while descending (downward), i.e., Maintain Descent[81]	Maintain vertical speed, maintain **TCAS II ver. 7.1** Descend, descend **ACAS Xa**			 **1500-4400 ft/min.**

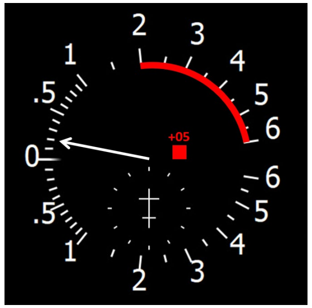
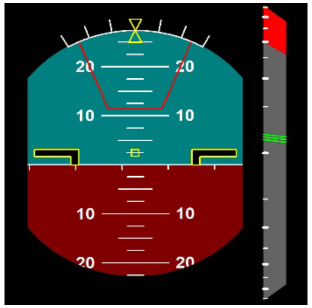
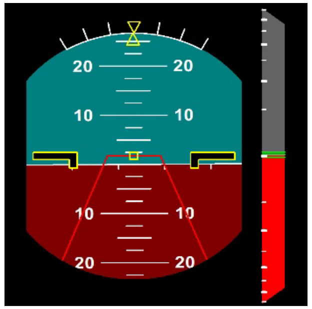
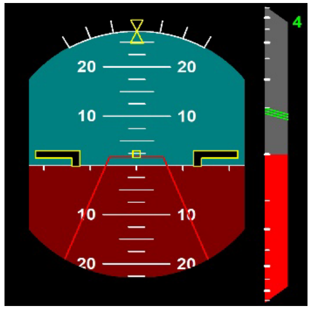
[80] This RA only occurs when the aircraft is already climbing at 1500 ft/min. or more. The green arc will span around the current vertical rate. The altitude of the intruder will be crossed.

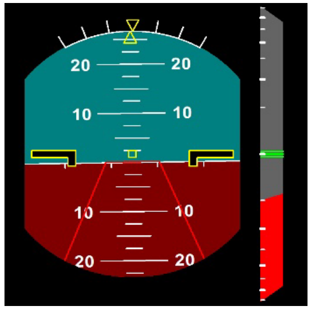
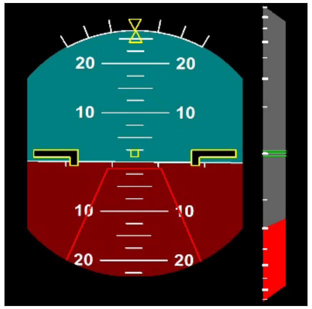
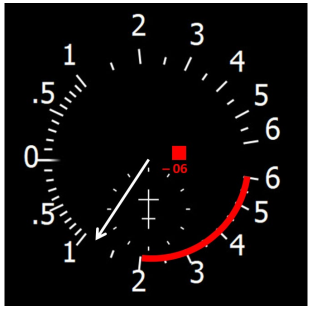
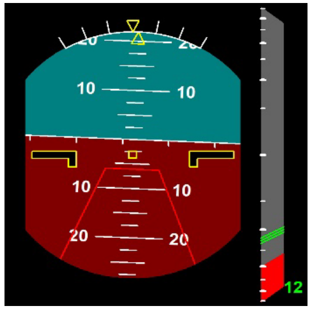
[81] This RA only occurs when the aircraft is already descending at 1500 ft/min. or more. The green arc will span around the current vertical rate.

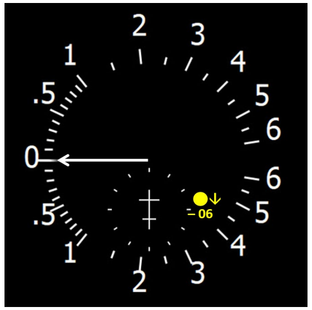
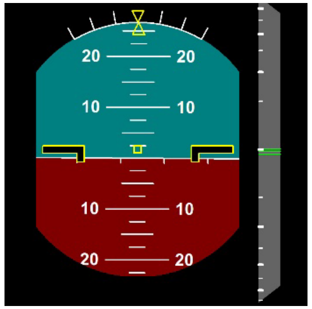
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Crossing Maintain Vertical Speed Issued while descending (downward), i.e., Maintain Crossing Descent[82]	Maintain vertical speed, crossing maintain **TCAS II ver. 7.1** Descend, crossing descend; descend, crossing descend **ACAS Xa**			 **1500-4400 ft/min.**
Do Not Climb Downward preventive RA	Monitor vertical speed **TCAS II ver. 7.1** Monitor vertical speed **ACAS Xa**			No manoeuvre required. Climb is prohibited.

[82] This RA only occurs when the aircraft is already descending at 1500 ft/min. or more. The green arc will span around the current vertical rate. The altitude of the intruder will be crossed.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Do Not Climb Weakening downward RA issued after Maintain Descent RA Not possible as an initial RA ACAS Xa only	n/a **TCAS II ver. 7.1** Monitor vertical speed **ACAS Xa**			No manoeuvre required. Climb is prohibited
Limit Climb 500 ft/min. Downward preventive RA TCAS II ver. 7.1 only	Monitor vertical speed **TCAS II ver. 7.1** n/a **ACAS Xa**			No manoeuvre required. Climb with the rate greater than 500 ft/min. is prohibited.
Limit Climb 1000 ft/min. Downward preventive RA TCAS II ver. 7.1 only	Monitor vertical speed **TCAS II ver. 7.1** n/a **ACAS Xa**			No manoeuvre required. Climb with the rate greater than 1000 ft/min. is prohibited.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Limit Climb 2000 ft/min. Downward preventive RA TCAS II ver. 7.1 only	Monitor vertical speed **TCAS II ver. 7.1** n/a **ACAS Xa**			No manoeuvre required. Climb with the rate greater than 2000 ft/min. is prohibited.
Do Not Descend Upward preventive RA	Monitor vertical speed **TCAS II ver. 7.1** Monitor vertical speed **ACAS Xa**			No manoeuvre required. Descent is prohibited.
Do Not Descend Weakening upward RA issued after Maintain Climb RA Not possible as an initial RA ACAS Xa only	n/a **TCAS II ver. 7.1** Monitor vertical speed **ACAS Xa**			No manoeuvre required. Descent is prohibited.

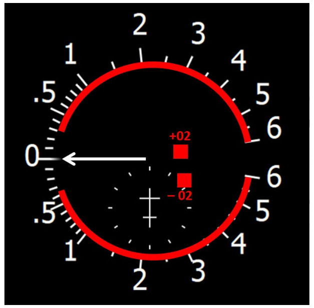
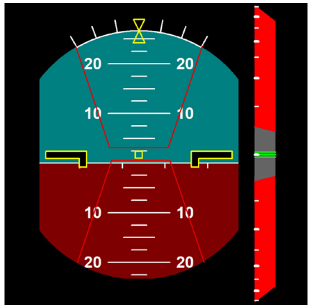
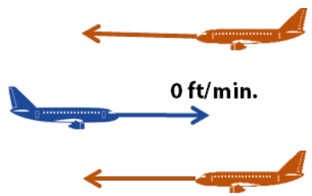
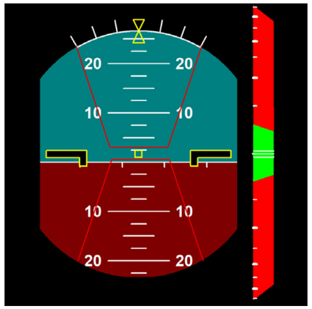
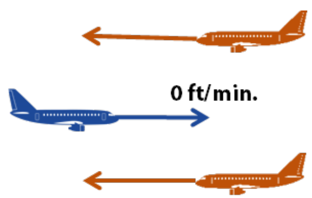
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Limit Descent 500 ft/min. Upward preventive RA TCAS II ver. 7.1 only	Monitor vertical speed TCAS II ver. 7.1 n/a ACAS Xa			No manoeuvre required. Descent with the rate greater than 500 ft/min. is prohibited.
Limit Descent 1000 ft/min. Upward preventive RA TCAS II ver. 7.1 only	Monitor vertical speed TCAS II ver. 7.1 n/a ACAS Xa			No manoeuvre required. Descent with the rate greater than 1000 ft/min. is prohibited.
Limit Descent 2000 ft/min. Upward preventive RA TCAS II ver. 7.1 only	Monitor vertical speed TCAS II ver. 7.1 n/a ACAS Xa			No manoeuvre required. Descent with the rate greater than 2000 ft/min. is prohibited.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
RA Termination	Clear of conflict TCAS II ver. 7.1 Clear of conflict ACAS Xa			Return to the last ATC clearance.

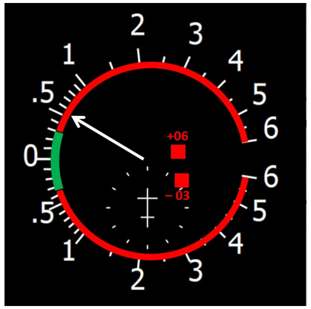
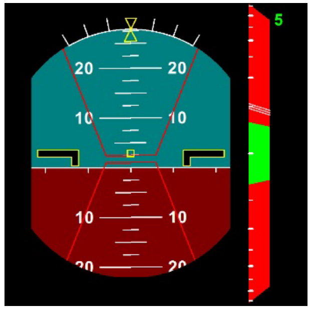
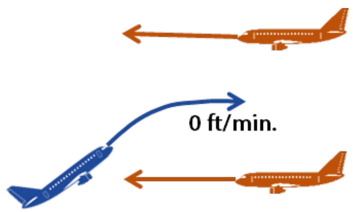
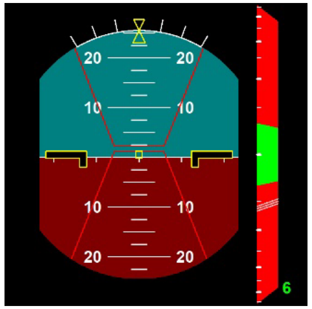
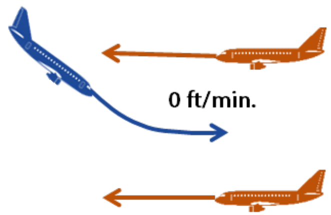
7.2 Multi-threat RAs

Examples of TCAS II version 7.1 and ACAS Xa RAs in multi- threat encounters and associated aural annunciations are shown in Table 8 below. Generic IVSI and EFIS displays depict how an advisory will be presented to the pilot (individual implementations may vary in detail). The required manoeuvre while responding to an advisory is shown in the last column. For information regarding ACAS Xu and sXu RAs see Sections 13.4 and 14.2 respectively.

Table 8: TCAS II version 7.1 and ACAS Xa multi-threat advisories.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Initial preventive RA in multi-threat encounter. Do Not Climb and Do Not Descend Red arc ranges may vary depending on the encounter geometry. TCAS II ver. 7.1 only	Monitor vertical speed **TCAS II ver. 7.1** n/a **ACAS Xa**			
Maintain existing null vertical speed[83] Issued while level	Maintain vertical speed, maintain **TCAS II ver. 7.1** Level off, level off **ACAS Xa**			

[83] If the maintain rate RA will cause the TCAS II equipped aircraft to cross through the intruder aircraft's altitude, the RA will be classified as a crossing RA and, consequently, the aural annunciation will be "*Maintain Vertical Speed, Crossing Maintain*". The word "crossing" will not be added to the Level Off annunciation for ACAS Xa.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Multi-threat encounter Issued while climbing	Level off, level off **TCAS II ver. 7.1** Level off, level off **ACAS Xa**			
Multi-threat encounter Issued while descending	Level off, level off **TCAS II ver. 7.1** Level off, level off **ACAS Xa**			

8. ACAS II FUNCTIONAL DESCRIPTION

8.1 Independent system

The main operational goal of ACAS II is to prevent midair collisions, acting independently of any ground-based systems, aircraft navigation and flight management systems. While assessing threats, in order to maintain its independence, ACAS II does not take into account the ATC clearance, pilot's intentions nor flight management systems inputs. ACAS II operates in all types and classes of airspace.

ACAS II is not designed to prevent losses of, nor to restore ATC separation, but to act as a last resort safety net to prevent midair collisions. Therefore, conflict resolution advice given by ACAS II will achieve, in the majority of cases, vertical spacing much lower than the standard ATC vertical separation. Moreover, the main ACAS II alerting criteria are time-based, not distance-based like most ATC separation standards. The alerting timing used by ACAS II ensures that errors in altimetry and delays in pilot responses will not compromise the safety provided by ACAS II.

8.2 RA inhibitions

8.2.1 Low level inhibitions

For all aircraft, pre-defined limitations apply at lower altitudes to prevent ACAS II alerts in proximity to the ground (to minimise the risk of collision with terrain or crew distraction in critical flight phases). Alerts are inhibited based on radar/radio altimeter reported heights above the ground level (AGL), see Table 9 and Figure 28. 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). For aircraft in a level flight, the +100 feet will be if their last vertical movement was a climb and –100 feet if a descent.

Increase Descent RAs are inhibited below 1550 feet AGL and Descend RAs are inhibited below 1100 feet while all RAs are inhibited below 1000 feet. When the aircraft passes below the inhibition altitude, the inhibited RA will be changed to a less strong RA in the same vertical sense (for example, Increase Descent RA will change to Descend RA and Descend RA will change to Monitor Vertical Speed RA). If the threat is still present, at 1000 feet any active RA will be terminated without the Clear of Conflict annunciation and changed to a TA (without a TA aural annunciation). See Table 10 for summary of TAs and RAs inhibitions.

TAs can be issued all the way to the ground; however, all aural annunciations will be inhibited below 500 feet AGL. For TCAS II, TAs against airborne intruders can be generated even when own aircraft is on the ground while for ACAS Xa these intruders will only be displayed as Other or Proximate traffic.

ACAS II will automatically fail if the input from the aircraft's barometric altimeter, radar/radio altimeter or transponder is lost. If there is no radar/radio altimeter input, RAs will be issued without the inhibits that are normally activated by proximity to the ground.

Table 9: ACAS II alert generation inhibitions.

Alert type	Inhibition altitude
Increase Descent RA	Inhibited below 1550 feet (±100 feet) AGL
Descend RA	Inhibited below 1100 feet (±100 feet) AGL
All RAs	Inhibited below 1000 feet (±100 feet) AGL
TA aural alerts	Inhibited below 500 feet (±100 feet) AGL
ACAS Xa only: TAs against airborne intruders	On the ground displayed as Other or Proximate Traffic

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

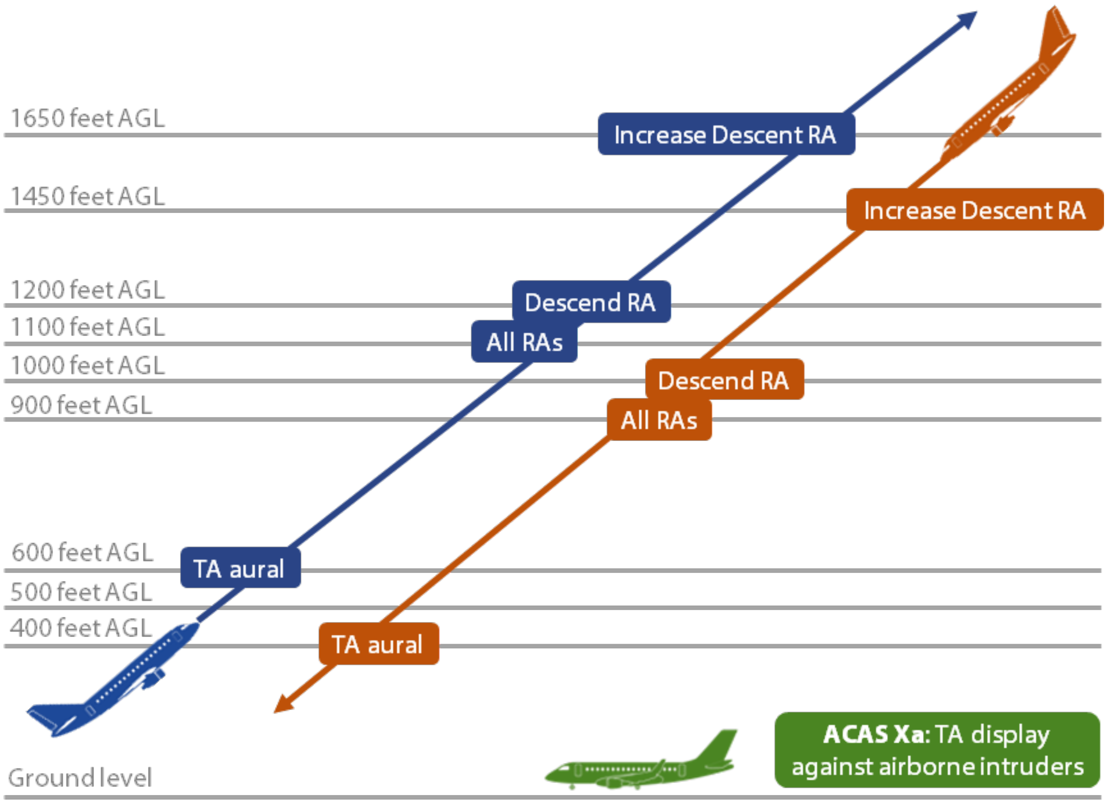


Figure 28: Illustration of ACAS II alert inhibitions.

8.2.2 Priority alert inhibitions

Some higher priority flight alerts, like GPWS, TAWS or wind shear detection warning take precedence over ACAS II alerts. When GPWS, TAWS or wind shear detection warnings have been activated, ACAS II will automatically be placed into TA-only mode with TA aural annunciation suppressed. Any RAs active at the time will be terminated, removed and replaced by a TA. ACAS II 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. See Table 10 for summary of TAs and RAs inhibitions.

Table 10: TA and RA inhibitons at low altitudes and during priority alerts.

	TA displayed	TA announced	RA displayed	RA announced
Below 550 feet AGL	✓	✗	✗	✗
Between 550 and 1000 feet AGL	✓	✓	✗	✗
Above 1000 feet AGL*	✓	✓	✓	✓
GPWS/TAWS/wind shear alert present	✓	✗	✗	✗
For 10 sec. after GPWS/TAWS/wind shear alert termination	✓	✓	✗	✗

* Some RAs are already inhibited below 1650 feet AGL. See Figure 28.
Note: all AGL altitude are +/- 100 feet.

8.2.3 Inhibition of Climb or Increase Climb RAs

TCAS II 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 inhibits are set in TCAS II hardware (programming pins) during installation. TCAS II compliant systems include provisions for these inhibits to be set in real time via inputs from a flight management system, but this feature is implemented on only a limited number of aircraft.

This feature is not used in ACAS Xa.

8.2.4 Aircraft performance considerations

In TCAS II, Climb and Increase Climb RAs are inhibited above certain altitudes and in some landing configurations if adequate performance does not exist to comply with these types of RAs. The decision regarding whether an aircraft type will have such inhibits set is made during the collision avoidance system certification on each aircraft type.

This feature is not used in ACAS Xa.

8.3 ACAS-ACAS coordination

8.3.1 TCAS II and ACAS Xa

In an ACAS-ACAS encounter (i.e., an encounter between two aircraft each equipped with TCAS II or ACAS Xa), own aircraft sends a message containing Vertical Resolution Advisory Complement (VRC) to the threat. The VRC contains a negative command, e.g., “do not pass above”. Before selecting an RA, ACAS II first checks if it has received a VRC from the threat. If no VRC has been received, the logic will select the optimum RA based on the encounter geometry. If the VRC has been received, own aircraft will select an RA complementary to the RA of the threat (i.e., in the opposite vertical sense).

Once an RA has been issued, each aircraft transmits ‘interrogations’ to the other aircraft via the Mode S data link in the form of a Resolution Advisory Complement (RAC) which contains a VRC. The receiving aircraft notes the RAC interrogation but does not reply. VRCs are sent in order to ensure the selection of complementary RAs by restricting the choice of manoeuvres available to the ACAS II receiving the RAC.

Coordination[84] interrogations are transmitted and received by aircraft's Mode S transponder 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). ACAS Xa is able to transmit coordination information in an ADS-B message to allow coordination with future collision avoidance systems that will not have 1030 MHz reception capability. See also Section 10.5 on air-ground and air-air communications.

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 not[85]. After coordinating, each ACAS II unit independently selects the RA's strength in relation to the conflict geometry.

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

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

Occasionally, the two aircraft may happen to see each other as a threat simultaneously 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 reversal RAs see Section 6.3.

In multi-aircraft encounters, when RAs are generated against several threats simultaneously, the negotiation of complementary RAs involves only two aircraft at a time, i.e., the coordination takes place with each ACAS-equipped threat individually.

8.3.2 ACAS Xu coordination

As ACAS Xu provides both vertical and horizontal RAs, the coordination message transmitted by ACAS Xu contains independent vertical and horizontal components. A threat aircraft with only a vertical RA capability (i.e., TCAS II or ACAS Xa), will only coordinate vertically with ACAS Xu.

For more information about ACAS Xu coordination see Section 13.5.

---

[84] The use of the term 'coordination' may be considered misleading, as it implies a process of negotiation. In reality, ACAS II entails no genuine coordination, but merely a straightforward announcement of intent.

[85] Only Crossing Descend, Crossing Climb and Crossing Maintain Vertical Speed RAs (the latter in TCAS II version 7.1 only) 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).

8.3.3 Future collision avoidance systems

ACAS Xa and TCAS II are both intended for aircraft with performance characteristics allowing them to climb at 2500 ft/min. (i.e., to respond to strengthening RAs) and discrete interrogation and reply capabilities on 1030/1090 MHz. Such aircraft are considered to be peers of each other.

However, in the future, less capable aircraft or aircraft without a discrete 1030/1090 MHz capability might be equipped with collision avoidance systems. ACAS Xa includes provisions to enable ACAS Xa to coordinate RAs with such new collision avoidance systems. Capability information will be exchanged to announce the coordination schemes available to each aircraft. The options include using ADS-B instead of 1030/1090 MHz interrogation and reply for coordination messages, and also an announcement that an aircraft should not be considered a peer of other ACAS Xa or TCAS II aircraft.

8.4 ACAS-ACAS encounters

TCAS II monitoring indicates (see Section 16.2) that in the majority 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. Based on simulations, it is believed that the same will be the case in the future if one or both aircraft in conflict are equipped with ACAS Xa. 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).

8.5 Altitude source

When feasible, pilots should ensure that the altitude data source used by the Pilot Flying is also used to provide altitude information to ACAS II and the ATC transponders. Using a common altitude source limits unnecessary RAs due to differences between altitude data sources.

8.6 Threat detection limitations

8.6.1 Threat’s equipage

As ACAS 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 ACAS II are shown in Table 11 (intruder perspective) and Table 12 (own aircraft perspective). 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 ACAS II. However, RAs are coordinated only between ACAS 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 11: ACAS II levels of protection (intruder perspective).

Intruder	Own aircraft: TCAS II	Own aircraft: ACAS Xa
No transponder or non-ICAO standard transponder	No protection	No ACAS X protection
Mode A transponder only	No protection	No protection
ADS-B only	No protection	TA*
Mode A/C transponder with no altitude reports	TA (only below FL155)	TA (only below FL155)
Mode C or Mode S transponder	TA & RA	TA & RA
TCAS I	TA & RA	TA & RA
TCAS II/ACAS Xa TA-only mode	TA & RA	TA & RA
TCAS II/ACAS Xa	TA & coordinated RA	TA & coordinated RA

* Optional feature. See Section 12.2.5 for more information.

Table 12: ACAS II levels of protection (own aircraft perspective).

Own aircraft: TCAS II/ACAS Xa 	Intruder 	
Transponder off/not operational		No protection
TCAS II/ACAS Xa off/not operational		No protection
TA-only mode	No Mode A/C transponder	No protection
	Mode A/C transponder with no altitude reports	TA (only below FL155)
	ADS-B only	TA*
	Mode A/C transponder	TA
	TCAS II/ACAS Xa	TA
TA/RA mode	No Mode A/C transponder	No protection
	Mode A/C transponder with no altitude reports	TA (only below FL155)
	ADS-B only	TA*
	Mode A/C transponder	TA & RA
	TCAS II/ACAS Xa	TA & coordinated RA
During GPWS, TAWS or wind shear alert	No Mode A/C transponder	No protection
	Mode A/C transponder with no altitude reports	TA (with no aural annunciation)
	ADS-B only	TA*
	Mode A/C transponder	TA (with no aural annunciation) ***
	TCAS II/ACAS Xa	

* Optional feature, ACAS Xa only. See Section 12.2.5 for more information.
** For 10 seconds after a GPWS, TAWS or wind shear alert terminates, no RAs will be generated. New TAs will be generated and displayed but without an aural annunciation.
*** Any RAs active at the time of GPWS, TAWS or wind share alert generation will be terminated, removed and replaced by a TA. For 10 seconds after a GPWS, TAWS or wind shear alert terminates, no RAs will be generated. New TAs will be generated and displayed but without an aural annunciation.

Note: Alerts against TCAS I equipped intruders will be generated based on the operational status of their transponder.

8.6.2 Threat's speed and vertical rate

TCAS II is capable of tracking Mode C and Mode S targets and issue alerts (TAs and RAs), subject to the following limitations:

- Closing speeds of up to 1200 kt above FL100 and 500 kt below FL100;
- Relative altitude rates of up to 10,000 ft/min.;
- Within 14 NM of own aircraft;
- Within ±3000 feet and whenever possible within ±10,000 feet altitude relative to own aircraft.

ACAS Xa is capable of tracking and issuing alerts (TAs and RAs) against intruders with the closing speed over 1200 kt and relative altitude rates over 10,000 ft/min.

8.7 ACAS II pressure setting

For the determination of collision avoidance resolution, ACAS II always utilises pressure altitude information which relates to the standard pressure (altimeter setting 1013.25 hPa or 29.92 inches of mercury)[86]. ACAS 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 ACAS II system at all[87]. As illustrated in an example below (Figure 29), one aircraft is flying at FL60 (i.e., on the standard altimeter setting 1013.25 hPa), while the other aircraft is at the altitude of 5000 feet using QNH altimeter setting of 977 hPa (effectively FL60). Although they may appear to be separated, ACAS II will compare their Flight Levels to determine any collision risk.

Additionally, below 1750 feet ACAS II also uses radar/radio altimeter data to invoke TA/RA inhibitions due to proximity to the ground (see Section 8.2.1).

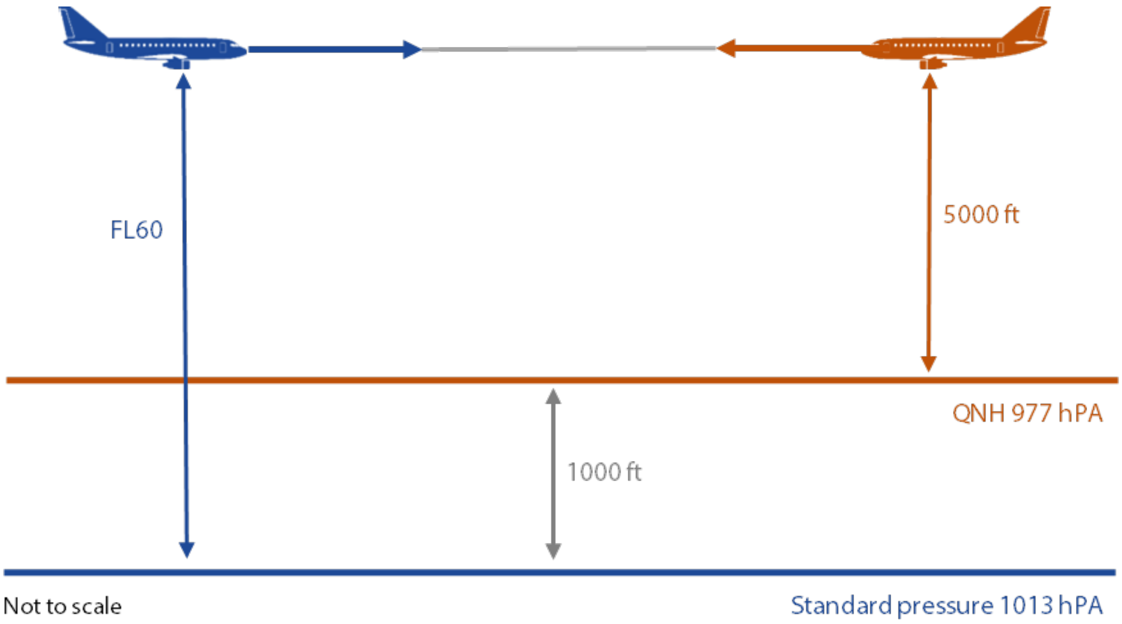


Figure 29: ACAS II altitude is by design referenced to the standard pressure setting.

---

[86] See SKYbrary for more information about altimeter pressure setting.

[87] Except some traffic displays which allow the crew to toggle between pressure corrected and standard pressure altitudes.

9. ACAS II OPERATIONS

9.1 Traffic Advisories

9.1.1 Pilot actions

The sole objective of a TA is to aid pilots with visual acquisition of an intruder and prepare them for a possible RA. No manoeuvres must be made in response to a TA. TAs are often generated when there is no loss of ATC separation. Chances are that a manoeuvre prompted by a TA may actually lead to a genuine loss of separation or RA which otherwise would not have occurred. Unless an RA has been issued, the pilot must comply with ATC instructions, including any given vertical rate and heading. **TAs are not 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.

Once a TA has been announced, pilots should attempt to establish visual contact with the intruder and other aircraft that may be in the vicinity. Pilots must not deviate from an assigned clearance (including ATC issued vertical rate instructions or headings) based only on TA information nor make horizontal manoeuvres based solely on information shown on the traffic display. Also, requesting ATC to provide traffic information is not recommended.

More information on Traffic Advisories:

ACAS Bulletin 16

9.1.2 Controller actions

TAs should not be reported to ATC, and no controller action is required if a controller becomes aware of a TA.

9.2 Resolution Advisories

9.2.1 Pilot actions

The objective of an RA is to achieve a safe vertical distance from a threat aircraft, rather than to ensure standard ATC separation. RAs are typically generated 15 to 35 seconds prior to the CPA (depending on altitude), although shorter generation times are possible in some geometries.

RAs can be generated before ATC separation minima are violated and even when ATC separation minima will not be violated[88]. In Europe, in over two-thirds of all RAs the ATC separation minima have not been violated at the time when the RA was issued.

In the event of an RA, pilots shall respond immediately by disconnecting the autopilot[89] 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 7 and Table 8). 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).

[88] Refer to ACAS Bulletin 27 for a description of close encounters where no RAs were generated, and ACAS Bulletin 28 for a case where RAs were generated without a loss of separation.

[89] An exception here is the Airbus AP/FD (Autopilot/Flight Director) TCAS capability. See Section 9.17.1 for more information.

If a decision is made not to respond to an RA, the flight crew negates the safety benefits provided by its own ACAS. Additionally, failing to respond reduces the safety benefits for 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 *¼ g*.

For reversal and increase (strengthening) RAs (see Sections 6.3 and 6.4 respectively), 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 ⅓ *g*.

Similar performance requirements are applicable to ACAS Xu equipped aircraft – see Section 13.4.4 for more information.

Practical advice on how to achieve the required acceleration is provided in European Union Aviation Safety Agency's (EASA) Guidance Material[90]: *"An acceleration of approximately ¼ 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 ⅓ 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 an ACAS II 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 II RA, particularly when the aircraft is less than 2500 feet above ground level (AGL).

Table 13 shows Traffic Display symbology and associated alerts and associated pilot actions. See Section 9.3 for information regarding RA reporting.

More information on RAs can be found in Sections 6.2 and subsequent.

[90] EASA Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Part-CAT, Annex to ED Decision 2012/018/R, initial issue 25 October 2012.

Table 13: ACAS II traffic display symbology and pilot associated actions.

Symbol	Traffic	Pilot	Vertical speed	ATC
	Other traffic*	Visual acquisition	Vertical speed reduction if traffic is at the level adjacent to the cleared level unless instructed by ATC to maintain a specific vertical rate or heading.	No ATC report
	Proximate traffic* Aircraft within 6 NM and 1200 feet of own aircraft			
	Traffic Advisory Typically generated 20-48 seconds before CPA	Visual acquisition Prepare for possible RA		
	Resolution Advisory Typically generated 15-35 seconds before CPA	Follow the RA as indicated by changing or maintaining the vertical speed	Vertical speed as required by the RA	Report the RA to ATC if it is causing a deviation from ATC clearance
	Clear of Conflict	Return to the original ATC clearance	As needed to return to the original clearance	Report to ATC returning to the original ATC clearance or seek alternative instructions

* Other and proximate traffic symbols can also be white.

9.2.2 Controller actions

Once the RA has been reported by the pilot, the controller must not attempt to modify the flight path of the aircraft involved in the encounter, including any level or heading changes. During an RA, cockpit workload is very high, and pilots should focus on responding to the RA. The controller must acknowledge the RA report with the standard phrase "*Roger*."

9.3 Interactions with ATC during RA

9.3.1 Responsibility for separation

An RA has important consequences for the responsibilities of pilots and air traffic controllers: 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, the controller must not 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).

9.3.2 Reporting RAs

RAs requiring a deviation from the current ATC clearance or instruction should be reported to ATC as soon as the aircrew's workload permits. If the controllers are not aware of the RA, they are also unaware of the change in the responsibility for providing separation. Therefore, RA reports to ATC should be timely and also they must clearly **specify the callsign and state unambiguously that the aircraft is responding to an RA** using the following phraseology[91]:

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

Reporting the sense (i.e., climb or descend) of the RA is not appropriate as it may change during the encounter.

The controller should acknowledge the receipt of the pilot TCAS RA report ("*Roger"*).

If the controllers are unaware of the RA, they are also unaware of the fundamental change in their task, that is, a shift from active control to merely monitoring the conflicting aircraft. Consequently, the controller might issue an instruction to an aircraft involved in an RA encounter. In the worst-case, this instruction might require the pilot to manoeuvre in a sense contrary to the RA.

It is equally important that pilots report to ATC when they receive an ACAS Clear of Conflict message. This report indicates to the controller that the RA is over and ATC must resume responsibility for providing separation. After a Clear of Conflict message has been posted by ACAS II, 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).

The Clear of Conflict report should be acknowledged by the controller, who may also provide an alternative clearance or instruction.

If an RA is terminated without a Clear of Conflict annunciation (see Section 6.10), the collision risk may persist. In such cases, flight crews are advised to continue monitoring surrounding traffic visually and seek advice from ATC.

If an ATC clearance or instruction contradictory to the RA is received (e.g., ATC instructs the pilot to descend while the RA is calling for climb), the pilot must follow the RA and inform ATC as follows:

[callsign] UNABLE, TCAS RA.

Any deviations from the standard phraseology may introduce uncertainties and confusion.

Note – the standard phraseology uses the term "*TCAS*" rather than "*ACAS*". TCAS II and ACAS Xa RAs are to be reported in the same manner; Figure 30 illustrates pilot-ATC radio exchanges during an RA.

---

[91] See Section 24.4.2 for the full text of ICAO PANS-ATM provision.

If requested by the crew, air traffic controllers should provide traffic information during the 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 (see Section 9.21). The implementation does not relieve the pilots from the responsibility of reporting RAs using the above-mentioned phraseology. ICAO has not published any provisions for operations of RA downlink.

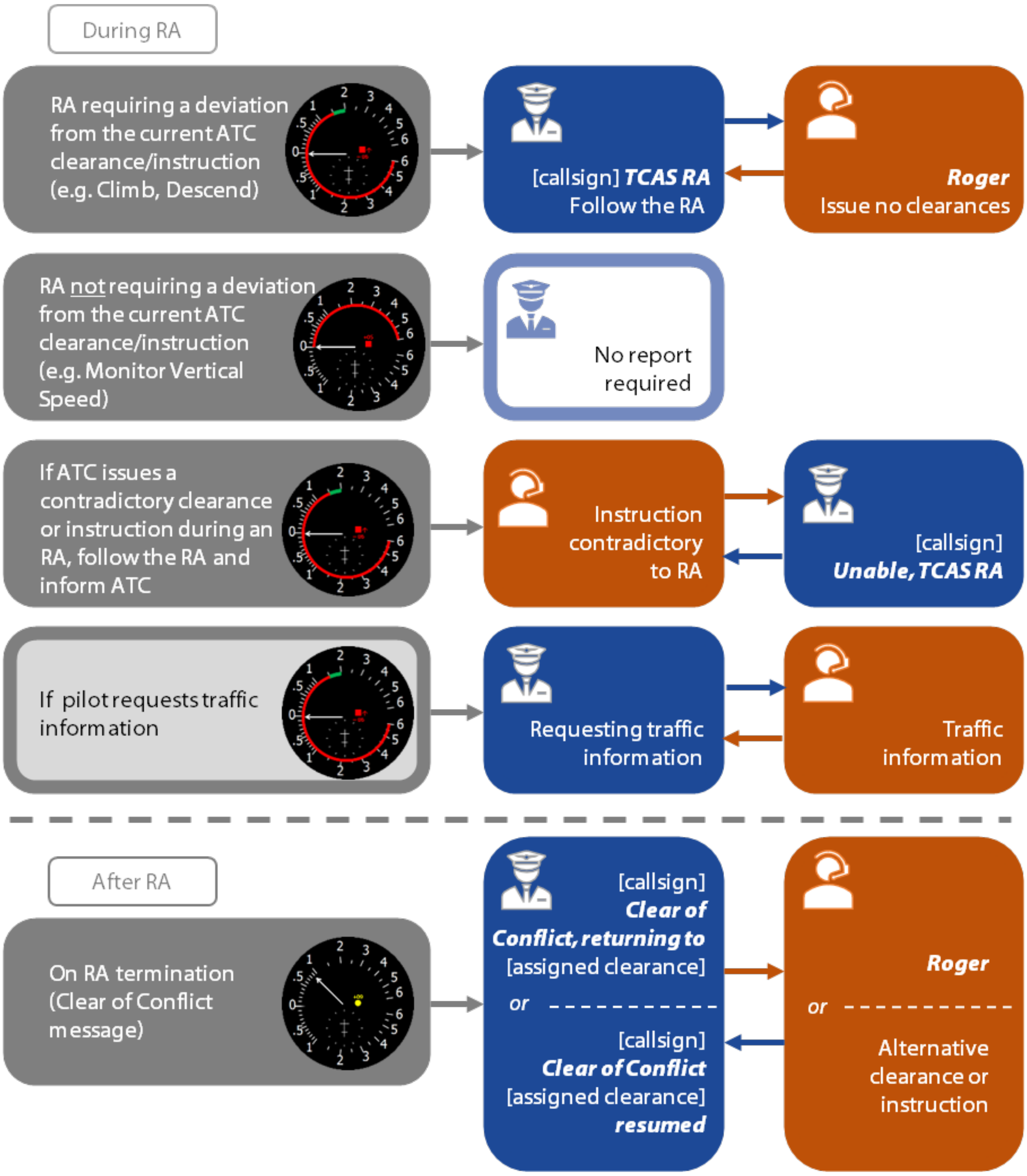


Figure 30: Pilot – ATC communication during and after an RA.

9.4 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. A typical example of a nuisance RA will be an RA in level off geometry when two aircraft are levelling off at adjacent flight levels, but RAs are generated as a risk of collision is diagnosed based on the closing speed and vertical rates (see Section 9.5 for more information).

An RA shall be considered a nuisance unless, at some point in the encounter in the absence of ACAS 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[92]. The evaluation of whether the RA is *nuisance* is impossible in real-time (i.e., during the event or shortly thereafter) and it can be done reliably in hindsight only through data analysis.

9.5 High vertical rates

The performance of modern aircraft allows pilots to climb and descend with high vertical rates. While this can provide operational benefits (i.e., fuel or time savings), it can become problematic when aircraft continue to climb/descend with a high vertical rate close to their cleared level. This is because RAs may be generated when a risk of collision is calculated based on the closing speeds and vertical rates as ACAS II does not know autopilot or flight management system inputs (see Figure 31). That may happen even when appropriate ATC instructions are being correctly followed by each crew. If, simultaneously, another aircraft is approaching an adjacent level, the combined vertical rates make RAs even more likely.

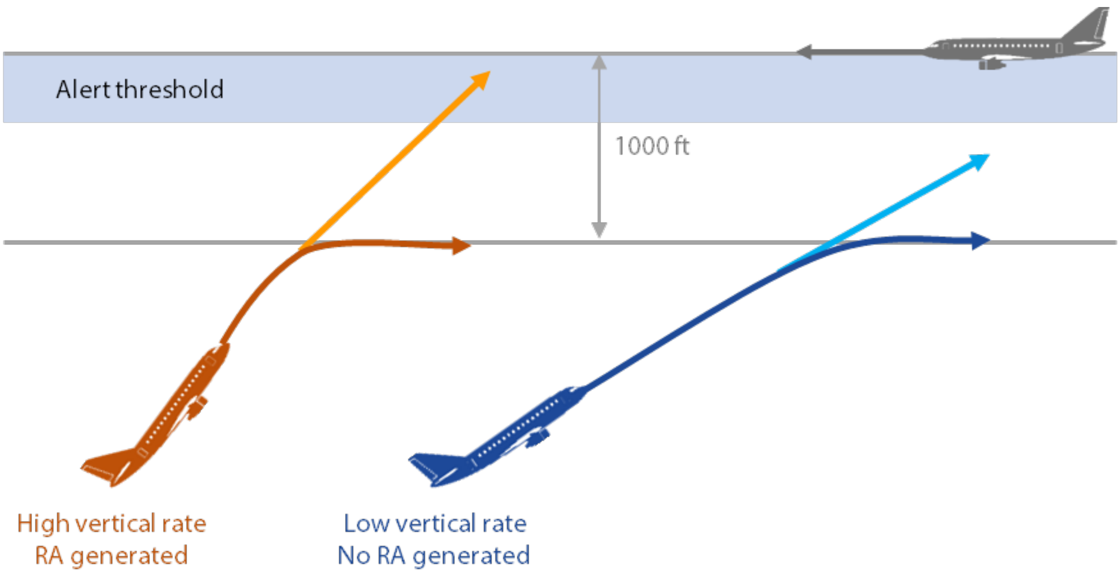


Figure 31: Approaching the cleared level with high vs. low vertical rate.

The majority of RAs occur within 2000 feet before level-off at the cleared level. Pilots and controllers often judge these RAs as operationally not required and refer to them as "nuisance" RAs. However, in real-time the pilot cannot (and should not) assess whether the RA is in fact operationally required.

More information on high vertical rates:

ACAS Bulletin 15

[92] ICAO Annex 10, Volume IV, 4.4.4.1.2.

ICAO Annex 6 (see Section 24.2) 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. Even when the ICAO vertical speed reduction recommendation are followed, in some geometries these RAs may occur.

However, pilots must comply with ATC vertical speed instructions which are used by air traffic controllers to ensure that all aircraft remain separated while traffic is flowing efficiently. Any deviation from ATC instructions can result in a loss of separation. If pilots are unable to comply with the instructions, ATC must be informed as soon as possible. A deviation from ATC clearance is authorised only in a response to RA.

More information on
ATC vertical rates instructions:

ACAS Bulletin 22

9.6 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[93] 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 Union 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 traffic[94].

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 own RAs.

9.7 Manoeuvring based on traffic display

The ACAS II traffic display (see Section 5.4) is provided for the purpose of assisting flight crews in the visual acquisition of aircraft in the vicinity and to improve their situational awareness. Due to its limited horizontal accuracy (see Section 5.4.5 for more information) it must be stressed that the traffic display is not suitable for self-separation, nor for sequencing (notwithstanding reported cases when the TCAS traffic display has been successfully used by pilots on the ground to prevent runway incursions).

More information on
traffic display:

ACAS Bulletin 6
ACAS Bulletin 32

In some case cases, flight crews make their own traffic assessment based on the traffic display information, and manoeuvre in anticipation of, or in contradiction to, ATC instructions. Such manoeuvres are inappropriate and could also be hazardous, as the traffic display indications can be misinterpreted as it provides only partial information because:

[93] See Section 24.5 for the full text of ICAO PANS-OPS provision.

[94] EASA Safety Information Bulletin 2013-11R1 of 20 January 2020 (ACAS II – Manoeuvres based on Visual Acquisition of Traffic).

- it has limited bearing accuracy (up to ±30° depending on the selected scale);
- it is based upon a moving reference[95];
- the flight crew will not be aware of the trajectory or intentions of other aircraft nor ATC instructions issued to them;
- it lacks track history and a speed vector (except some modern implementations);
- it lacks identity information (except some modern implementations);
- there is a risk that some aircraft in the vicinity might not be displayed;
- there is a risk that flight crew could attribute a target symbol to the wrong aircraft.

Consequently, avoidance manoeuvres based solely on the traffic display may create a problem or cause a situation to deteriorate.

It should be noted that ACAS II surveillance range is limited to 30 NM and 10,000 feet; however, in high-density airspace the ACAS II surveillance range might be reduced to as little as 5 NM to reduce undesired interference with other systems (without compromising the collision avoidance capability). Thus, not all aircraft in the vicinity will necessarily be shown on the traffic display.

9.8 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 ACAS 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 ACAS II and may render the other aircraft's ACAS II less effective than if own aircraft were not ACAS II equipped.

See Section 16.9.1 for statistical data concerning inappropriate pilot responses and Section 9.19 on investigations of ACAS II occurrences.

9.9 Closely spaced parallel approaches

As recommended by ICAO[96], when in the air ACAS 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[97]. However, the safety benefit provided by ACAS 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.

ACAS Xo (see Section 12.3) can prevent unwanted RAs during parallel approaches with runways 3000 feet apart or more.

[95] As the own aircraft itself is moving, the displacement of the intruder's symbol does not correspond to the intruder's actual ground track.

[96] See the quotes from ICAO PANS-OPS in Section 24.5 and ICAO ACAS Manual in Section 24.6.

[97] See Section 17.6 on unnecessary RAs during parallel approaches due to *tau*-cap mechanism.

9.10 RAs while aircraft is turning

Flying the RA is the highest priority. Therefore, if the aircraft is turning, and this makes achieving the required vertical rate difficult or impossible, the turn should be stopped (i.e., level the wings and fly the RA). RAs take precedence over any ATC instructions, clearances or a requirement to follow a specific route.

It may happen that stopping the turn will put own aircraft in closer horizontal proximity to the threat aircraft, but ACAS II is evaluating the situation every second and it will change the RA as required.

ICAO ACAS Manual (Doc 9863)[98] 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.*"

9.11 RAs at the maximum altitude

If an 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 airspeed will be traded for height. Some TCAS II equipped aircraft have built-in inhibits which will preclude Climb and Increase Climb RAs at maximum altitudes. Instead, a Do Not Descend RA (announced "*Monitor vertical speed*") will be issued. This functionality is not available for ACAS Xa.

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 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. If no response is possible, the pilot must never manoeuvre opposite to an RA.

9.12 TA-only mode operations

Under normal circumstances, the operating mode of ACAS II is TA/RA. In certain conditions and when approved by the applicable authority, it may be acceptable to operate with ACAS II in TA-only mode. That includes closely spaced parallel approaches and in the event of an inflight failure or performance limiting condition (that may include an engine failure or emergency descent, as specified by aircraft's operating manual).

Aircraft operating in TA-only mode will not benefit from safety protection offered by ACAS II (see Table 13), as no RAs will be generated against intruders equipped with altitude reporting transponders. Only visual and aural TA alerts will be provided. Additionally, an aircraft in TA-only mode will be treated by other ACAS II equipped aircraft as an intruder equipped only with an altitude-reporting transponder but without ACAS II.

More information on TA-only mode:

ACAS Bulletin 26

See Section 16.9.2 for statistical data concerning operations in TA-only mode.

[98] Para. 6.3.1.5 d).

9.13 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 temporarily inoperative. MEL provisions may also allow for operations with ACAS II out of service.

The circumstances under which that is allowed vary. According to the EASA Easy Access Rules for Generic Master Minimum Equipment List, ACAS II falls under Category C, i.e., the inoperative item shall be rectified within 10 calendar days, excluding the day of discovery. However, some local authorities and/or operators may introduce a more restrictive rectification deadline. For instance, in German airspace the time period during which ACAS II may be inoperative is reduced to 3 days[99]. This applies to all aircraft. It should be noted that although transponder rectification intervals are different, ACAS II will not function without an operational transponder.

Equipage and flight planning requirements are subject to change at any time. Aircraft operators should refer to the individual States authorities and/or publications (e.g., AIPs) for more information and up-to-date requirements.

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.

ATC authorities are not required to determine whether an aircraft is fitted with ACAS II, nor is it their role to monitor its serviceability. This is because ATC procedures applied to aircraft equipped with ACAS II are the same as those applied to non-equipped aircraft[100].

See Section 16.9.2 for statistical data concerning TCAS II serviceability.

9.14 ACAS II/transponder operations on the ground

Although there have been reported cases when the ACAS II traffic display had been successfully used by pilots on the ground to prevent runway incursions, it must be stressed that the traffic display has not been designed for operations on the ground.

Routine operation of ACAS II on the ground (with the transponder selected to TA-ONLY or TA/RA) can degrade surveillance performed by airborne ACAS II units and performance of ATC radars due to interference caused by superfluous Mode S interrogations. However, ACAS Xa uses ADS-B for surveillance, and active interrogation is not attempted when ACAS Xa is operating on the airport surface (i.e., it is known that own aircraft is on the ground).

When on the ground, ACAS II 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 ATC 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.

Procedures that allow the crew to select the operating mode where ACAS II is disabled, but the Mode S transponder remains active should be applied. The pilots should check and follow any procedures applicable to the given airport. In the absence of any specific local procedures, the pilots may turn ACAS 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 final. It should be noted that it may take several seconds to display traffic when turning ACAS II on (implementation dependent).

---

[99] German AIP GEN 1.5 para. 5 dated 7 October 2021.

[100] ICAO PANS-ATM Doc 4444, para 15.7.3.1 states: "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".

Until recently, generally recommended manual modes of ACAS II/transponder operations were as explained in and illustrated in Figure 32. However, the introduction of modern and more sophisticated cockpit automation makes these recommendations not generally applicable anymore. For instance, on Airbus A350 and A380 aircraft, in order to reduce crew's workload, a single-action default mode solution has been introduced that makes Mode S selective calling and mode ADS-B data broadcast operative at push-back, while Mode A and C remain inhibited. ACAS II is automatically turned on but remains in TA-only mode until the aircraft climbs through 1000 feet AGL after departure[101]. Above 1000 feet, ACAS II will automatically switch to TA/RA mode (i.e., providing full protection). Other automatic solution may be available for other aircraft types.

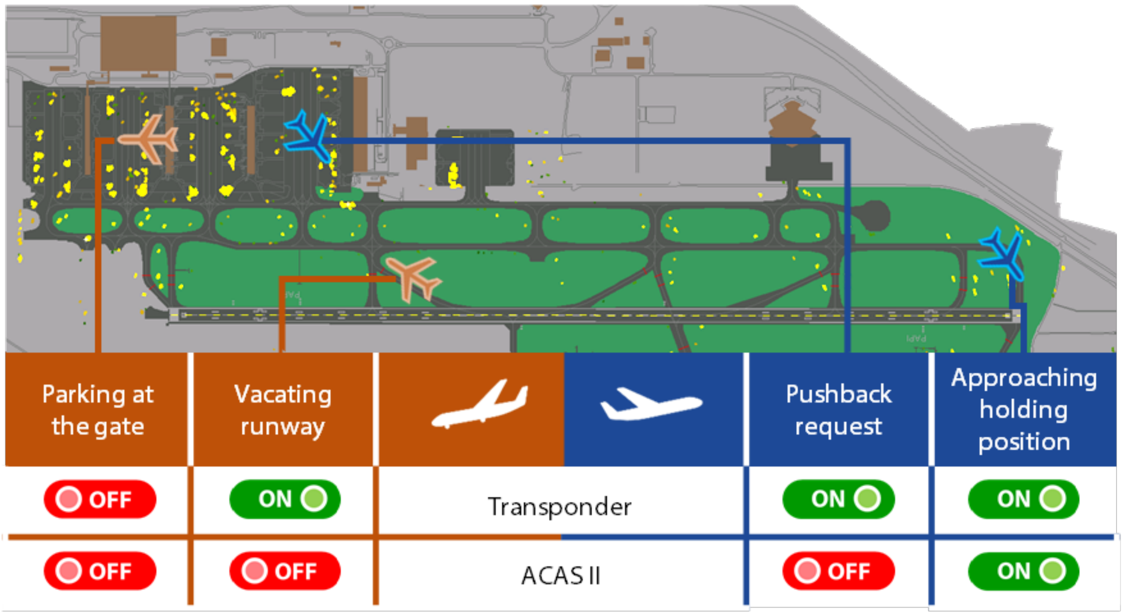


Figure 32: Manual ACAS II/transponder operation on the ground.

Note: not applicable to aircraft with systems automatically selecting transponder and ACAS II modes of operation.

9.15 Interceptions of ACAS II equipped aircraft

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

Special transponder operating procedures are needed in the case of interception, so the intercepted ACAS II equipped aircraft does not perceive the interceptor as a collision threat and does not perform manoeuvres in response to an RA. Such manoeuvres can be disruptive or might be misinterpreted by the interceptor as an indication of unfriendly intentions, depending on the reasons for the intercept.

ICAO provisions for interceptions and ACAS II operations are outlined in Annex 2, ACAS Manual (Doc 9863) and Manual Concerning Interception of Civil Aircraft (Doc 9433).

In the case of interception, two scenarios are to be considered:

- **demonstrative intercept** with a military escort mission; and
- **covert intercept,** i.e., an unexpected approach towards a selected target.

[101] RAs are inhibited below 1000 feet AGL.

9.15.1 Demonstrative interceptions

During demonstrative intercepts, it may be desirable to permit TAs but prevent RAs on the aircraft being intercepted. Therefore, the interceptor aircraft should disable barometric altitude reporting but leave all civil modes enabled. This will allow ACAS II on the intercepted aircraft to detect the interceptor, but only TAs can be generated. Ground-based ATC systems would also be able track the interceptor; however, without altitude information. TAs will be generated if the interception occurs below FL155, if above the interceptor will be visible on the ACAS II traffic displays of the aircraft being intercepted, but no TAs will be generated[102]. See Figure 33 below.

The interceptor aircraft should re-enable altitude reporting after completion of the intercept mission.

If the interceptor aircraft does not have a means to disable barometric altitude reporting, refer to Section 9.15.2.

Figure 33: Demonstrative interception of ACAS II equipped aircraft.

9.15.2 Covert interceptions

Covert interceptions will be undertaken if there is a concern regarding flight safety, like a prolonged loss of communications or unlawful interference.

During covert intercepts, the interceptor pilot should disable all civil transponder modes and ADS-B Out signal. This will ensure that the interceptor aircraft will not trigger ACAS II alerts (TAs or RAs) or other situational awareness alerts (on the ACAS II traffic display) on the intercepted aircraft. That should be done well outside the ACAS II tracking range (nominally 14 NM) and ADS-B In range (which is equipment dependent but can be significantly farther than ACAS II range). See Figure 34 below. It may be desirable for all civil transponder modes to be disabled prior to take-off of the interceptor.

It should be noted that with all civil modes disabled, the interceptor will not be visible to ground-based ATC systems (except primary radars) and ADS-B receivers.

This procedure will prevent the intercepted aircraft from performing evasive manoeuvres responding to an RA (caused by the interceptor) which could be interpreted as non-friendly actions by the interceptor pilot.

The interceptor aircraft should re-enable altitude reporting after completion of the intercept mission.

Figure 34: Covert interception of ACAS II equipped aircraft.

[102] For more information, see Section 6.11 on Non-Altitude Reporting intruders.

9.16 Military formation flights

Military aircraft often operate in formation (i.e., two or more aircraft flying close to each other). In a standard military formation, each aircraft remains within 1 NM horizontally and 100 feet vertically from the formation leader.

Only the lead aircraft (formation leader) should have their transponder switched on[103] to prevent undesirable effects on near-by ACAS-equipped aircraft (see Section 17.3) as well as on ATC radar systems (see Figure 35). If the lead aircraft is equipped with ACAS II, it should be the only aircraft in the formation operating ACAS II. If the lead aircraft is equipped with ACAS II, it should operate in the TA/RA mode. As all other aircraft in the formation operate with their transponders off; therefore, their ACAS II will not be operational[104].

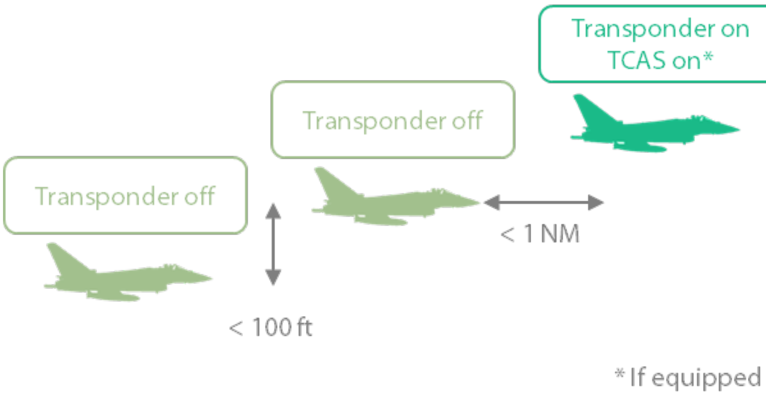


Figure 35: Transponder and ACAS II operations for formation flights.

9.17 Additional ACAS II capabilities

9.17.1 Airbus Autopilot/Flight Director (AP/FD) capability

The Airbus AP/FD (**A**uto**p**ilot/**F**light **D**irector) TCAS capability is a guidance mode which allows the aircraft to automatically fly the RA if the autopilot is engaged, or allows the pilot to hand fly the RA by following the flight director commands[105]. AP/FD TCAS is installed on all A350 and A380 aircraft and on all A320 family of aircraft produced since February 2017, and on all A330 aircraft produced since April 2012. AP/FD TCAS is not available for A340s. As of September 2021, 33% of A330s and 31% of A320 family of aircraft operated with AP/FD enabled[106].

At the time of writing, the AP/FD functionality is not yet available for ACAS Xa equipped aircraft.

By design, the AP/FD RA guidance performance is equivalent or better than manually flown RA manoeuvres.

[103] EUROCONTROL Specification for ECAC Area Rules for OAT-IFR, version 3.0, change 5, 6 November 2019, para. 2.4.3.2.

[104] Idem. Para 2.3.1.2.

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

[106] Source: Airbus – Safe Handling of TCAS Alerts.

A Flight Mode Annunciator (FMA) will indicate if the aircraft has the AP/FD function enabled by displaying the word **TCAS**. In this case, the flight crew can use the AP/FD TCAS function in either automatic or manual flight.

Once a TA has been generated, the Pilot Flying will announce to the other crew member(s) "*TCAS blue*", ensure that auto thrust is engaged, and prepare to either:

- Fly the potential RA manoeuvre using autopilot, or
- Manually fly the RA with flight director guidance.

When the AP/FD functionality is unavailable (either not installed or turned off), the pilot will disconnect both the autopilot and flight director once an RA is triggered and follow the RA procedure avoiding the red zone and moving to the green zone on the vertical speed scale.

If the AP/FD functionality is engaged when an RA is triggered, the pilot can either leave the autopilot on and monitor that the vertical speed reaches the green zone on the vertical speed scale, or manually follow the RA using flight director guidance.

If the aircraft is the normal flight envelope, in response to a corrective RA, the AP/FD RA mode will fly the aircraft towards a target vertical speed equal to the vertical speed prescribed by the RA with a margin of 200 ft/min. added on top the prescribed vertical speed to help flight crew to monitor the RA response. If the corrective RA prescribes a null vertical speed (e.g., a Level Off RA), the aircraft will fly towards a target vertical speed (i.e., 0 ft/min.).

In response to a preventive RA, which prohibited vertical speeds range is not equal to the current vertical speed, the aircraft will continue to fly the intended trajectory while maintaining the current vertical speed outside the range of forbidden vertical speeds. If aircraft's current vertical speed is within the range of RA's prohibited vertical speeds, the AP/FD mode will change the current vertical speed to be outside the range of forbidden vertical speeds, applying a 200 ft/min. margin.

While responding to a Monitor Vertical Speed RA, the AP/FD mode will still conduct any autopilot programmed altitude captures. See Figure 36.

The RA response manoeuvre starts with a delay of not more than 3, 4 or 5 seconds and accelerations of 0.15, 0.20 or 0.25 *g* respectively. These response parameters are applied to all RAs (i.e., including Increase and Reversal RAs).

When the RA is terminated, the AP/FD function will guide the aircraft to the selected altitude. All low level inhibitions are applicable (see Section 8.2.1).

On some aircraft equipped with an automatic emergency descent function, this function will disarm for the duration of the RA. After a Clear of Conflict message is posted, it will arm automatically again.

The AP/FD responses to RAs, should be reported to ATC, if causing a departure from ATC clearance (i.e., following the same principles as manually flown RAs described in Section 9.3).

The majority of aircraft equipped with AP/FD are also fitted with TCAP (see Section 9.17.2). However, the two are independent functions.

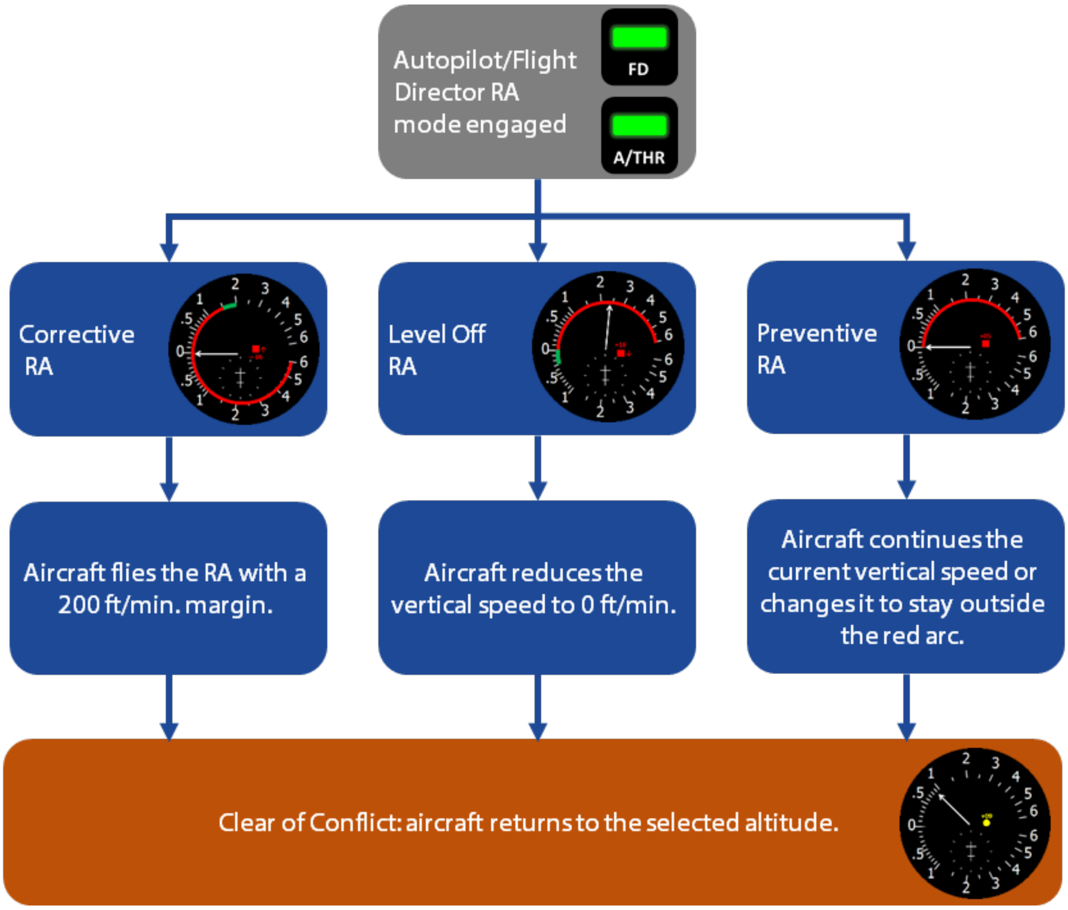


Figure 36: Airbus AP/FD mode.

9.17.2 Airbus TCAS Alert Prevention (TCAP) functionality

A TCAP (**TC**AS **A**lert **P**revention) functionality[107] has been introduced by Airbus to prevent the generation of RAs in 1000-foot level-off geometries. The TCAP functionality is installed on A350 aircraft and on A380 aircraft delivered since July 2013 and on all A320 family of aircraft produced since early 2021 as well as on all A330 aircraft produced since October 2017[108]. The functionality uses a new altitude capture law for flight guidance computers, which decreases aircraft's vertical rate when approaching the selected altitude, once a TA has been generated and the autopilot and/or flight director are engaged (see Figure 37).

At the time of writing, the TCAP functionality is not yet available for ACAS Xa equipped aircraft.

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

The majority of aircraft equipped with TCAP are also fitted with AP/FD (see Section 9.17.1). However, the two are independent functions.

If the flight crew is instructed by ATC to maintain a given vertical speed, action might be required by the crew at the time of TA to prevent the TCAP vertical speed reduction.

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

[108] Source: Airbus – Safe Handling of TCAS Alerts.

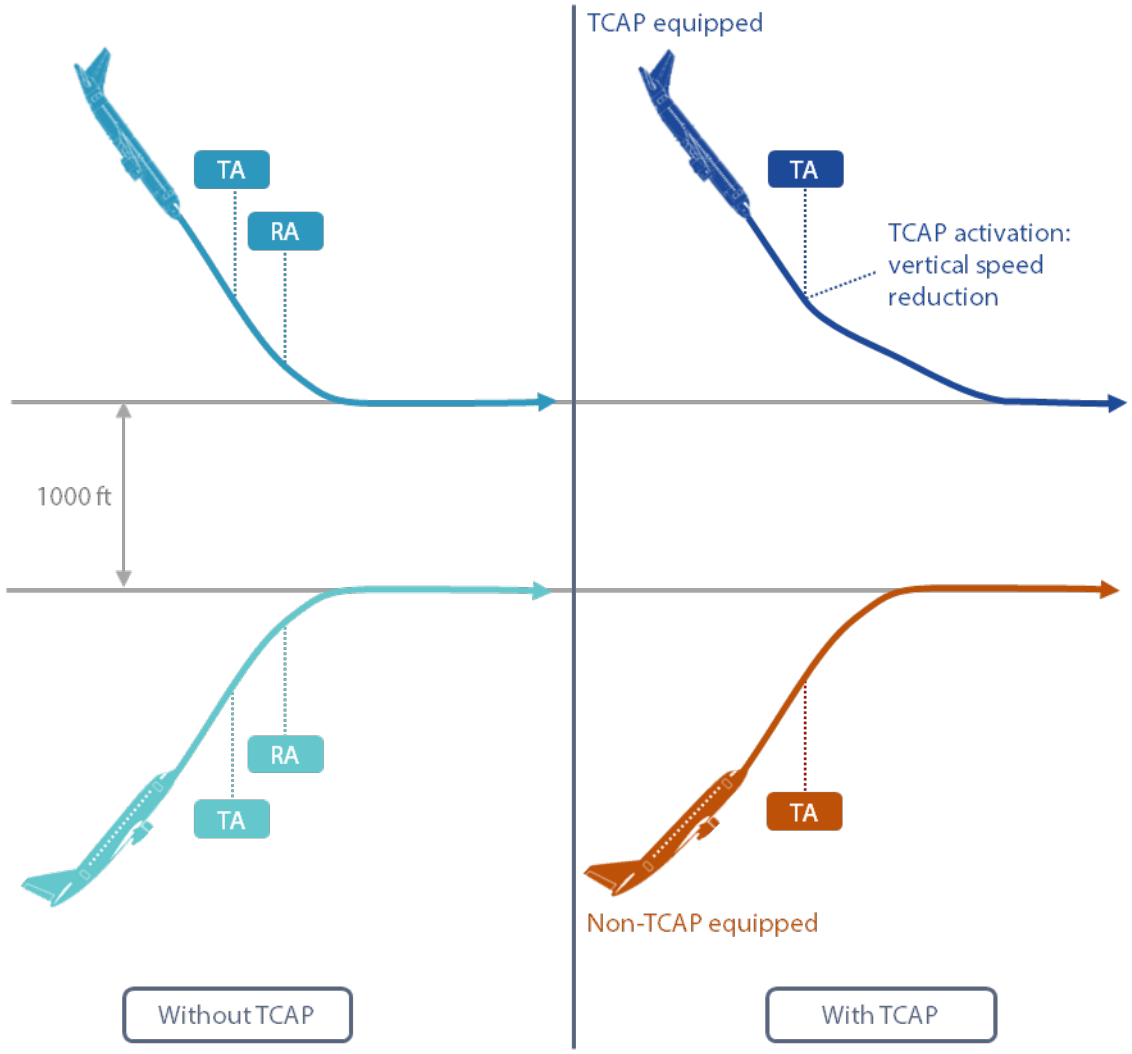


Figure 37: Illustration of an encounter without and with TCAP functionality.

9.18 ACAS II operational performance monitoring

ACAS II performance must be monitored to ensure it delivers its intended safety benefits and to identify any latent design flaws, as well as operational or training issues. The monitoring may also aid identification of airspace design issues, like "hot spots" (i.e., areas where RAs occur frequently).

The following technologies can be used to receive ACAS capability reports and RA downlinks on the ground:

- Mode S RA Report – Messages extracted by Mode S ground radar;
- RA Broadcast – Spontaneous broadcast of RA information, repeated every 1 second or 8 seconds, or upon an RA change;
- ACAS Coordination Message – Air-to-air messages exchanged between aircraft to coordinate an RA;
- 1090 Extended Squitter – Spontaneous broadcast of RA information, repeated every second.

The ACAS capability report provides details on the ACAS version and operational mode (off, TA-only, or TA/RA). Meanwhile, the RA downlink conveys information that helps determine the type of RA issued and identifies the other aircraft involved.

Intruder identification can be provided either through the intruder's Mode S address or by specifying its range and bearing.

RA downlink messages provide information on RAs as they occurred on the aircraft, with a latency of depending on the technology used.

The format for Mode S RA downlink messages is different for TCAS II, ACAS Xa, and ACAS Xu. Although, the same set of bits is used, they have been assigned differently. In order for the downlink messages to be interpreted correctly in the ground system, the type and version of ACAS II system must be derived from a Mode S downlink register.

TAs are not downlinked.

Aircraft operators can monitor the frequency of RAs as well as the quality of pilot responses to RAs, using Flight Data Monitoring, Flight Data Recorders, and dedicated ACAS recorders[109]. To assist aircraft operators in assessing pilot compliance[110] with RAs, IATA (International Air Transport Association) and EUROCONTROL have jointly published the Guidance Material RAs[111]. Additionally, a dedicated online tool is available on SKYbrary to facilitate these assessments by grading pilot responses to RAs.

9.19 Investigation of ACAS II occurrences

RAs are relatively infrequent and when they occur, they evolve quickly and may take pilots by surprise. Although pilots are trained to respond to RAs, these events are particularly stressful and involve heavy workload.

RAs are complex events involving multiple parties who, at the time of the event, do not have a complete picture or all the information concerning the event. Pilots can occasionally misinterpret the aural or visual warnings. Consequently, drawing conclusions on the usefulness or correctness of RAs can be reliably done only in hindsight through investigation and examination of:

> More information on investigating RAs:
>
> ACAS Bulletin 24

- radar recordings;
- RA downlink messages;
- airborne flight data recordings (Flight Data Recorders, Flight Data Monitoring, etc.);
- reports of the involved parties.

While assessing RA downlink messages, it should be considered that RAs are downlinked with latency corresponding to the rotation of the radar antenna. Therefore, the time of the downlinked RA does not necessarily correspond precisely to the time at which the RA occurred – the RA occurred within the time frame between the previous and current downlink messages (assuming flawless surveillance).

Furthermore, RA downlink messages can only be correctly interpreted if the type of ACAS II system sending the downlink message is known, as the format of RA downlink messages varies between TCAS II version 7.1 and ACAS Xa. The type of ACAS II system can also be derived from Mode S radar downlink messages.

[109] The quality of pilot responses to RAs can also be assessed using radar data; however, due to latency issues, this assessment is not as accurate as when using FDM.

[110] An illustrative example of an RA not being followed can be found in ACAS Bulletin 30.

[111] The Guidance Material is available from IATA. More information on SKYbrary.

Any assessment of the RA can be reliably done only in hindsight through investigation and examination of recordings and other data. Assessing ACAS II performance requires access to the actual flight paths of both aircraft. The investigation should identify the real causes of the event and find operational errors or training shortcomings If it is found that ACAS II has not performed as required, the investigation should seek to establish the source of the problem and how it should be addressed. The investigation may reveal previously unknown problems with the equipment.

Any investigation is a complex process taking into consideration several elements (how did the conflict develop, what were the contributing factors, etc.?) and should take the following into consideration:

- Was (were) the aircraft equipped with an ACAS II system as required?
- Which version of ACAS II was used?
- Was ACAS II operational?
- Was ACAS II switched on in the correct mode of operations (TA-only vs TA/RA)?
- Was an RA issued or missing?
- Which RAs were issued?
- Did the pilot(s) respond timely and correctly to the RAs (using the IATA/EUROCONTROL pilot compliance assessment methodology, see Section 9.18 above)?
- Did ACAS II work as designed?
- What was the vertical and horizontal separation at the CPA?
- Was the RA reported in real-time to ATC as required?
- Was the threat visually acquired?

Examining the following "what-if" scenarios may provide illustrative examples that can be used for training or safety improvements:

- Would the outcome be different had the pilot followed the RA correctly?
- Would the outcome be different if one aircraft were not equipped?
- What would the separation be if there were no RAs?

In addition to the pilot compliance assessment tool mentioned above, EUROCONTROL's CAVEAT (**C**ollision **A**voidance **V**alidation and **E**valuation **T**ool) tool can be used to support any ACAS II event investigation. CAVEAT is a Windows-based tool for replaying and analysing the performance of ACAS II systems. For incident and accident analysis, CAVEAT can process radar data and provide an interface to examine the data in detail by simulating the trajectories for each aircraft as well as cockpit instruments. For more information see SKYbrary.

9.20 ACAS II and ATC operations

The provision of air traffic services to aircraft equipped with ACAS II are identical to those that are not equipped. In particular, the prevention of collisions and the provision of separation must exclude consideration of aircraft capabilities dependent on ACAS equipment[112].

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. The response to an RA can result in a loss of separation with either the aircraft causing the RA or a third aircraft. Although concern about this possibility is understandable (and cannot be dismissed) the need for collision avoidance takes precedence. ACAS 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, ACAS II will respond effectively.

[112] See the quote from ICAO PANS-ATM (Doc 4444) in Section 24.4.1.

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 (see also Section 9.5).

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).

ACAS 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.

More information on
ACAS II and ATC interactions:

ACAS Bulletin 19
ACAS Bulletin 22

In the case of close aircraft proximity and in the absence of an RA report, controllers should provide horizontal avoiding instructions (rather than vertical) as they will not interfere with RA vertical manoeuvres 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).

See also Section 9.3.2 on RA reporting.

9.21 RA downlink display to controller

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[113]. TAs are not downlinked.

Due to surveillance latency, the RA downlink information is presented to the controller with a delay of up to several seconds, depending on the type of downlink method and timing of the RA as well as the ground ATC system processing delays. That may cause the RA displayed to the controller to be outdated, i.e., the RA has changed in the meantime.

Implementation details vary. In some, only basic information is shown to the controller (indicating an RA has occurred but no RA sense) while others show the sense of RA.

The implementation does not relieve the pilots from reporting RAs using the mentioned phraseology mentioned in Section 9.3.2.

It should be noted that although the same set of bits is used in TCAS II and ACAS Xa to downlink RAs, the bits have been assigned differently. Therefore, to interpret the downlink messages correctly, the type and version of ACAS II system must be derived from a Mode S downlink register.

ICAO has not published any provisions for operations of RA downlink.

9.22 ACAS II and ground-based Short Term Conflict Alert (STCA)

The Short Term Conflict Alert (STCA) is a ground-based system that generates alerts on a controller's radar screen, warning of potential or actual infringements of separation minima.

TCAS II and STCA operate independently, providing redundancy and minimizing single points of failure. The only common source of data between the two systems is the altitude reports from aircraft transponders. However, that TCAS II and STCA are not entirely compatible. While the desired behaviour is for STCA to alert at least 30 seconds before the first RA, STCA may sometimes trigger significantly later – occasionally even after the RA has occurred.

[113] More information about RA downlink can be on SKYbrary.

This discrepancy arises from the differences outlined in Table 14.

Providing sufficient warning time is not always possible, particularly in the case of sudden, unexpected manoeuvres. Additionally, STCA and TCAS II have limited or no knowledge [114] of controller and pilot intentions. It should be noted that when a controller issues an instruction in response to an STCA alert, an RA may have already been triggered or could be triggered shortly, even if the pilot follows the controller's instruction.

STCA does not provide any conflict resolution advice; the appropriate action must be determined by the controller and communicated to the pilot.

Table 14: Differences between STCA and ACAS II.

	 **STCA (ground system)**	**ACAS II**  **(airborne system)**
Performance	Ground-based surveillance has 4 to 10 seconds update rate and good azimuth resolution. Tracks often based on multiple data sources (ACAS II tracks based on single data source).	ACAS II surveillance function has 1 second update rate and potentially poor azimuth resolution.
Vertical tracking	STCA uses tracked altitude and vertical rate based on reported altitudes (25-foot or 100-foot precision).	ACAS II 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.	ACAS II 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.	ACAS II 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.

[114] To optimize alerting behaviour and reduce the number of operationally unwanted alerts, some STCA systems use downlinked aircraft parameters, such as Selected Flight Level.

10. TCAS II AND ACAS XA/XO SURVEILLANCE

10.1 Surveillance function

The surveillance function enables an ACAS II equipped aircraft to interrogate surrounding Mode S and Mode A/C ICAO compliant transponders. In addition, ACAS Xa may also use ADS-B signals to improve its performance. The requirement is to determine the relative positions and altitudes of the intruder aircraft. ACAS II equipment computes the range of the intruding aircraft by using the round-trip time between the transmission of the interrogation and the receipt of the reply. Altitude information is provided by decoding the information in the received reply from other transponders.

ACAS II can simultaneously track at least 30 aircraft. The required nominal tracking range of the ACAS II is 14 NM. In case of high traffic density, the interference limiting feature may reduce system range to approximately 4.5 NM. Because the surveillance reliability degrades as the range increases, the equipment assesses as possible collision threats mainly those targets within a maximum range of 12 NM. Nominally, for TCAS II no target outside the range of 12 NM will generate an RA. ACAS II systems are able to detect ACAS broadcast interrogations from ACAS equipped aircraft out to a nominal range of 30 NM. If the number of targets exceeds the surveillance capacity at any range up to 14 NM, the long-range targets will be dropped.

The ACAS II 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 ACAS 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.

In an encounter the situation is likely to be asymmetrical – each involved aircraft's surveillance will see the situation slightly differently (as surveillance is never absolutely perfect) and will issue alerts based on its own assessment (alerts will be coordinated with ACAS II equipped threats).

10.1.1 Intruders fitted with Mode S transponders

ACAS II surveillance of Mode S equipped aircraft is based on the selective address feature of the Mode S transponder. ACAS 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 aircraft[115], the track will be ignored.

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

An aircraft equipped with a Mode S transponder that does not provide altitude information will be tracked and could be displayed as a Non-Altitude Reporting target (NAR). See Section 6.11 for more information.

ACAS 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 and to show surrounding traffic on traffic display.

---

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

10.1.2 Intruders fitted with Mode A/C transponders

ACAS II uses a modified Mode C interrogation to interrogate Mode A/C transponders. This interrogation is known as the *Mode C only all-call*. 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 and to show surrounding traffic on traffic display.

If the intruder aircraft is equipped with a Mode A/C transponder but does not provide altitude information this aircraft will be tracked as a Non-Altitude Reporting (NAR) target (see Section 6.11 for more information).

10.1.3 Intruders fitted with ADS-B (in addition to transponder)

If an ADS-B intruder is fitted in addition with Mode S (or Mode A/C) transponder, the ADS-B position may be used by both TCAS II and ACAS Xa to reduce the number of surveillance interrogations (see Section 10.4 on Hybrid Surveillance). Additionally, ACAS Xa will use ADS-B messages to estimate range, altitude, and bearing for collision avoidance purposes, provided that the active surveillance information remains valid. If ADS-B fails validation for an intruder, the system reverts to using active surveillance for this intruder for threat resolution.

10.1.4 Intruders fitted with ADS-B only

Aircraft providing only ADS-B position information will not be tracked by TCAS II.

As an option, ACAS Xa provides an AOTO (ADS-B Only TA Only) function which will track ADS-B only aircraft; however, only TAs but no RAs will be generated against such aircraft. See Section 12.2.5 for more information on AOTO.

When AOTO is not implemented, ADS-B only and ADS-R (Automatic Dependent Surveillance – Re-broadcast) only targets will be displayed only as non-threats or proximate traffic as appropriate; however, neither TAs nor RAs will be generated against these intruders.

10.1.5 Intruders fitted with Mode A transponders only

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

10.2 Interference limiting

The surveillance function contains a mechanism limiting electromagnetic interference in the 1030/1090 MHz band. Each ACAS II unit is designed to limit its own transmissions. ACAS II is able to count the number of ACAS units, within cover, due to the broadcast, every 1 or 8 seconds[116], of an *ACAS* II *presence* message, which contains the Mode S 24-bit address of the sender. As the number of ACAS 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”.

[116] Every 8 seconds for older TCAS II installations (prior to 2013) and 1 second for newer TCAS II installations and all ACAS Xa installations.

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 (with no indication to flight crew).

10.3 ACAS II performance in high density airspace

In terminal areas and near major airports, a high density of aircraft can be found. For example, in addition to ACAS II equipped aircraft, clusters of transponder equipped helicopters or gliders can be encountered. This can adversely affect ACAS II performance in the following ways:

- A high density of ACAS II equipped aircraft can reduce the surveillance range of ACAS II units to approximately 4.5 NM;
- As a high density of Mode A/C transponders can lead to garbling and loss of correlated replies, the ACAS II tracker performance can be degraded and, consequently, the ability of ACAS II to provide effective collision avoidance advice can be limited.

10.4 Hybrid surveillance

Hybrid surveillance is a method that decreases the number of Mode S surveillance interrogations made by an aircraft's ACAS II unit. The feature, which is standard for ACAS Xa systems, was first introduced in 2006 as an option for TCAS II version 7.1.

With active surveillance, ACAS 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 Global Navigation Satellite System (GNSS) and received on own aircraft by the use of Mode S Extended Squitter, i.e., 1090 MHz ADS-B, also known as 1090ES[117].

The intent of hybrid surveillance is to reduce the ACAS 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 ACAS II.

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. ADS-B data is used by ACAS Xa for both hybrid surveillance and threat resolution, while TCAS II version 7.1 used ADS-B only for hybrid surveillance, but not for threat resolution.

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

[117] Standards for Hybrid Surveillance have been published in RTCA DO-300A.

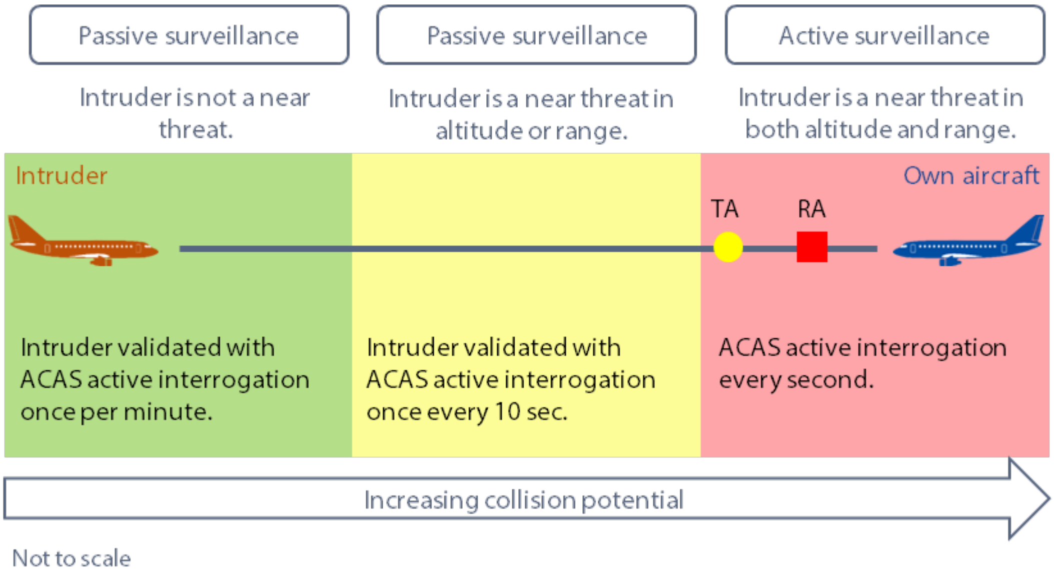


Figure 38: Hybrid surveillance – transition from passive to active surveillance.

10.5 Air-ground and air-air communications

The ACAS air-ground and air-air communication messages (as depicted in Figure 39) are critical for safe and reliable functioning of ACAS II. Above all, they ensure that compatible RAs are selected. They also allow for RA activity to be detected on the ground for the purpose of incident investigations, RA monitoring or ATC operations (i.e., RA downlink display to controllers, see Section 9.21).

10.5.1 RA coordination

In encounters between two aircraft equipped with TCAS II or ACAS Xa, once an RA has been issued each aircraft transmits 'interrogations' to the other aircraft via the Mode S data link to ensure the compatibility of the resolution advice. Coordination interrogations use the same 1030/1090 MHz channels as surveillance interrogations and are transmitted at least once per second by each aircraft's Mode S transponder for the duration of the RA. See Section 8.3 for more information about ACAS-ACAS coordination.

10.5.2 RA Report

Using the Mode S data link, ACAS 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.

Although the same set of bits is used for RA reports in TCAS II and ACAS Xa, they have been assigned differently, so their interpretation is not the same.

The RA reports can be used for ACAS II performance monitoring (see Section 9.18), investigating RA events (see Section 9.19) or display of RA downlink to controllers (see Section 9.21).

10.5.3 RA Broadcast Message

ACAS 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 for ACAS Xa and newer TCAS II system or every 8 seconds for legacy TCAS II systems[118]. 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.

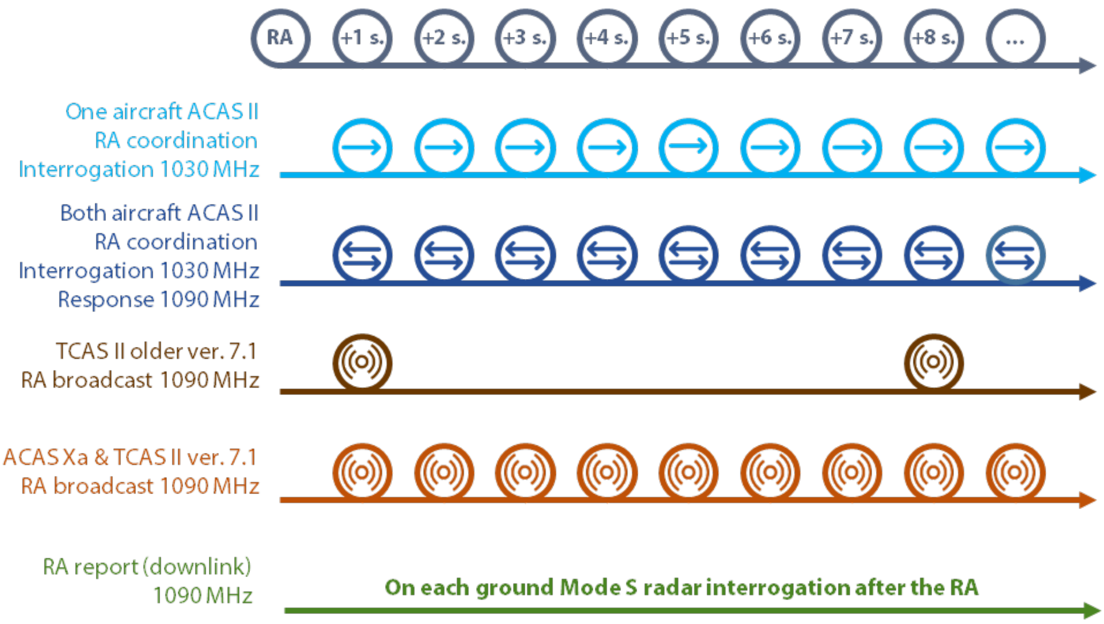


Figure 39: Air-ground and air-air communications timeline.

10.5.4 Sensitivity Level Control commands

Mode S radar ground stations can transmit Sensitivity Level Control commands to aircraft equipped with TCAS II version 7.1, instructing the system to adjust its sensitivity level[119] based on the operational environment. This capability was intended to tailor TCAS II behaviour in specific areas, for example, reducing unnecessary RAs during approaches into high-elevation airports, and to support a more effective balance between timely collision warnings and overall alert rates.

However, the Sensitivity Level Control command concept was never implemented, primarily due to its complexity, the absence of ground radar systems supporting the function, and the lack of established operational procedures.

Sensitivity levels are not used in ACAS Xa; therefore, Sensitivity Level Control commands are not applicable to ACAS Xa systems.

[118] A change to TCAS II MOPS (published as RTCA DO-185B and EUROCAE ED-143) 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.

[119] See also Section 11.1.3 for more information about sensitivity levels.

11. TCAS II SYSTEM

11.1 TCAS II collision avoidance logic

11.1.1 Concept

The TCAS II collision avoidance logic, or CAS (Collision Avoidance System) logic is based on two basic concepts: the warning time (see Section 11.1.2) and the sensitivity levels (see Section 11.1.3). 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.

11.1.2 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 Section 11.2.3 for more information about threat detection.

11.1.3 Sensitivity levels

A trade-off is needed between the protection that the 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 41) around each TCAS II equipped aircraft. The sensitivity level depends on the altitude of own aircraft and varies from 1 to 7 (see Table 15 and Figure 40). The greater the *SL*, the more protection is provided. The *SL* is also coordinated with each ACAS equipped intruder, with the higher of the two *SLs* applying to both aircraft[120]; however, *ALIM* (the threshold for corrective RAs – see Table 16) 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. TCAS II uses radar/radio altimeter readings (when available) to estimate height above ground which is used to determine whether the aircraft is in *SL2* or *SL3*. Beyond *SL3* barometric altitude is used to determine in which *SL* the aircraft is.

See Section 11.2.3 for more information about threat detection.

[120] Sensitivity levels are not used in ACAS Xa to make RA selection, but only to maintain interoperability with the legacy TCAS II systems. ACAS Xa will never indicate operation at a level greater than *SL3*. This ensures that ACAS Xa will not influence TCAS II advisory determination that may be affected by intruder sensitivity levels greater than *SL3*.

11.1.4 Modes of operations

The TCAS II logic converts the TCAS II/transponder modes of operations (see Section 5.3) into sensitivity levels as follows:

- When **"STANDBY"** mode is selected by the pilot, the TCAS II 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 II equipment performs the surveillance function. However, only TAs are provided. The equipment does not provide any RAs. An aircraft operating in "TA-only" mode is treated by other TCAS II aircraft as unequipped and *SL2* is assumed. See Section 9.12 for more information on TA-only mode operations.
- When the pilot selects **"AUTOMATIC"** or **"TA/RA"** mode, TCAS II automatically selects the *SL* based on the current altitude of own aircraft. *SL2* is selected when the TCAS II aircraft is between 0 and 1000 feet AGL 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 15 provides the altitude threshold at which TCAS II automatically changes *SL* and the associated *SL* for that altitude band.

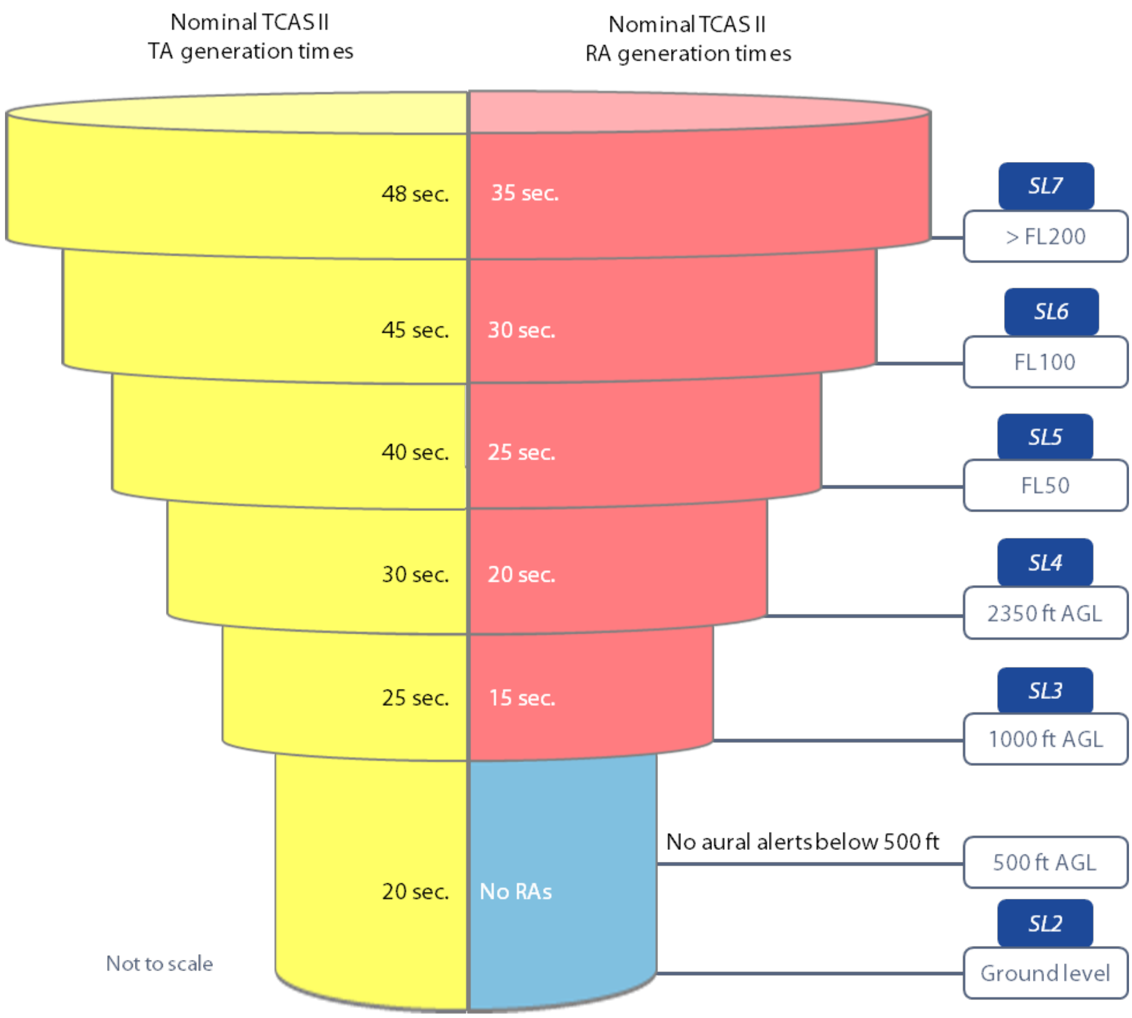


Figure 40: TCAS II nominal warning times and sensitivity levels.

Table 15: TCAS II sensitivity levels.

Own Altitude	Sensitivity levels (*SL*)
Standby mode	1
0 – 1000 feet AGL	2
1000 – 2350 feet AGL	3
2350 feet AGL – FL50	4
FL50 – FL100	5
FL100 – FL200	6
Above FL200	7

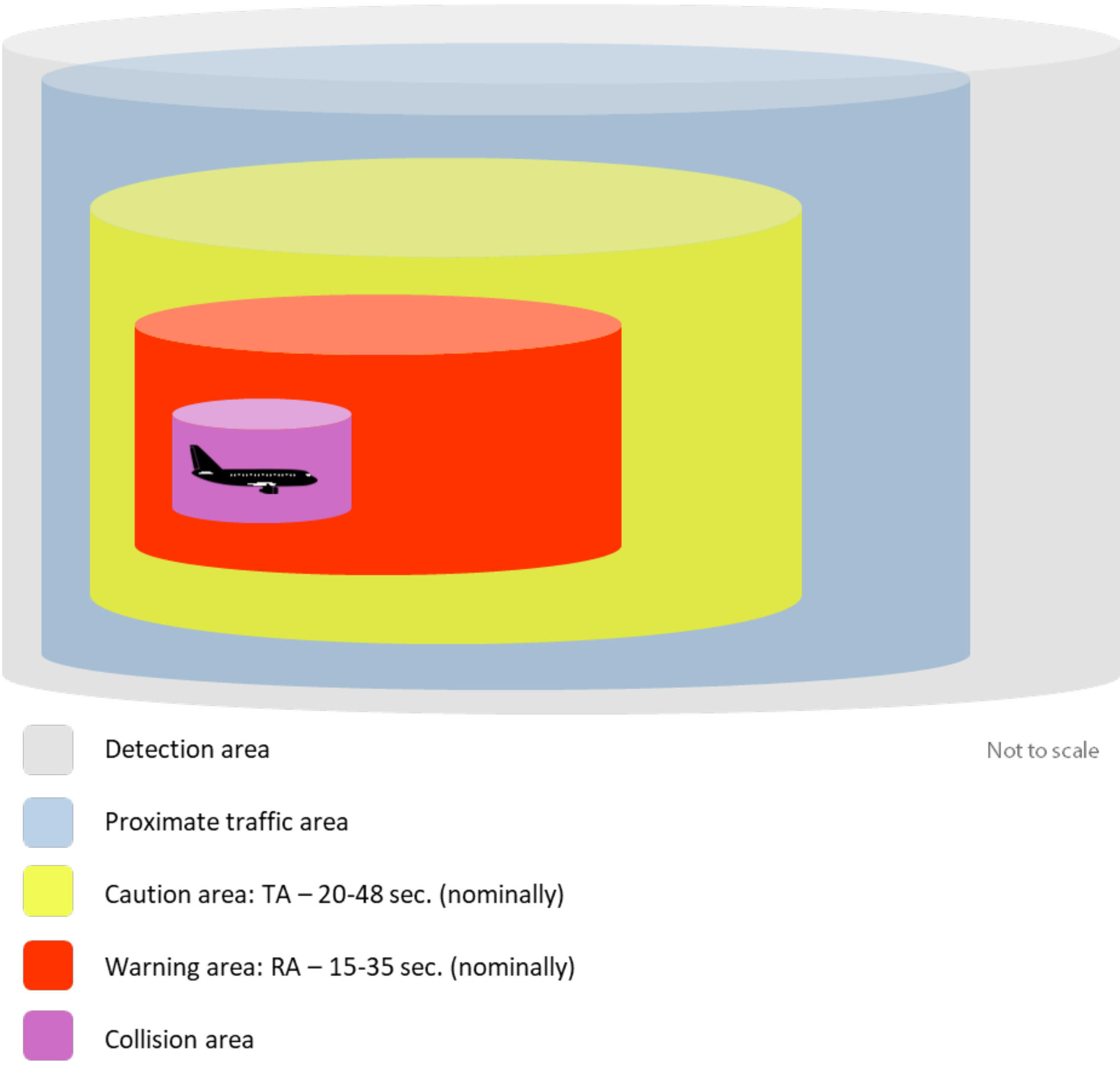


Figure 41: TCAS II protected volume.

11.2 TCAS II logic

In normal operation, the TCAS II logic works continuously on a nominal 1-second cycle. The logic functions used to perform the collision avoidance task are shown in Figure 42. 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. TCAS II is a deterministic system, i.e., given the same inputs, it will always produce the same outputs.

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

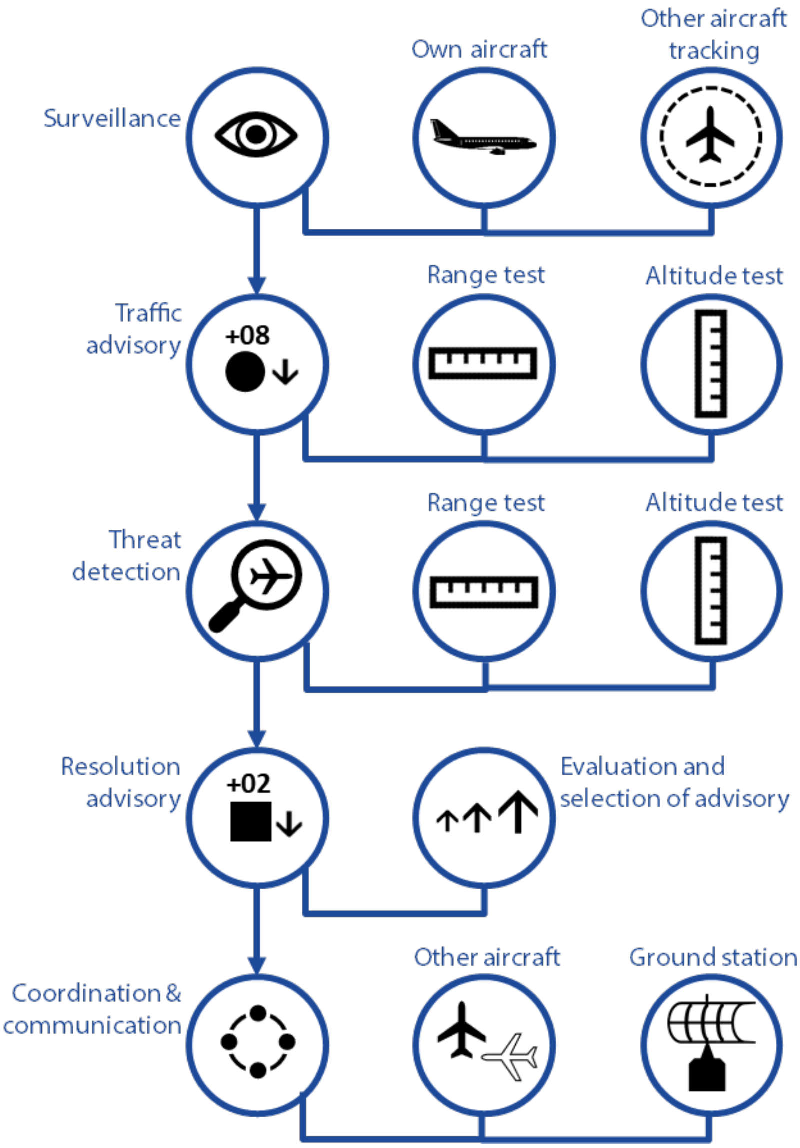


Figure 42: TCAS II logic functions.

11.2.1 Tracking

Using the surveillance reports (slant range, bearing[121] and altitude) provided each second (every 5 seconds in case of "reduced surveillance"), the TCAS II 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)[122] 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 own 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. Mode S equipped intruders will report their status as "airborne" or "on the ground" and neither RAs nor TAs will be generated to the aircraft reporting "on the ground". For Mode A/C equipped intruders, 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 43). 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.

[121] 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 in Section 11.2.3).

[122] Some older airframes use own Mode C altitude (100-foot precision). At the time of writing, approximately a quarter of aircraft captured by Mode S radars reported their altitude in 100-foot increments.

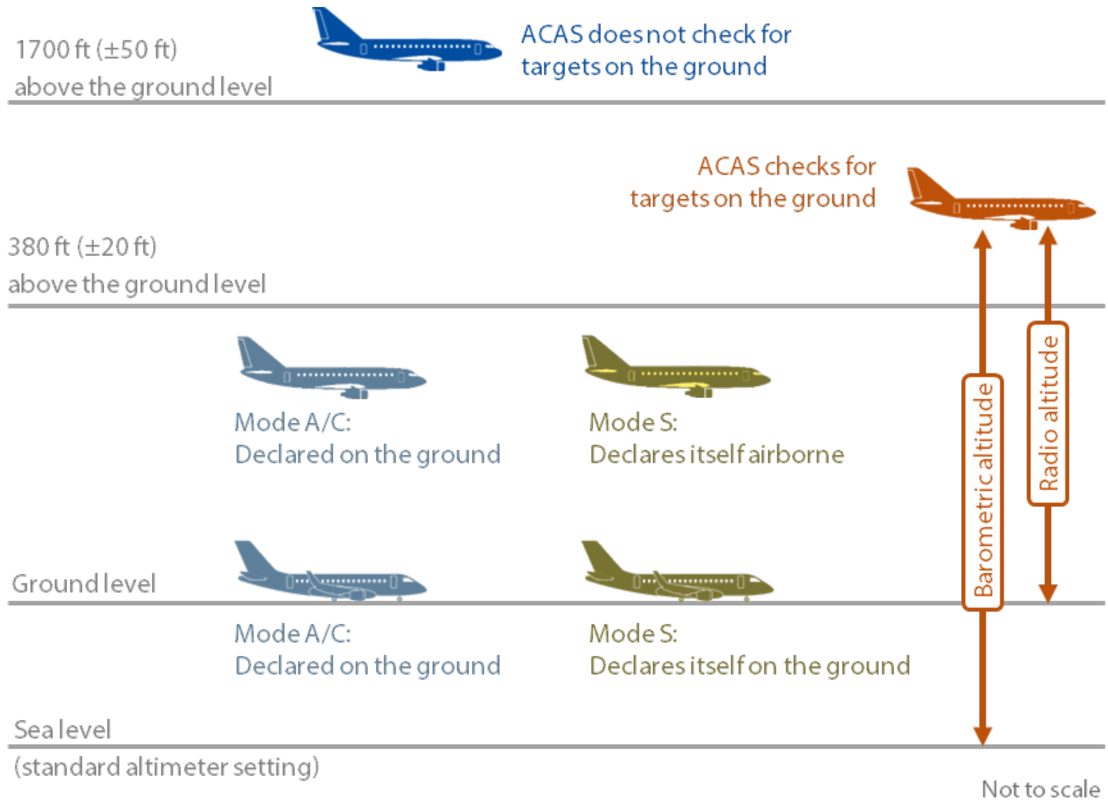


Figure 43: Target on-the-ground determination.

11.2.2 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 (i.e., 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.

11.2.3 Threat detection

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

The warning time, or *tau* (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)[123] has been received from the threat.

11.2.3.1 Range Test

The Range Test passes if the aircraft are currently close in range, or are projected to be close in range within the time threshold *tau*: "close in range" effectively means within a distance parameter called *DMOD*[124]. 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 a dynamic factor (equal to the parameter *DMOD* squared divided by the slant range) 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 where the relative bearing of other aircraft is used in the collision avoidance logic.

11.2.3.2 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).

11.2.3.3 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 41) 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 16. A further parameter, *ALIM*, (used when selecting the RA strength and direction) is a function of altitude and is also shown in Table 16.

[123] See Section 8.3 for more information on Resolution Advisory Complement.

[124] 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).

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 16).

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 16: 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

11.3 TCAS II TAs

The Traffic Advisory function uses a simplified algorithm, similar to the RA generation logic but with greater alert thresholds (see Table 16). The vertical triggering thresholds for TAs are 850 feet above and below the TCAS equipped aircraft below FL420 and 1200 feet above FL420.

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 (see Section 5.4.2 for display symbology).

11.4 TCAS II RAs

The full range of TCAS II RAs and associated cockpit presentation, as well as aural messages, are presented in Table 7 for single threat encounters and in Table 8 for multi-threat encounters. The Sections below explain how RAs are selected, changed and terminated.

11.4.1 Advisory selection

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

11.4.1.1 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 44 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 ¼ *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.

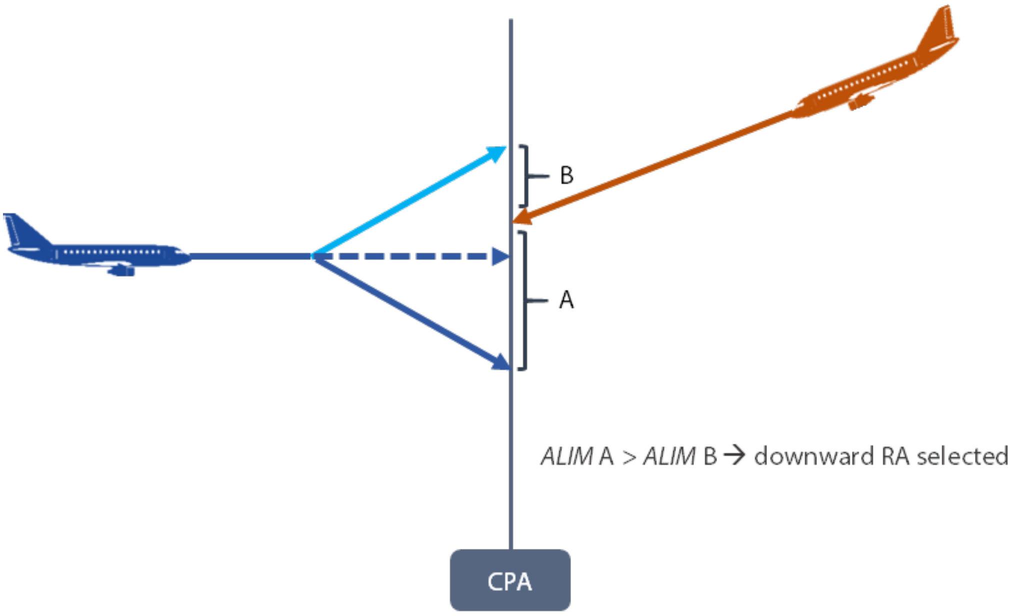


Figure 44: RA sense selection.

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 45 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 46).

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.

An RA is altitude crossing if own TCAS II aircraft is currently at least 100 feet below or above the threat aircraft for upward or downward sense advisories, respectively. An RA can be considered crossing regardless of whether the word "*crossing*" is included in the aural annunciation.

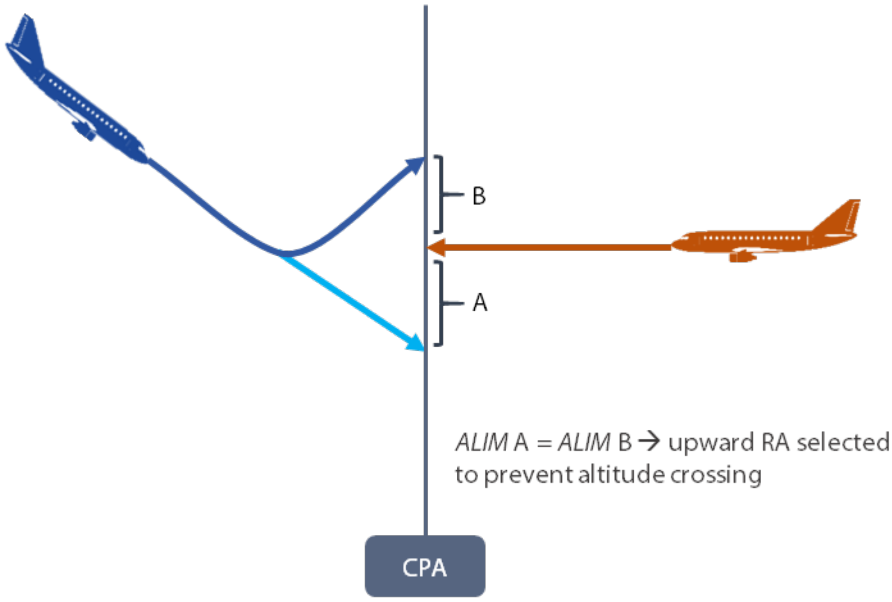


Figure 45: Non-crossing RA.

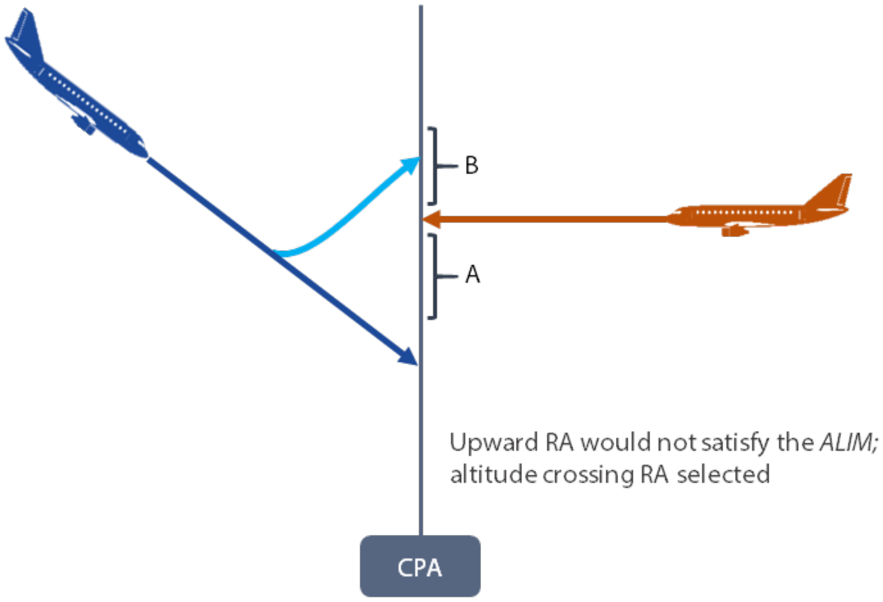


Figure 46: Crossing RA.

11.4.1.2 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 47), in which the vertical rate limit of 0 ft/min. would be selected as the lowest strength RA which achieves *ALIM* separation).

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.

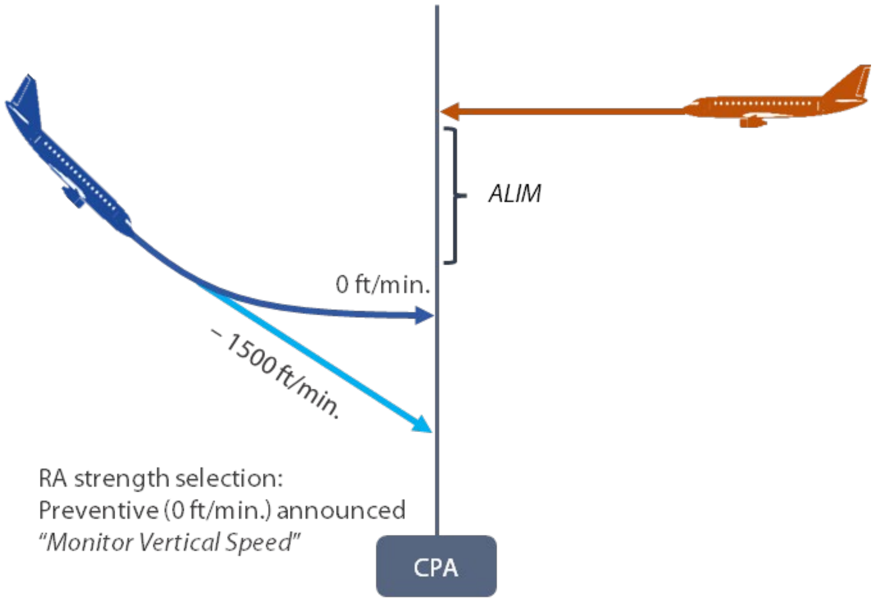


Figure 47: RA strength selection.

After the initial RA is selected, the logic continuously monitors the vertical separation that will be provided at CPA and if necessary, the initial RA will be modified (see Section 11.4.2).

11.4.2 Subsequent (modified) advisories

TCAS II is evaluating the situation every second during the encounter and it can strengthen, reverse, weaken or terminate the RA as required. 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 ⅓ *g*.

11.4.2.1 Strengthening advisories

If, prior to CPA, the logic determines that the response to an RA is not providing the vertical distance equal or greater to *ALIM* (because, for instance the threat aircraft has manoeuvred in the same vertical sense) then the strength can be increased. In the case illustrated in Figure 48, the strength will be increased from the descent rate from the 1500 ft/min. required by the initial Descend RA to 2500 ft/min. (i.e., Increase Descent RA).

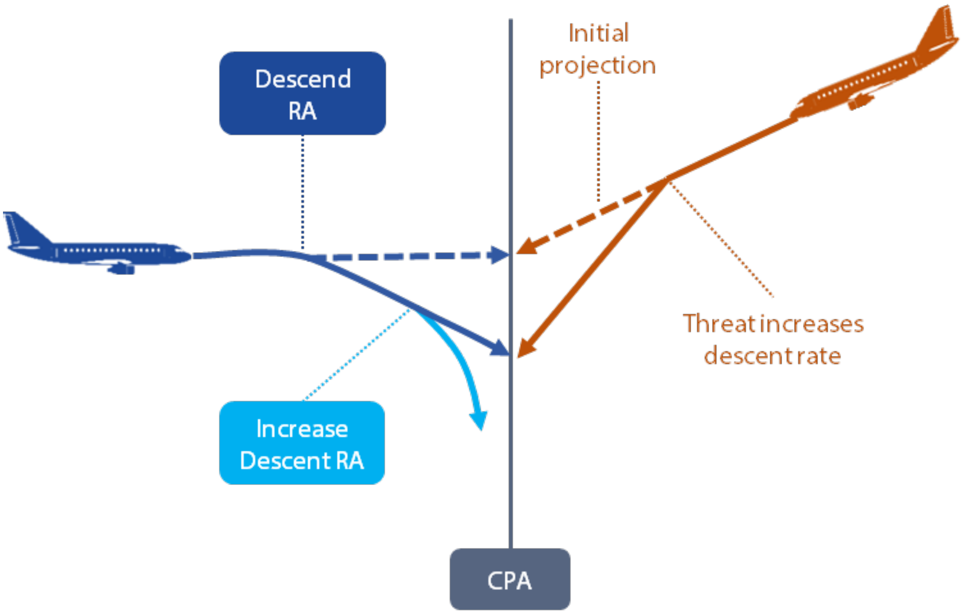


Figure 48: Increase vertical rate RA.

11.4.2.2 Reversal advisories

The logic may also change the vertical sense of the RA (from climb to descend or the other way around), if it determines that the initially selected RA is not working.

Figure 49 shows an encounter where an initial Climb RA requires a change to a Reversal Descent RA after the threat aircraft manoeuvres.

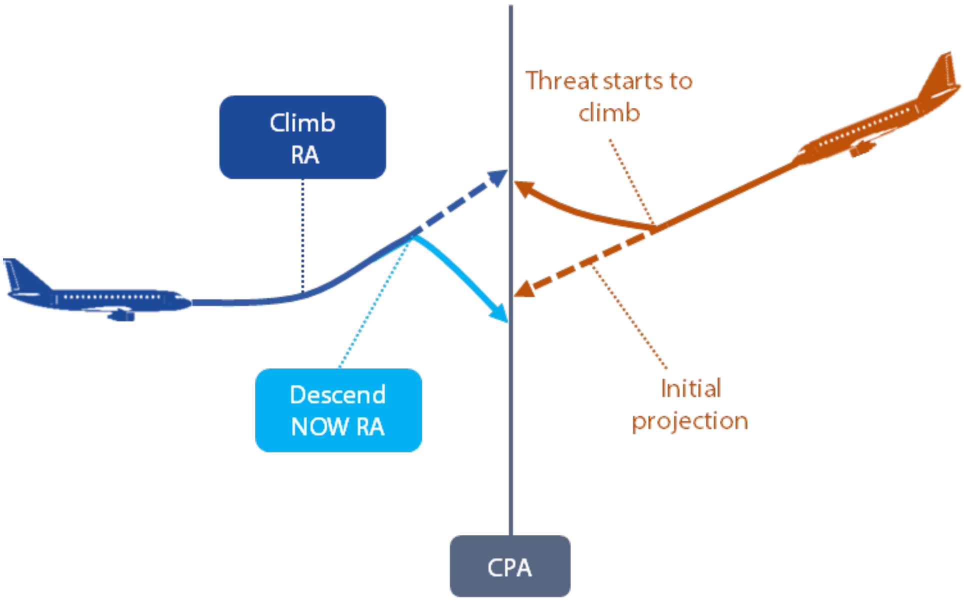


Figure 49: Sense reversal RA.

11.4.2.3 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 RA (see Figure 50). This is done to minimise unnecessary deviations from the original altitude.

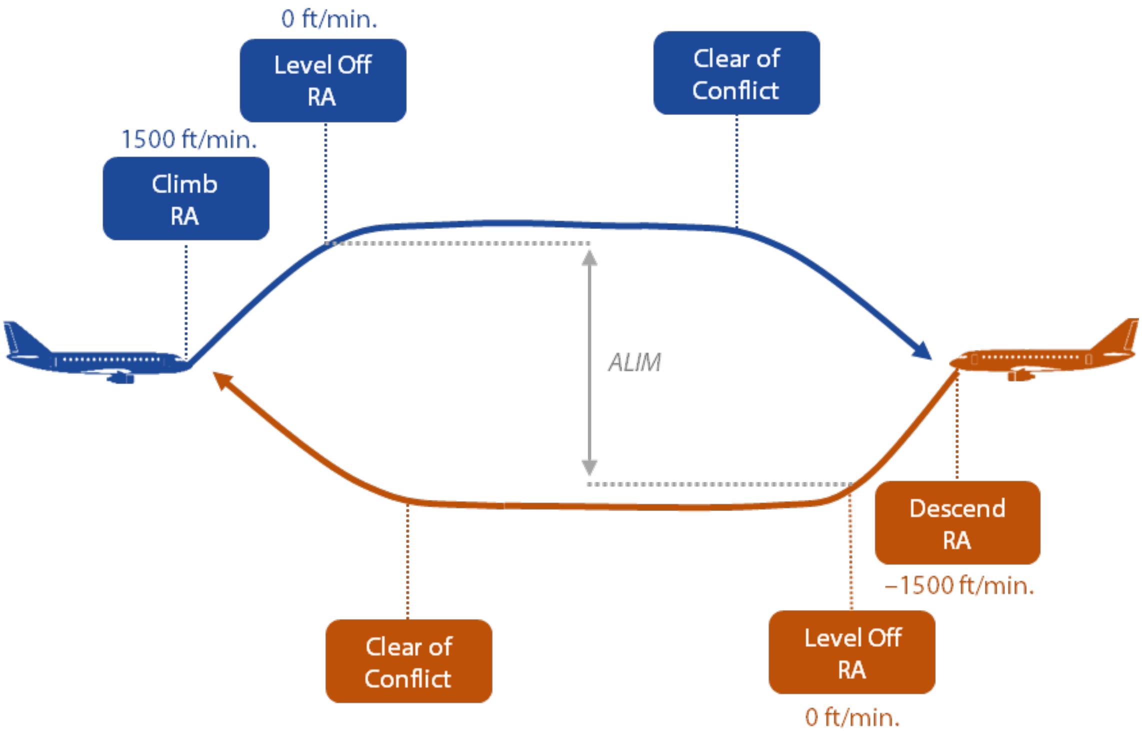


Figure 50: Weakening RAs.

11.4.3 RA termination

For TCAS II, the intruder ceases to be a threat when the range between the own 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 RA 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 or the RA is inhibited because a higher priority alert (e.g., GPWS, TAWS)[125] or the aircraft descends through the low level inhibition threshold (900 feet AGL)[126], an RA will be removed and terminated but no Clear of Conflict annunciation made.

If an RA is removed without a Clear of Conflict annunciation, the collision risk may still be present, so the pilots are advised to continue monitoring surrounding traffic visually and seek advice from ATC.

[125] See Section 8.2.2.

[126] See Section 8.2.1.

11.5 Multi-threat logic

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

It is possible that the RA selected in such encounters may not provide *ALIM* separation from all intruders. An initial multi-threat RA can be any of the initial RAs shown in Table 7 and Table 8 or a combination of upward and downward sense RAs. The multi-threat logic is designed to utilise increase rate RAs and reversals RAs to best resolve multi-threat encounters.

11.6 RA duration

TCAS II 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 seconds[127];
- Minimum time before weakening RA can be issued – 10 seconds.

A strengthening RA can be issued without any delay.

11.7 Performance monitoring

TCAS II software continuously and automatically monitors its own health and performance. The performance monitoring operates whenever power is applied to TCAS II. In addition, the performance monitor includes a pilot-initiated test feature that includes expanded tests of TCAS II 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 II processor. For example, own aircraft pressure and radar/radio altimeter altitude inputs or the connection of TCAS II to the aircraft suppression bus.

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

[127] Geometric reversals only: coordination (tiebreaker) reversals can be issued without any delay (see Section 6.3).

12. ACAS XA AND ACAS XO SYSTEMS

12.1 ACAS Xa vs. TCAS II

One of the main ACAS Xa design objectives was the improvement in safety while reducing the unnecessary alert rate. Operational monitoring of TCAS II revealed numerous cases where RAs were generated in situations when they were not needed (i.e., there was only a remote risk of collision or no risk at all).

ACAS Xa is designed as a replacement of existing TCAS II systems[128]. Although ACAS Xa system will mainly use the same hardware (antennas and displays) as the current TCAS II system, a drop-in replacement may not always be possible (due to differences in interfaces and connections). The displays and alerts will be familiar to pilots. The same low level RA inhibition[129] as in TCAS II will be applied. ACAS Xa is fully compatible with current TCAS II systems (versions 6.04a, 7.0 and 7.1) and both systems will coordinate complementary advisories.

Like TCAS II, ACAS Xa is a deterministic system. Given the same inputs, ACAS Xa will produce the same outputs. There is no randomization as part of the on-board algorithm.

The main differences between TCAS II and ACAS Xa are described below.

12.1.1 Surveillance

- All installations of ACAS Xa systems will include the use of hybrid surveillance (see Section 10.4) to extend display range and limit interference.
- TAs and RAs can be issued against targets providing ADS-B data as long as it is validated with active surveillance.
- The usage of ADS-B provides safety and operational advantages by minimising unnecessary alerts and optimising alerting in general. If ADS-B fails validation for an intruder, the system reverts back to using active surveillance of that intruder for threat resolution.
- ACAS Xa provides an annunciation in case of unexpected transponder transition to standby (which would consequently cause ACAS Xa to stop providing collision avoidance protection) when such an annunciation is not already provided by the existing aircraft avionics installation.
- The format for Mode S RA downlink messages has been modified for ACAS Xa. The same set of bits is used; however, they have been assigned differently to provide ground stations with more information about the type of RA issued, in order to support ACAS monitoring or incident investigation.
- Using the available surveillance data, ACAS Xa determines own aircraft state and each intruder state at least once a second. The resulting distribution takes into account the probabilistic dynamic model (i.e., where and how fast the aircraft is likely to move) and the probabilistic sensor model (taking into account any sensor errors). This distribution points to the place in the numeric logic table where the best action to take can be found, i.e., whether to issue an RA (see Figure 51).

---

[128] Although ACAS Xa equipped aircraft may be delivered together with ACAS Xo variant, the aircraft may not be equipped with instruments allowing the crew to select targets.

[129] See Section 8.2.1.

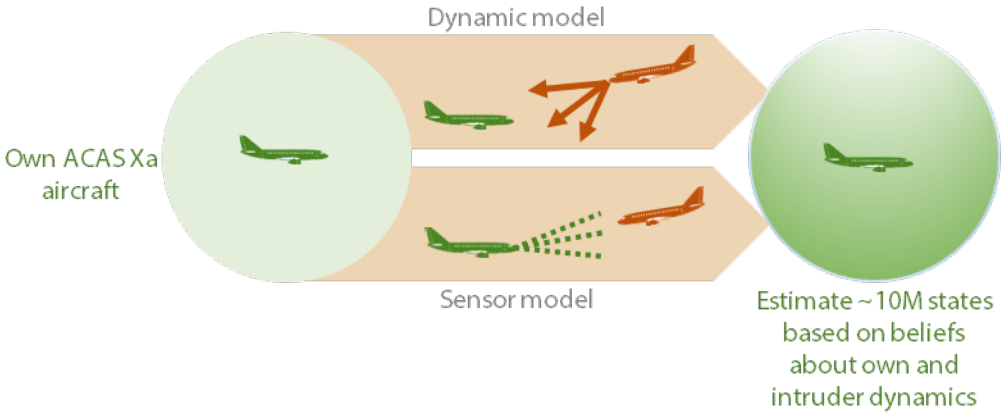


Figure 51: ACAS Xa state estimation.

12.1.2 Logic

- ACAS Xa does not use the sensitivity levels (see Section 11.1.3) which are present in the TCAS II design, except as an operating mode indicator (see Section 12.2.6).
- ACAS Xa alerts are based on perceived risk and filter out many potential RAs where risk is low. As a result, ACAS Xa will not alert in some encounters where TCAS II would produce an alert and does alert in some encounters where TCAS II does not.
- TCAS II relies exclusively on interrogation mechanisms using transponders on-board aircraft to determine the intruder's current and projected future position. Based on a fixed set of rules, the advisory logic issues alerts against a potential threat on the basis of time of closest approach and projected miss distance. Instead of using a set of hard-coded rules, ACAS Xa 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 (see Figure 52).
- An ACAS Xa higher Mode S address aircraft ("*slave*") can issue a geometric reversal (see Section 6.3.2) if the lower Mode S address aircraft ("*master*") has not yet issued an RA. Consequently, on rare occasions there can be two geometric reversals in one encounter.

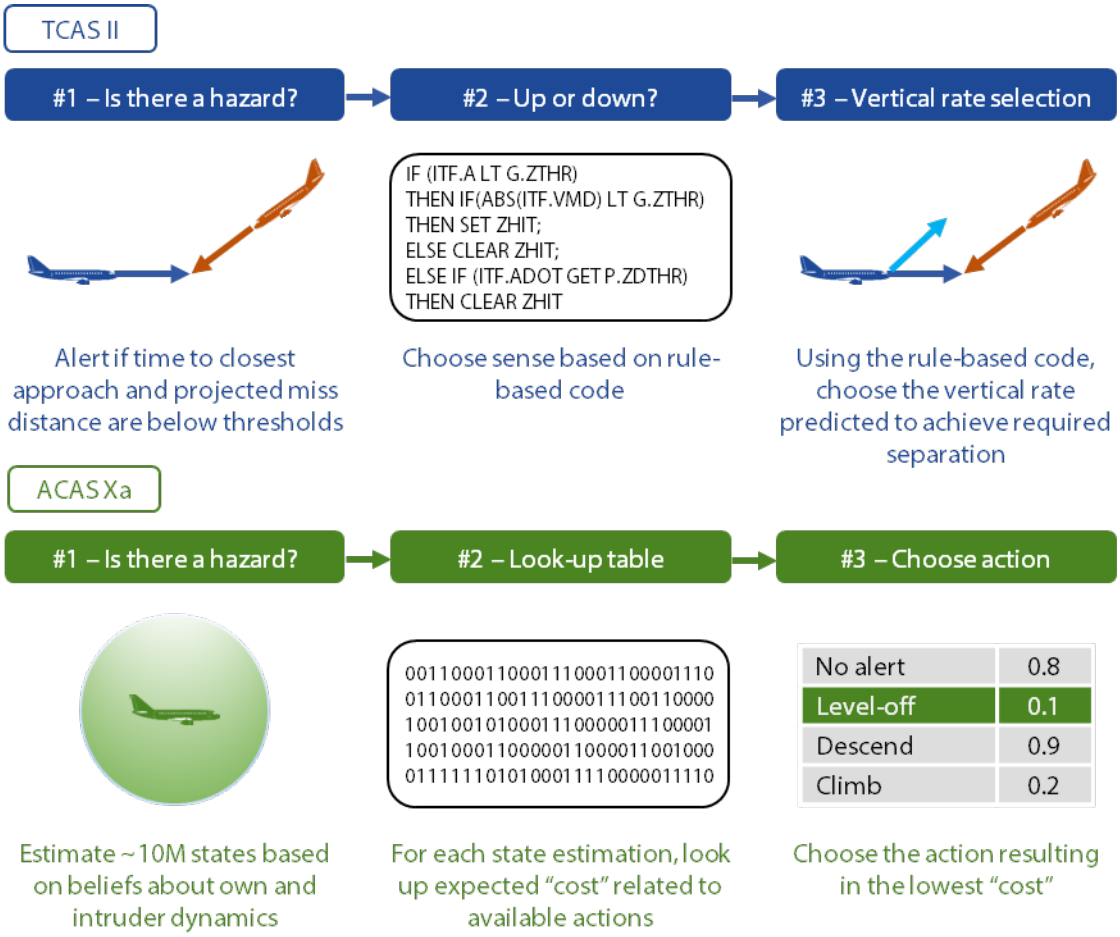


Figure 52: RA selection process: TCAS II vs. ACAS Xa.

12.1.3 Alerts and traffic display

- The range of RAs used by ACAS Xa is similar to those used by TCAS II. However, vertical speed limits for preventive RAs are not used and the aural annunciations for Maintain Vertical Speed RAs are different (see Section 12.2.4).
- The minimum time limits on RA duration used in TCAS II (see Section 11.6) are not used in ACAS Xa.
- While ACAS Xa aircraft is on the ground, airborne intruders are displayed as Other (non-threat) or Proximate traffic but not, unlike TCAS II, as TAs.
- ACAS Xa may generate an RA at a different time before the CPA than TCAS II or generate an RA in situations when TCAS II would have not generated an RA. The average relative timing of ACAS Xa TAs and RAs is within 3 seconds of similar TCAS II alerts[130].
- ACAS Xa will issue alert against some high vertical rate intruders while TCAS II will not. TCAS II RAs are restricted to intruders with vertical rates less than 10,000 ft/min. while ACAS Xa has no upper limit. Consequently, in the areas where military activities are conducted close to civil operations, more RAs against military intruders may occur.
- TCAS II can issue crossing RAs with vertical separation up to 150 feet. ACAS Xa can issue crossing RAs with greater vertical separation. This increases the number of crossing RAs with ACAS Xa in certain encounter types, specifically against military intruders with very high vertical rate.

[130] As indicated by a simulation of a large set of recorded radar tracks in US airspace. Generally, in safety critical encounters, ACAS Xa alerts earlier and in non-safety critical encounters ACAS Xa will wait to alert. However, the timing difference on individual encounters can vary in either direction. Source: ICAO ACAS Manual, Doc 9863, 3rd edition.

12.2 ACAS Xa logic

ACAS Xa detects threats and resolves conflicts using Markov Decision Process (a kind of a decision theoretic approach), rather than a rule based approach like TCAS II.

The logic functions used to perform the collision avoidance task are shown in Figure 53. A statistical representation of where the aircraft will be in the future is used to determine the best action to take (i.e., whether to issue an advisory and its strengths) based on a numeric lookup table. The lookup table that is optimised with respect to a probabilistic model of the airspace and a set of safety and operational considerations. Once an intruder is detected, ACAS Xa will conduct once per second an estimate of approximately 10 million possible future states of own aircraft and the intruder. Optimisation of the alerting thresholds should allow ACAS Xa to improve safety comparing to TCAS II while issuing fewer RAs.

The ACAS Xa logic is composed of two main software modules: Surveillance and Tracking Module (STM) and Threat Resolution Module (TRM).

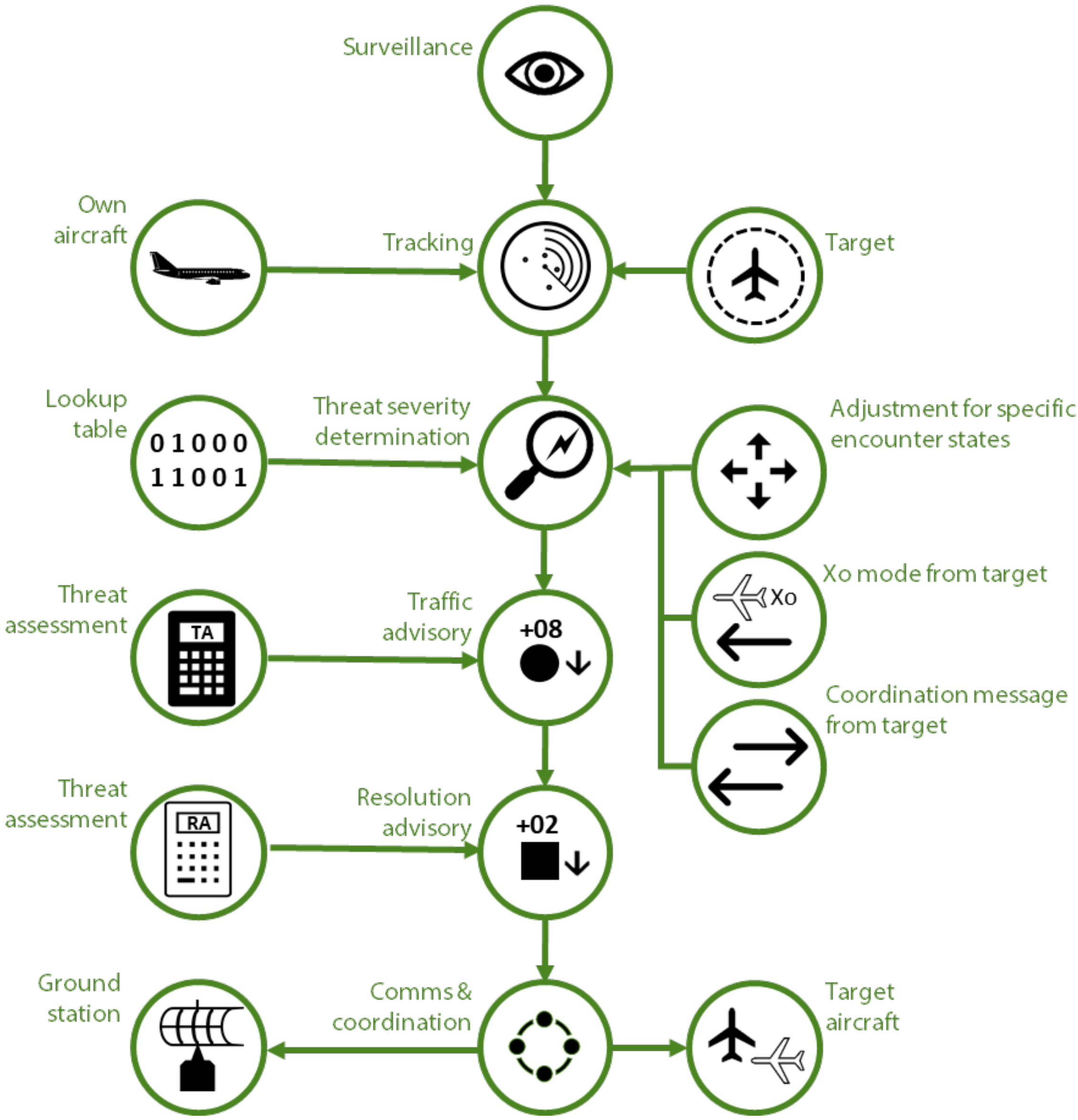


Figure 53: ACAS Xa logic functions.

12.2.1 Surveillance and Tracking Module (STM)

ACAS Xa detects and tracks aircraft by receiving measurements from on-board surveillance systems of surrounding traffic. Based on these measurements, it estimates the relative position and velocity of nearby aircraft. To compensate for the inherent imperfection of sensors, the STM takes into account measurement and dynamic uncertainty by representing relative positions and velocities as a probabilistic state distribution (see Figure 51).

The STM processes all surveillance and own aircraft data. The STM generates several outputs, most importantly:

- Own and intruder data in the format required by the TRM including RA coordination data;
- Intruder information required for the traffic display.

The STM makes use of active surveillance data, ADS-B data, and ADS-R data and maintains independent tracks for each source. ACAS Xa will process ADS-R messages which are re-broadcast by ADS-B ground stations (when this service is available), in a manner consistent with the processing of other ADS-B messages. The usage of ADS-B data provides safety and operational benefits by optimising alerting.

The STM marks each track with information allowing the TRM to determine if the track can be used for generating RAs and TAs or TAs only. ADS-B data is marked as qualifying for RA generation if it passes an STM active surveillance validation. TAs and RAs can only be issued as long as the intruder tracks are validated with active surveillance, in order to mitigate the risk of GNSS spoofing or jamming and inaccurate ADS-B information (see Section 17.7 for more information on spoofing or jamming). If an ADS-B track fails validation via active interrogation and reply, ACAS Xa will revert to using active surveillance for threat resolution logic. Once STM active validation fails on an ADS-B track, that track will no longer be provided to the TRM.

12.2.2 Threat Resolution Module (TRM)

The determination of traffic threats is done by TRM based on the track data provided by STM. If a threat is established, TRM will determine which alert (TA or RA) is to be generated. TRM also generates RA coordination messages to the threat aircraft and RA downlink messages to the ground.

The TRM assigns a “cost” (score) to each subsequent action. The actions include issuing a TA, an RA and its sense (e.g., Climb, Descend), Clear of Conflict, or no advisory. The lowest “cost” action is selected. The lowest “cost” will represent an action that provides the best collision avoidance solution and minimum operational disruption (see the bottom part of Figure 52).

“Cost” estimation is performed separately for offline “costs” (i.e., “cost” associated with each possible resolution advice) and on-line “costs” (i.e., “cost” associated with alert low level inhibitions or other aircraft parameters). The outputs of both “costs” are merged.

Offline “cost” provide “costs” for all possible actions for each intruder. These “costs” are derived using lookup tables that were generated during the system design using an offline optimisation process. These tables are indexed by *tau*, relative altitude, own aircraft vertical rate, intruder vertical rate, and the current RA.

Online “costs” capture characteristics of the current state, for instance altitudes. There are two types of online “costs”: independent and dependent on the RA coordination state of own aircraft and the intruder aircraft. The outputs contain the sum of online “costs” associated with each action for an individual intruder.

12.2.3 ACAS Xa Traffic Advisories

ACAS Xa will issue TAs based on dedicated thresholds. When the alerting logic determines that the "costs" are trending towards generating an RA, a TA will be issued to draw the pilot's attention to the intruder. The timing of TAs may be different in TCAS II and ACAS Xa, but they serve the same purpose – to alert the pilot of potential threat.

12.2.4 ACAS Xa Resolution Advisories

ACAS Xa uses a similar range of RAs as TCAS II. The differences are described below and summarised in Table 17 below. The full range of TCAS II and ACAS Xa RAs and associated cockpit presentation, as well as aural messages, are presented in Table 7 for single threat encounters and in Table 8 for multi-threat encounters.

- ACAS Xa will not issue an RA calling for vertical speed limitations (i.e., Monitor Vertical Speed RAs) other than 0 ft/min., whereas TCAS II allows Monitor Vertical Speed RAs with vertical speed limitations of 0, 500, 1000, and 2000 ft/min.
- In ACAS Xa, Maintain Vertical Speed RAs while climbing and while descending will weaken to Do Not Descend and Do Not Climb RAs, respectively (announced "*Monitor Vertical Speed*").
- In ACAS Xa, the aural annunciations "*Maintain vertical speed, maintain*" and "*Maintain vertical speed, crossing maintain*" are not used. RAs to maintain vertical speed, including crossing RAs will be announced as "*Climb, climb*", "*Climb, crossing climb*", "*Descend, descend*" or "*Descend, crossing descend*" RAs, depending on the vertical sense of the required manoeuvre. Reversal RAs to maintain vertical speed will be announced as "*Climb, climb NOW; climb, climb NOW*" and "*Descend, descend NOW; descend, descend NOW*" RAs, depending on the vertical sense of the required manoeuvre.
- In multi-threat encounters RAs to maintain the existing null vertical rate (i.e., level flight) will be announced by ACAS Xa as "*Level off, level off*" rather than "*Maintain vertical speed, maintain*" as in TCAS II.
- Preventive "*Monitor vertical speed*" RAs (prohibiting climb and descend at the same time) are not used by ACAS Xa in multi-threat encounters.

ACAS Xa does not base its alert determination on heuristic rules and fixed thresholds like TCAS II, but on resolution tables that have been optimised using encounter models. ACAS Xa may generate an RA at a different time before the CPA than TCAS II or generate an RA in situations when TCAS II would have not generated an RA.

Like TCAS II, ACAS Xa is evaluating the situation every second during the encounter and it will strengthen, weaken, revers or terminate the RA if required. There are no RA duration limits in ACAS Xa, i.e., an RA is updated as soon as the logic determines the need to do so.

Expected pilot responses to all RAs are identical in TCAS II and ACAS Xa.

ACAS Xa will terminate the RA once the intruder ceases to be a threat. The pilot then is required to return to the original clearance, unless otherwise instructed by ATC (see Section 9.20). The same conditions for RA termination and removal apply to ACAS Xa as they do to TCAS II (see Section 11.4.3).

ACAS Xa has been tuned to reverse RAs in the same manner as TCAS II version 7.1 in case of "vertical chase with low vertical miss distance" (see Section 3.2.3.2).

Table 17: Differneces in TCAS II and ACAS Xa RA aural announciations.

Advisory	Aural annunciation	
	TCAS II ver. 7.1	**ACAS Xa**
Maintain Vertical Speed Issued while climbing	Maintain vertical speed, maintain	Climb, climb
Crossing Maintain Vertical Speed Issued while climbing	Maintain vertical speed, crossing maintain	Climb, crossing climb; climb crossing climb
Maintain Vertical Speed Issued while descending	Maintain vertical speed, maintain	Descend, descend
Crossing Maintain Vertical Speed Issued while descending	Maintain vertical speed, crossing maintain	Descend, crossing descend; descend, crossing descend
Limit Climb to 500, 1000 or 2000 ft/min.	Monitor vertical speed	—
Limit Descent to 500, 1000 or 2000 ft/min.	Monitor vertical speed	—
Do Not Climb Weakening RA Issued after Maintain Descent RA	—	Monitor vertical speed
Do Not Descend Weakening RA Issued after Maintain Climb RA	—	Monitor vertical speed
Multi-threat encounter Maintain existing vertical speed RA	Maintain vertical speed, maintain	Level off, level off
Multi-threat encounter Preventive Do Not Climb & Descend RA	Monitor vertical speed	—

12.2.5 ACAS Xa ADS-B Only TA Only (AOTO) mode

An AOTO (**A**DS-B **O**nly **T**A **O**nly) mode is an optional ACAS Xa functionality. In this mode, a TA, as a manufacturer option, may be generated against ADS-B only intruders (i.e., not equipped with a Mode S or Mode A/C transponder); however, the TA will never progress to an RA, even as separation distances decrease. By design, RAs are not possible against non-transponder equipped intruders since there is no mechanism to conduct an exchange of coordination messages (which are done via the transponder antenna).

If this feature is enabled, then the TA symbol will be different from a TA symbol that can progress to an RA. It may also include text near the symbol (TA-only) to help in differentiating the symbol to minimise crew errors that could otherwise lead the pilots to falsely wait for the system to issue an RA.

Currently, in Europe there are no approved operational procedures for the use of AOTO mode.

12.2.6 Sensitivity levels and modes of operation

In ACAS Xa sensitivity levels (SL) are not used to modify the protection volume according to altitude as in TCAS II (see Section 11.1.3). Unlike TCAS II, ACAS Xa uses *SLs* only as an operating mode indicator (standby, TA-only or TA/RA modes – see Sections 5.3 and 11.1.4) and to maintain interoperability with legacy TCAS II systems.

In TA/RA mode, ACAS Xa will always transmit *SL3* to TCAS II aircraft. This ensures that ACAS Xa will not influence TCAS II RA determination because of the *SL* of the TCAS II aircraft and, consequently, a TCAS II aircraft at *SL3* or higher will select an RA based on its own *SL*.

12.3 ACAS Xo

TCAS II and ACAS Xa design may increase the number of unnecessary RAs in visual separation procedures and closely spaced parallel operations. These procedures often involve separation inside of alerting thresholds, thus resulting in nuisance alerts. ACAS Xo is intended for these situations. Currently, there are two modes within ACAS Xo: DNA (**D**esignated **N**o **A**lert) and CSPO-3000 (**C**losely **S**paced **P**arallel **O**perations **3000**[131]); additional applications are possible in the future. Currently, the use of ACAS Xo is limited to one mode and one aircraft at a time. ACAS Xo use cases are depicted in Figure 54.

More modes may be developed in the future, including multi-aircraft mode and automatic selection of the ACAS Xo mode. ACAS Xo installations will have to be integrated with an Airborne Separation Assurance Systems (ASAS) interface to allow the designation of traffic[132]. While use of the ASAS or similar system is required to provide the controls and displays necessary for ACAS Xo, the initial ACAS Xo modes are designed for standalone use (i.e., no corresponding ASAS applications are needed). ACAS Xo requires the use of ADS-B In equipment.

For ACAS Xo systems, the warning times or conditions for issuing an RA may differ, or RAs may be suppressed altogether, when an intruder is designated for special processing.

Examples of traffic display symbols for ACAS Xo implementations are shown in Table 5.

Currently, in Europe there are no approved operational procedures for use of any these modes.

12.3.1 Designated No Alerts (DNA)

Visual separation procedures and closely spaced parallel operations often result in spacing between the aircraft that are inside of ACAS Xa alerting thresholds, thus resulting in unnecessary alerts. Unnecessary alerts may decrease the effectiveness of the collision avoidance function, as flight crews may ignore RAs. DNA function will give the pilot an option to select a DNA mode on one intruder to suppress any TAs and RAs against this aircraft, while ACAS Xa will continue to provide collision avoidance protection against all other altitude reporting aircraft and will still be performing RA coordination with other aircraft. During multi-threat encounters involving the designated aircraft, DNA mode will be automatically suspended.

Designated traffic will be automatically undesignated if the aircraft are diverging and are more than 6 NM latterly.

[131] 3000-foot (915-meter) spacing between parallel runways.

[132] ASAS applications are described in RTCA DO-317C.

12.3.2 Closely Spaced Parallel Operations 3000 (CSPO-3000)

A CSPO-3000 mode, for closely spaced parallel approaches when runways are spaced by 3000 feet (915 metres) or more, will provide the pilot an option to designate traffic to which a modified collision avoidance logic will be applicable during closely spaced parallel operations. ACAS Xa protection is maintained on all other altitude reporting aircraft. When the CSPO-3000 mode is selected, the available RAs are the same as in a normal mode of operations. The size of the protection "bubble" depicted in Figure 54 is not fixed like the TCAS II protection volume (see Figure 41) as it is based on probabilistic rules.

The CSPO-3000 mode is unavailable when the own aircraft ACAS Xa system is in TA-only mode, own aircraft is above FL140 and no traffic designated; or own aircraft is above FL140, traffic is designated and there is no RA in progress.

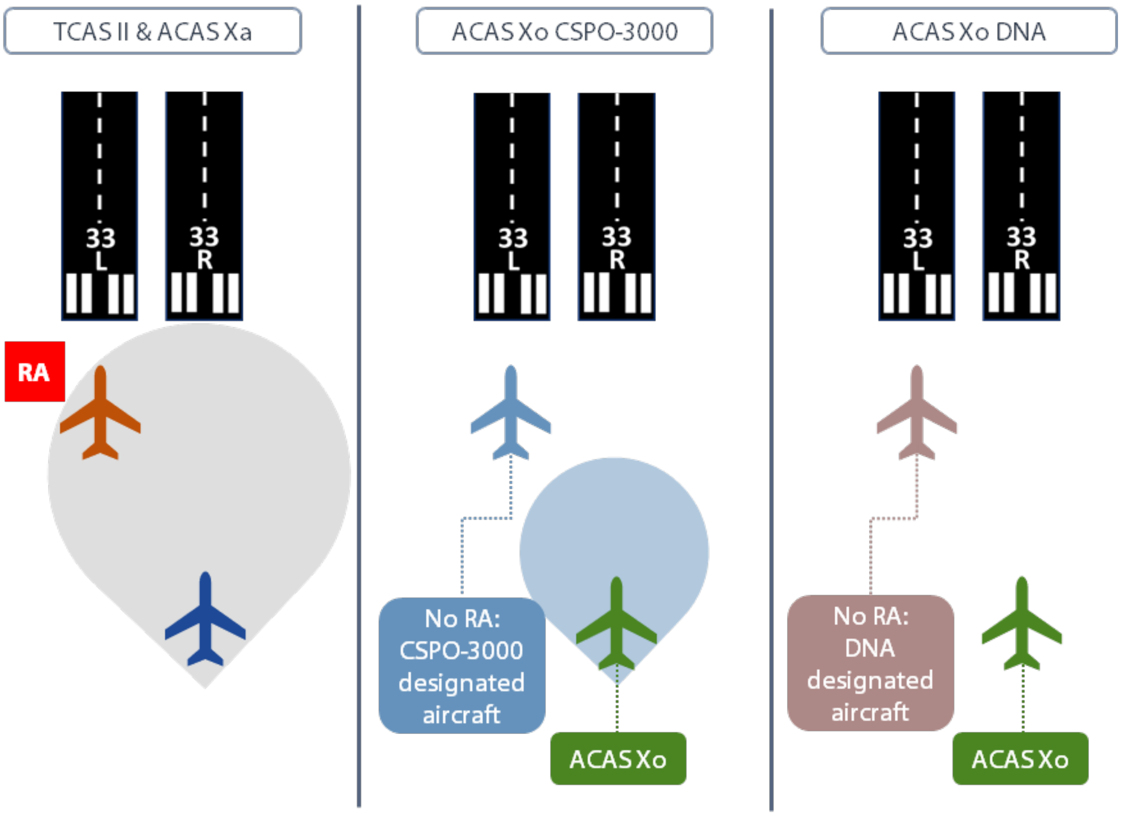


Figure 54: ACAS Xo DNA and CSPO-3000 use cases.

12.4 ACAS Xa/Xo performance monitoring

The ACAS Xa/Xo equipment contains a performance monitor function to monitor continuously and automatically all pertinent ACAS Xa/Xo functions and performance. If the performance monitoring function determines that ACAS Xa/Xo is no longer able to operate, or the system is turned off and the crew notified of the failure.

In addition, each processing cycle, the ACAS Xa/Xo monitor function determines the status of own transponder, as functioning Mode S transponder is required for the ACAS Xa/Xo system to operate. If own transponder status is determined to be standby or failed when the aircraft is airborne and radar/radio altimeter altitude is greater than 1550 feet (±100 feet), the crew will be notified. The indication that collision avoidance is not available may be provided using another aircraft display system (aurally and visually) through an aircraft master caution and alerting system. Alternatively, ACAS Xa/Xo will provide a visual annunciation "*TCAS standby*" on the TCAS display and an aural annunciation "*TCAS standby*". This annunciation is not made during normal transitions to standby, for instance, upon landing or during higher priority flight deck alerts (e.g., GPWS, TAWS). This solution is intended to prevent the accidents and incidents caused by a loss of transponder signal by one of the aircraft (like it was in the case of the Brazil midair collision described earlier or in the case of incident described in the ACAS II Bulletin no. 23).

13. ACAS Xu SYSTEM

13.1 ACAS Xu overview

ACAS Xu is designed for Remotely Piloted Aircraft Systems (RPAS)[133] with a wide range of surveillance technologies and performance characteristics. The term RPAS refers to an aircraft that can be operated without the possibility of direct human intervention from within or on the aircraft.

ACAS Xu provides both collision avoidance and Remain Well Clear (RWC) functionalities (see Section 15.2). The name ACAS has been retained despite the addition of the RWC functionality which is a form of separation provision.

ACAS Xu is intended to improve safety by acting as a last-resort safety net against aiming to prevent midair collisions or near midair collisions with:

- **Cooperative intruders,** i.e., aircraft that are equipped with a means of electronic identification (e.g., a transponder, ADS-B or ADS-R) that allows own aircraft to receive state information (e.g., altitude) of the intruder;
- **Non-cooperative intruders,** i.e., aircraft that are not equipped with a transponder nor ADS-B transmitter for which all state data must be determined by own aircraft onboard sensors, such as an onboard air-to-air radar (ATAR).

ACAS Xu operates independently of ground-based aids and ATC. Aircraft equipped with ACAS Xu can interrogate airborne transponders, receive ADS-B messages, and use non-cooperative surveillance to determine the location of other aircraft to assess the risk of collision.

ACAS Xu aircraft are to be equipped with a barometric altimeter capable of providing altitude information to the ACAS Xu system as well as a Mode S transponder. The Mode S transponder provides the following information about own aircraft to the ACAS Xu system: Mode S address, Mode A code, altitude, and altitude quantization. Furthermore, the Mode S transponder is used to coordinate RAs with other suitably equipped aircraft and broadcast RA information to the ground. Additionally, the Mode S transponder is responsible for communicating own aircraft ACAS equipage to other aircraft in the vicinity and to the ground.

ACAS Xu needs to know the altitude above ground level to avoid issuing RAs which may cause own aircraft to be unsafely close to the ground. When AGL altitude is available and credible, it is used by ACAS Xu in the threat-resolution decision-making process.

Although ACAS Xu is an extension to ACAS Xa/Xo, it differs in the following areas:

- In addition to a collision avoidance function, ACAS Xu also provides an RWC function;
- ACAS Xu does not provide TAs;
- In addition to conflict resolution advice in the vertical plane, ACAS Xu also provides alerts in the horizontal plane;
- In addition to cooperative surveillance, ACAS Xu can use non-cooperative surveillance inputs as part of its threat resolution logic;
- Optionally, ACAS Xu may automatically respond to RAs and return to course after conflict termination;
- ACAS Xu can issue RAs (in certain conditions) against ADS-B only tracks.

---

[133] See Section 13.8 for information regarding other collision avoidance systems for RPAS.

Note: Due to the complexity of the ACAS Xu system – its design, operations, and logic aspects extend beyond the scope of this ACAS Guide – its description is not as detailed as the coverage of TCAS II and ACAS Xa/Xo. The Reader is advised to refer to the ACAS Xu and DAA MOPS for more information (see Sections 23.2 and 23.3).

13.2 ACAS Xu surveillance and tracking

ACAS Xu uses three main sources of surveillance to track potential threats: active surveillance, passive surveillance (ADS-B and ADS-R), and non-cooperative surveillance.

When airborne, the ACAS Xu equipment will periodically transmit active interrogation signals. These interrogations are received by other aircraft's altitude reporting transponders. ACAS Xu will detect the presence of Mode S-equipped aircraft and will receive a reply containing other aircraft's altitude. The ACAS Xu will compute the range of the other aircraft using the time difference between the transmission of the interrogation and the receipt of the reply. ACAS Xu uses hybrid surveillance to extend display range and limit interference (see Section 10.4).

ACAS Xu will also use surveillance information provided by ADS-B and ADS-R of other aircraft, including the location and speed of those aircraft. The quality of ADS-B surveillance enhances the performance of collision avoidance by ACAS Xu. ACAS Xu will process ADS-R messages that are re-broadcast by ADS-B ground stations (when available).

Non-cooperative surveillance data is also received via an air-to-air primary radar (ATAR), which provides track data rather than raw measurements. The system provides an estimate of the location of all intruders (with or without a transponder onboard) within the radar detection volume.

Data from all surveillance sources are tracked and correlated. As with the ACAS Xa system (see Section 12.2.1), the STM module will select one surveillance track for each target. This data will be used to determine whether any manoeuvre guidance or action must be issued. Conflict resolution advice will be coordinated with other aircraft carrying equipment capable of generating RAs.

ACAS Xu can issue RAs based on the ADS-B track if the ADS-B data is validated with active or ATAR surveillance. If ADS-B fails validation, the system reverts to using active or ATAR surveillance for threat resolution. ACAS Xu will also generate RWC alerts.

13.3 Threat resolution

Similarly to ACAS Xa (see Section 12.2.2), the ACAS Xu TRM module uses intruder track data to assess whether an intruder is a threat to own aircraft. If the intruder poses a threat, a recommended action is selected and communicated to the pilot. That action can be in both the vertical and horizontal plane.

Vertical and horizontal manoeuvres are determined independently by separate vertical and horizontal TRM threat logics. Vertical and horizontal alerting and guidance are depicted independently on the relevant displays. The timing of vertical and horizontal alerts may not coincide. If the timing coincides, the pilot is expected to respond to both recommended manoeuvres, resulting in a blended manoeuvre (a combination of both vertical and horizontal response) – see Section 13.4.2 more information.

13.4 ACAS Xu RAs

ACAS Xu RAs will indicate vertical and horizontal manoeuvres that are predicted to either increase or maintain the existing separation from the threat aircraft. ACAS Xu is the first operational ACAS system ever to incorporate horizontal RAs.

In some cases, an intruder (or intruders) can result in RAs being issued in both the vertical and horizontal planes (i.e., a Blended RA).

Table 18: Key alerting differences between ACAS II and ACAS Xu alerting

	TCAS II & ACAS Xa	ACAS Xu
TAs	Issued	Not issued
RAs against ADS-B only threats	Not issued	Issued
Corrective RAs required vertical rate	1500 ft/min.	1000 ft/min.
Strengthening RA required vertical rate	2500 ft/min.	2000 ft/min.
Preventive RAs annunciation	*"Monitor vertical speed"*	*"Traffic, monitor"*
Weakening preventive RAs annunciation	*"Monitor vertical speed"*	No annunciation
Horizontal RAs	Not issued	Issued, including blended RAs
RA termination	*"Clear of conflict"*	No annunciation

In addition to horizontal RAs, ACAS Xu provides a set of vertical RAs as TCAS II and ACAS Xa, including crossing RAs (see Table 7 and Table 8). The key differences between TCAS II/ACAS Xa and ACAS Xu systems alerting are outlined in Table 18.

RAs are displayed to the pilot in a similar manner to other systems, using green and red arcs (or equivalent) indicating to the pilots how they should manoeuvre the aircraft to reach the required vertical rate and which rates are prohibited. Similar aural annunciations are used. The following differences should be noted:

- ACAS Xu corrective RAs (including crossing RAs) require a vertical rate of 1000 ft/min.;
- ACAS Xu reversal RAs require a vertical rate of 1000 ft/min.;
- ACAS Xu strengthening RAs require a vertical rate of 2000 ft/min.;
- Similarly to ACAS Xa, instead of Maintain Vertical Rate RAs Climb or Descend RAs are issued, as appropriate;
- There are no aural annunciations associated with weakening preventive RAs;
- Preventive RAs (like Do Not Climb or Do Not Descend) are announced *"Traffic, monitor"* rather than "*Monitor vertical speed*" as in ACAS II;
- For reversal RAs, when the aircraft is level or moving in the vertical sense required by the RA no green arc will be shown nor aural annunciation made;
- There is no Clear of Conflict annunciation.

A vertical RA will terminate when the horizontal component of the TRM determines that no further horizontal guidance is needed to resolve the conflict. RA reversals are determined independently in the vertical and horizontal dimensions.

ACAS Xu vertical RAs can be combined with DAA alerts as well as horizontal RAs.

13.4.1 Horizontal RAs

The requirements for the display and annunciation of horizontal RAs are contained in ACAS Xu MOPS as well as Detect and Avoid MOPS (see Section 23.2).

The same display and annunciation philosophy is used for horizontal RAs as it is for vertical RAs: on a heading display required and prohibited heading ranges are marked in green and red respectively. An example of a heading display showing a Turn Left RA is shown in Figure 55 (implementation details may vary, including the incorporation of traffic display into RA display). In this example, the own aircraft's heading in 360° and ACAS Xu issues a Turn Left RA with a target track angle of 300°.The horizontal RA required heading (fly-to) band begins at the target track angle and extends 15° in the direction of the commanded turn. The red prohibited heading band begins at the required heading (i.e., 300°) and extends in the other direction, to 180° (i.e., behind own aircraft current heading). If a horizontal RWC guidance is present at the same time, it may be displayed at the remainder of the compass rose.

The direction of required turn is announced either "*Turn left*" or "*Turn right*".

Reversal horizontal RAs (i.e., a change from a right turn to a left turn or vice versa) annunciations contained the word "*NOW*" (similarly to vertical reversal RAs annunciations), e.g., "*Turn right NOW*". RA reversals are determined independently in the vertical and horizontal dimensions.

Figure 55: Example of heading display with a horizontal RA.

A horizontal RA will terminate when the horizontal component of the TRM determines that no further horizontal guidance is needed to resolve the conflict. There is no Clear of Conflict annunciation.

13.4.2 Blended RAs

In some cases, an intruder or intruders can result in RAs being issued in both vertical and horizontal directions, resulting in a **Blended RA**. Once issued, the vertical and horizontal components of a Blended RA will each continue independently until they are no longer needed in that direction to resolve the conflict. Blended RAs are simultaneously displayed on the relevant instrumentation for each direction. Vertical and horizontal aural annunciations will be combined into a single one, e.g., "*Turn left, turn left and climb*".

A Blended RA will terminate only when the RAs in both dimensions have been terminated.

Blended RAs allow ACAS Xu to achieve the best safety performance possible with the aircraft manoeuvre performance available at the time.

13.4.3 Automatic response to RAs

ACAS Xu equipped aircraft can be equipped with the implementation of an automatic RA (both horizontal and vertical) response function or allow a remote pilot to fly RAs. If implemented, the functional processing of the automated execution of RAs as well as DAA's Return-to-Course is not considered part of the ACAS Xu equipment. The requirements for automatic response, including an option for pilot override, are contained in DAA MOPS (see Section 23.2).

13.4.4 Aircraft performance

The following aircraft performance is expected in order to comply with ACAS Xu RAs[134]:

Vertical sense:

- Manoeuvre initiated within 5 seconds for an initial RA and vertical acceleration of ¼ *g*;
- Manoeuvre initiated within 2½ seconds for a reversal RA and vertical acceleration of ⅓ *g*;
- Achieved vertical rate of 1000 ft/min. for Climb and Descend RAs and 2000 ft/min. for Increase Climb and Increase Descent RAs.

Horizontal sense:

- Manoeuvre initiated within 5 seconds for an initial RA;
- Manoeuvre initiated within 2½ seconds for a reversal RA;
- Turn rate of 3 deg./sec (degrees per second) with horizontal acceleration of 1 deg./sec^2 (degree per second squared).

ACAS Xu can be installed on aircraft that are at times incapable of conforming with the performance requirements listed above. In these cases, the ACAS Xu logic will attempt to compensate for the reduced aircraft performance.

Through dynamic aircraft performance inputs to the ACAS Xu logic, the current own aircraft vertical and horizontal manoeuvre capabilities can be considered to compensate for reduced aircraft performance and issue RAs earlier in an encounter.

13.5 Coordinating RAs against ACAS-equipped threats

For ACAS Xu equipped aircraft, RA coordination principles are similar to those for ACAS II, as described in Section 8.3.

In encounters between two aircraft equipped with a collision avoidance system capable of generating RAs, once an RA has been issued each aircraft will transmit 'interrogations' to the other aircraft to ensure the compatibility of the resolution advice.

ACAS Xu will transmit to each threat its intent with respect to that threat (e.g., whether to pass above or below it, to the left or to the right), and will receive from each threat the intention of that threat with respect to own aircraft. In multi-aircraft encounters, coordination will take place with each suitably equipped threat individually.

As ACAS Xu provides both vertical and horizontal RAs, the coordination message transmitted by ACAS Xu will contain independent vertical and horizontal components. A threat aircraft with only a vertical RA capability (i.e., TCAS II or ACAS Xa), will only coordinate vertically with ACAS Xu.

---

[134] The values listed below are not applicable to RWC manoeuvres.

For the DAA alerting (see Section 15) only Collision Avoidance (CA) will be coordinated. Although the Remain Well Clear (RWC) function provides only suggestive guidance, not directive, it is still required to be compatible with any RAs generated by the intruder aircraft (without any explicit coordination that is done for RAs).

Before selecting an RA, ACAS Xu will first check if it has received a Vertical Resolution Advisory Complement (VRC) or Horizontal Resolution Advisory Complement (HRC) from the threat. If no VRC or HRC has been received, ACAS Xu will select the optimum RA based on the encounter geometry. If a VRC or HRC has been received, ACAS Xu will initially select an RA based on an intent complementary to that of the threat. The exception to this rule applies if less than 3 seconds have elapsed since a "*slave aircraft*" selected a crossing RA; in this case, a "*master aircraft*" has the option of reversing the "*slave aircraft*" to a non-crossing RA[135].

For information regarding coordination with future collision avoidance systems, see Section 8.3.3.

13.6 ACAS Xu on the ground

ACAS Xu does not support operations on the ground. While on the ground, ACAS Xu displays airborne intruders as Other Traffic.

13.7 Hybrid surveillance

As with for TCAS II and ACAS Xa/Xo, the hybrid surveillance functionality for ACAS Xu is to reduce the interrogation rates while not degrading collision avoidance protection offered by the system. The hybrid surveillance is a standard functionality of ACAS Xu; however, loss of hybrid surveillance will not result in a loss of ACAS Xu collision avoidance abilities.

For more information about hybrid surveillance see Section 10.4.

13.8 Other collision avoidance systems for RPAS

The increase in the number of operations by RPAS in recent years, for both civil and military purposes facilitated the development and introductions of various collision avoidance systems and *detect & avoid* systems for this category of aircraft.

These systems, developed by various manufacturers, do not necessarily follow the standards defined in the ACAS Xu MOPS and utilise proprietary algorithms and solutions. Collison avoidance and DAA manoeuvres commanded by these systems may or may not be compatible with collision avoidance manoeuvres given by the ACAS X or TCAS II systems. Aviation standardisation bodies and regulators are undertaking steps to ensure compatibility of collision avoidance systems.

[135] Terms "*master aircraft*" and "*slave aircraft*" are explained in Section 21.

14. ACAS sXu SYSTEM

14.1 Overview

The ACAS sXu system is a part of ACAS X family of systems and a derivative of the ACAS Xu system. It is designed for small RPAS[136] operating beyond visual line of sight by the pilot and not receiving any ATC services. ACAS sXu utilises a range of surveillance technologies that are available to this category of aircraft and adapted to their performance and manoeuvring characteristics, in order to provide DAA capability.

ACAS sXu in intended for aircraft that are not operating under Instrument Flight Rules (IFR) and are not equipped with a transponder not ADS-B. Consequently, ACAS sXu equipped aircraft will not be visible to TCAS II, ACAS Xa and ACAS Xu systems.

ACAS sXu provides primary tactical mitigation against the risk of midair collision with manned and large unmanned aircraft as well as against other small RPAS.

The ACAS sXu logic has the same general system architecture as ACAS Xa, consisting of STM module (see Section 12.2.1) and TRM module (see Section 12.2.2).

ACAS sXu is design to provide DAA protection against airborne intruders using the following primary surveillance data inputs:

- ADS-B In (ACAS sXu requires both 1090 MHz Extended Squitter (1090ES) and 978 MHz Universal Access Transceiver (UAT) In equipage);
- Non-Cooperative (ACAS sXu requires the ability to receive non-cooperative surveillance data when operating in airspace with non-cooperative intruders);
- Vehicle-to-vehicle (V2V) data (yet to be defined link that will enable communications directly between various airborne platforms).

ACAS sXu requires several own data inputs, including height above the ground, pressure altitude, speed and several more.

Small RPAS operations incorporate automated responses to the DAA system. All ACAS sXu DAA guidance is directive, i.e., ACAS sXu directs the specific manoeuvre(s) to perform. That allows for auto response to directive guidance response without precluding pilot response. Rather than including separate RWC and collision avoidance functions, ACAS sXu provides one level of alerting and guidance. The protection volume size is based on intruder type: a larger alerting volume for manned aircraft and larger RPAS and a smaller volume for other small RPAS.

ACAS sXu does not perform collision avoidance manoeuvre coordination with TCAS II, ACAS Xa nor ACAS Xo equipped aircraft. Coordination with other suitably equipped small RPAS is possible using V2V link (not yet available).

Since ACAS sXu is expected to operate at low altitudes, it incorporates a terrain and obstacle awareness capability. As a standard feature, the ACAS sXu logic uses the own aircraft's altitude above ground level for vertical alerting. Optionally, terrain and obstacle data for the surrounding region can be fed to the logic. ACAS sXu will prioritize the avoidance of aircraft over avoidance of terrain and obstacles.

Note: Due to the complexity of the ACAS sXu system – its design, operations, and logic extending beyond the scope of this ACAS Guide – its description is limited. The Reader is advised to refer to the ACAS sXu and DAA MOPS for more information (see Section 23.2).

[136] There is no strict definition of "small RPAS". Typically, RPAS weighting less than 25 kg on take-off (including the payload) with a wingspan less than 7.5 metres are considered to be small RPAS.

14.2 ACAS sXu RAs

14.2.1 Vertical RAs

ACAS sXu uses a similar set of vertical RAs as ACAS Xu (see Section 13.4.1) with the following differences:

- ACAS sXu corrective RAs (including crossing RAs) require a vertical rate of 500 ft/min.;
- ACAS sXu reversal RAs also require a vertical rate of 500 ft/min.

14.2.2 Horizontal RAs

Horizontal RAs, in the addition to those available for ACAS Xu (see Section 13.4.1), feature a Maintain Target Angle RA (i.e., an RA requiring to continue the present heading).

14.2.3 Blended RAs

For ACAS sXu, the same principles apply as for ACAS Xu – see Section 13.4.2.

14.2.4 Automatic responses to RAs

ACAS sXu is suitable for pilot and automatic response to RAs. Auto-response is the nominal configuration and has been assumed during logic development and optimization.

14.2.5 Aircraft performance

Nominally, the following aircraft performance is expected in order to comply with ACAS sXu RAs:

Vertical sense:

- Manoeuvre initiated within 1 second for all RA if responded to automatically[137];
- Vertical acceleration of ¼ *g* for initial RAs;
- Vertical acceleration of ⅓ *g* for reversal and subsequent Climb and Descend RAs.

Horizontal sense:

- Turn rate of 3 deg./sec (degrees per second) with horizontal acceleration of 3 deg./sec^2 (degree per second squared).

[137] For pilot responses, nominal response times are longer and vary from 5-10 seconds for initial RAs and 3-5 seconds for subsequent.

15. Detect & Avoid Alerting

15.1 DAA overview

Before the advent of RPAS, manned aircraft were assumed to be adequately safe from collision risk when operating in VMC because the pilot was able to see and avoid other traffic (i.e., *see & avoid*, refer to Section 2.2 for more information).

RPAS operations are conducted without the possibility of direct human intervention from within or on the aircraft. RPAS pilots operate from remote stations where they are provided with the means to pilot, monitor and control the operation of the RPAS both on the ground and in the air. The remote pilots are provided with the tools necessary to effectively operate the flight, including the resolution of traffic conflict situations. The controls, displays and alarms might be different from those of manned aircraft (and, consequently, the procedures for and training of remote pilots will be different).

The *detect & avoid* (DAA) functionality allows the remote pilots to exercise their responsibilities with regards to *see & avoid* by detects, tracking proximate traffic, and providing traffic situation information to the remote pilot. In case a collision hazard is detected by DAA, it will provide a collision avoidance alert to the remote pilot together with appropriate collision avoidance manoeuvre guidance to assist the remote pilot in avoiding a collision.

Furthermore, if there is no response from the remote pilot to the collision avoidance alert, the DAA will automatically initiate an appropriate collision avoidance manoeuvre. The DAA will inform the remote pilot and, if possible, ATC as well using an appropriate Mode S or ADS–B message.

Following initiation of a collision avoidance manoeuvre (automatic or by a remote pilot), the DAA will terminate the manoeuvre on a remote pilot command. The DAA will issue a Clear of Conflict message to the remote pilot once the collision risk has cleared.

The DAA system performs its function against both cooperative and non-cooperative intruders in VMC as well as cooperative intruders in IMC. The collision avoidance function provided by DAA is similar to the function that ACAS II provides on manned aircraft.

However, there are a few noticeable differences with ACAS II:

- The DAA system will also provide RAs against non-cooperative aircraft;
- The DAA system will provide RAs in the vertical plane (i.e., up or down), horizontal plane (i.e., left or right) or a combination of both;
- The DAA system will not issue TAs as the RWC alert will serve this purpose (see Section 15.2 below for more information).

The DAA traffic display indicates the position of the intruding aircraft relative to the own aircraft and is intended to provide information of surrounding traffic to the remote pilot. Some of the symbols used on DAA systems traffic displays are shown in Table 5.

Regulatory decision on the operations of DAA systems as well as relevant operational procedures have not been published at the time of writing.

15.2 Remain Well Clear (RWC)

The purpose of the Remain Well Clear (RWC) function is to ensure that an aircraft is not operated in such proximity as to cause a collision hazard (with other aircraft, objects or terrain). Remaining well clear of collision hazards in manned aviation is left to pilot discretion. As it is subjective, various parameters were adopted as a set of RWC minima.

RWC alerting and guidance indicates vertical and horizontal manoeuvres against intruder aircraft to either regain or maintain Well Clear to prevent a potential RA that may occur if no action is taken. If the threat aircraft is itself equipped with a collision avoidance equipment capable of generating RAs, a coordination procedure via the air-to-air Mode S data link will be performed to ensure that the RAs are compatible.

RWC alerts are intended to alert the remote pilot to the presence of an intruding aircraft with an alerting time that should normally allow for the remote pilot to contact ATC to request a new clearance (when operating in controlled airspace). For this reason, the RWC alert is expected to be issued with a longer alerting time than that provided by an ACAS II TA.

Standardisation bodies adopted various RWC minima parameters, varying depending on the own aircraft collision avoidance equipage, intruding aircraft collision avoidance equipage, class of airspace and other factors. The detailed description of RWC minima is outside the scope of this ACAS Guide. For more information, the Reader is advised to refer to RTCA and/or EUROCAE standardisation documents (see references in Sections 23.2 and 23.3).

15.3 Provision of DAA information to ground systems

Like TCAS II and ACAS Xa, ACAS Xu communicates with ground monitoring equipment. ACAS Xu provides DAA alerting and guidance information to the ground using five different means. This information can be used to monitor ACAS Xu performance, to provide information for incident investigations, and to provide "RA downlink display to controller" (see Section 9.21). The formats have been revised for ACAS Xu to provide more detailed information than ACAS Xa/Xo, including details about horizontal RAs and RWC alerting and guidance.

16. RA Statistics and Assessment of Pilot Compliance

In the late 2010s, a large amount of aircraft track data was collected for the period of 12 months using Mode S radars located in core European airspace[138]. The obtained data was used for the TCAS II statistical and performance study of which full details are available in the report referred to in the footnote[139]. The data presented in this Section is derived from this study.

It should be noted that the data reflects the pre-COVID-19 pandemic traffic levels. The reduction in air traffic due to the COVID-related restrictions certainly had an impact on the frequency of TCAS II alerts, as due to the lower traffic density and the lower number of flights, there were fewer aircraft and they were less likely to be in conflict. Initial monitoring data indicates that the number of RAs dropped to 25-30% of the pre-COVID situation.

The same set of data was subsequently used in the study assessing pilot compliance with RAs[140], which is summarised in Section 16.9.1.

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. EUROCONTROL's EVAIR project[141] collects and processes reports received from other sources (e.g., pilot or ATC reports) and supports the involved parties with feedback regarding the events.

16.1 Frequency of RAs and TAs

16.1.1 Radar derived data

The data collected for the above-mentioned study comprise just over 9 million flight hours. That represented approximately 55% of all European traffic at the time. In this data set, there were 1242 valid[142] first[143] RAs recorded in 1072 encounters[144]. This means, an RA was observed approximately every 7250 flight hours or 3½ times a day (see Table 19). It is believed that outside the core airspace, the frequency of RAs is lower due to lower traffic volumes.

---

[138] Airspace in western and central part of Europe where traffic density is high.

[139] EUROCONTROL: TCAS – Selected Statistical and Performance Data in Core European Airspace, EUROCONTROL, 15 February 2021 – available on SKYbrary.

[140] EUROCONTROL: The assessment of pilot compliance with TCAS RAs, TCAS mode selection and serviceability using ATC radar data, EUROCONTROL, edition 2.2, 10 February 2022 – available on SKYbrary.

[141] EUROCONTROL Voluntary ATM Incident Reporting. For more information and to access full reports go to EVAIR website.

[142] Approximately 1% of all recorded RAs were excluded from the study as anomalous, i.e., the recording did not contain a valid string of bits.

[143] First RA refers to the initial RA issued to an aircraft during an encounter. The first RA may or may not be the only RA in this encounter.

[144] Cases when two aircraft are in proximity and one or both of them receive an RA.

Table 19: RA frequency in core European airspace

RA frequency Core European airspace	
⏱	Every 7250 flight hours
📅	3 ½ RAs per day

16.1.2 Aircraft derived data

TCAS RA monitoring data collected on the ground is subject to limitations, e.g., latency of radar rotation, limited detection, etc. Additionally, TAs cannot be recorded on the ground, as they are not downlinked. To expand on the data set obtained from radar recordings, data was obtained from a number of airlines on their TCAS statistics collected through the Flight Data Monitoring (FDM) scheme.

This data set indicates that an RA occurs approximately once per 3000 sectors flown by a short and medium haul fleet (single aisle aircraft) and once per 1050 sectors for a long haul fleet (wide body aircraft).

TAs are much more frequent events – they occur once every 14 legs (flight sectors) for short/medium haul fleet and 11 legs for long haul. A TA to RA ratio is approximately 215:1 and 95:1 for short/medium haul and long haul fleets respectively (Table 20).

Table 20: Aircraft derived TA and RA frequency data

	Flight legs per RA	Flight legs per TA	TA:RA ratio
Short/medium haul	~3000	~14	~215:1
Long haul	~1050	~11	~95:1

16.2 Encounter distribution by threat type

In the vast majority of encounters, only one aircraft involved received an RA (see Figure 56). In only 170 (15.9%) cases both aircraft received RAs. 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.

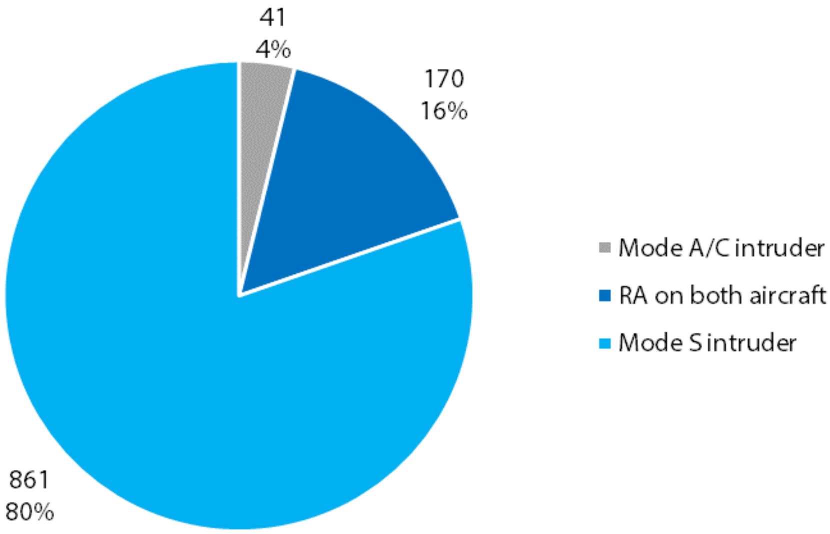


Figure 56: Encounter distribution by threat type.

16.3 Encounter distribution by threat type and Flight Level

In European airspace, the majority of encounters resulting in an RA or RAs occurred in upper airspace, i.e., above FL290 as illustrated in Figure 57. A distribution of encounters by Flight Level and threat type is shown in Figure 58.

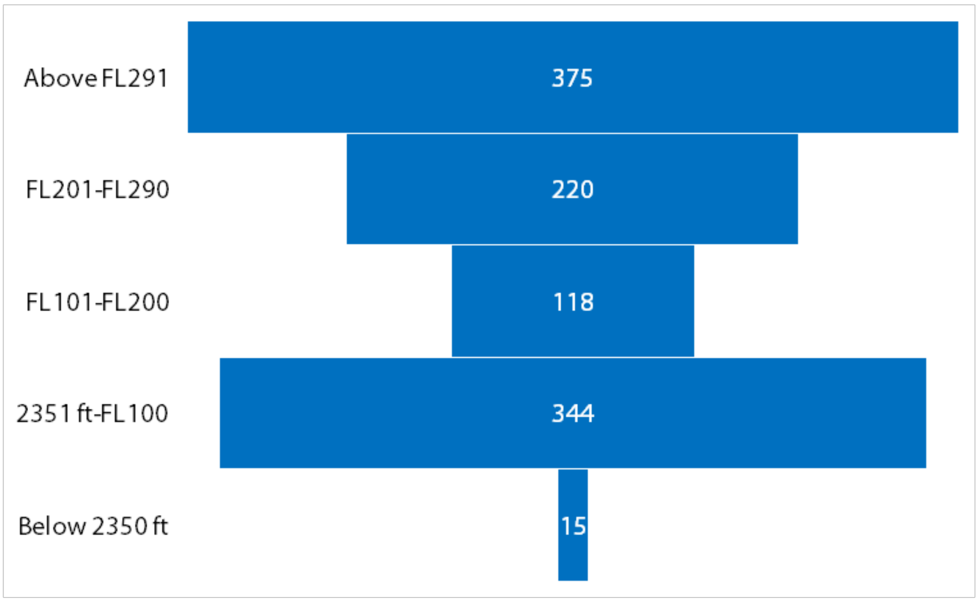


Figure 57: RA distribution by Flight Level

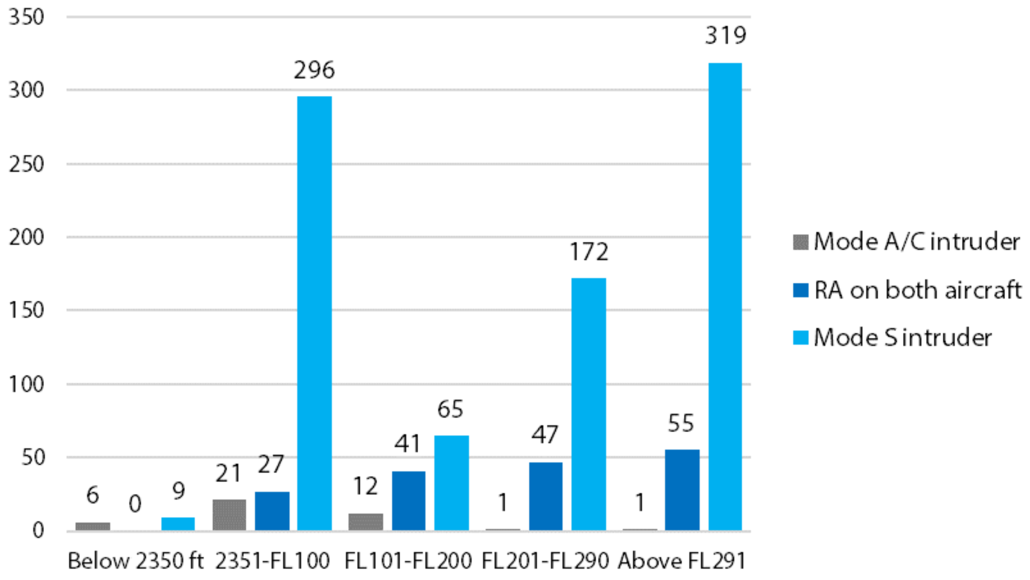


Figure 58: Encounter distribution by threat type and Flight Level.

16.4 RA distribution by RA type

16.4.1 Initial RAs

The most common initial RA (64.0%) was a Level Off RA, followed by Monitor Vertical Speed, Climb and Descend RAs (see Figure 59). Some RAs are rare: out of 1242 recorded RAs there were only 4 Maintain Vertical Speed, 2 Crossing Descend, and 1 Crossing Climb RAs. There were no Crossing Maintain Vertical Speed RAs recorded as an initial RA.

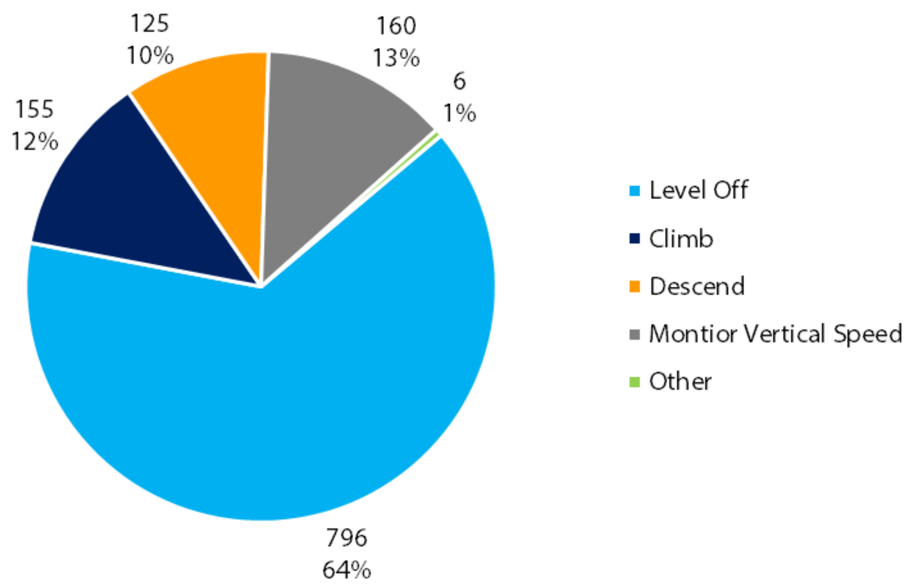


Figure 59: Initial RAs by RA type.

16.4.2 Subsequent RAs

Only 16.8% of initial RAs resulted in a subsequent RA. Here, the most common were again Level Off (82.3%) RAs, followed by Climb and Descend RAs (see Figure 60). Maintain Vertical Speed RAs were issued four times, while Reversal RAs occurred in five cases and Increase RAs were recorded only twice. Other RAs were not observed.

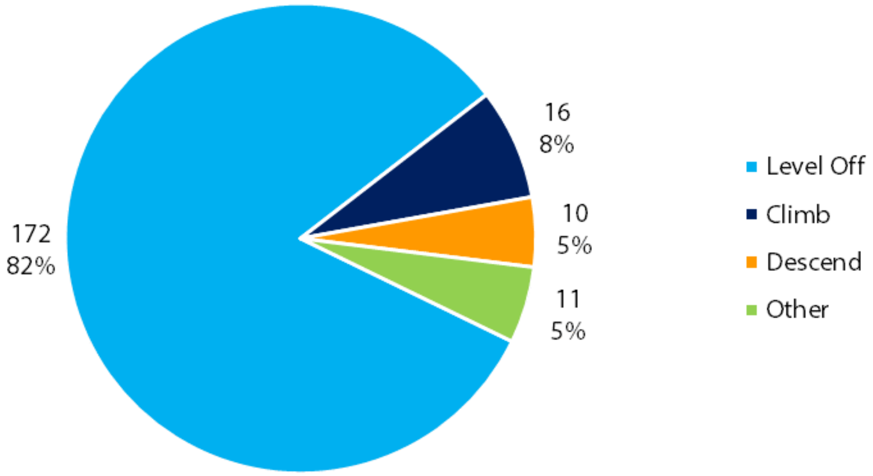


Figure 60: Number of subsequent RAs by RA type.

16.5 Vertical rates at the time of RA

Radar data monitoring indicates that at the time of the RA, as much as 16.9% of aircraft had a vertical rate in excess of 2000 ft/min. Only 6.2% RAs were generated when the aircraft was level (see Figure 61).

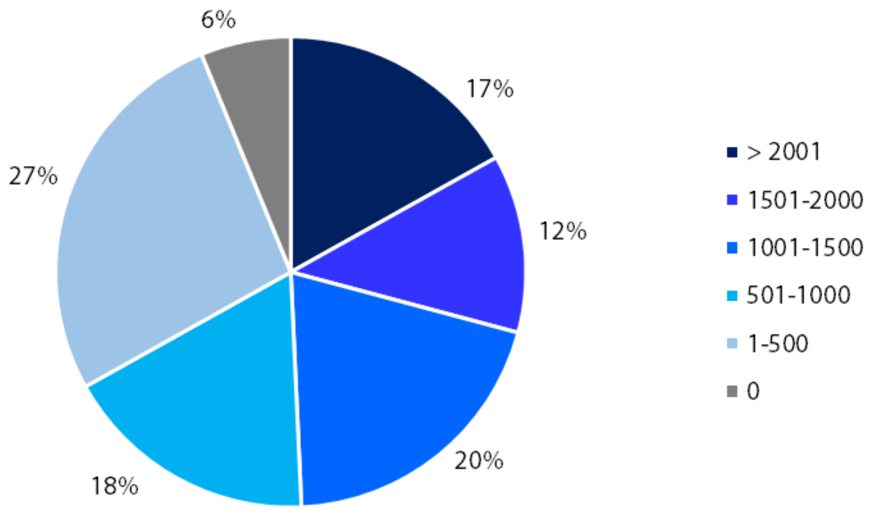


Figure 61: Vertical rate (ft/min.) at the time of RA.

More than a half (53.6%) of all Level Off RAs occurred when the aircraft's vertical rate was over 2000 ft/min. and in 34.1% of cases the vertical rate was between 1501 and 2000 ft/min. The RAs due to excessive vertical rates are not operationally needed and can be avoided in many cases if vertical rate reductions, as recommended by ICAO (see Section 24.2), are applied.

16.6 RA duration

The average RA duration was 25 seconds, and more than half of all RAs (53.5%) lasted between 21 and 40 seconds. Only a fraction of RAs were 4 seconds or shorter, or longer than 41 (4.8% and 3.5% respectively). See Figure 62 below.

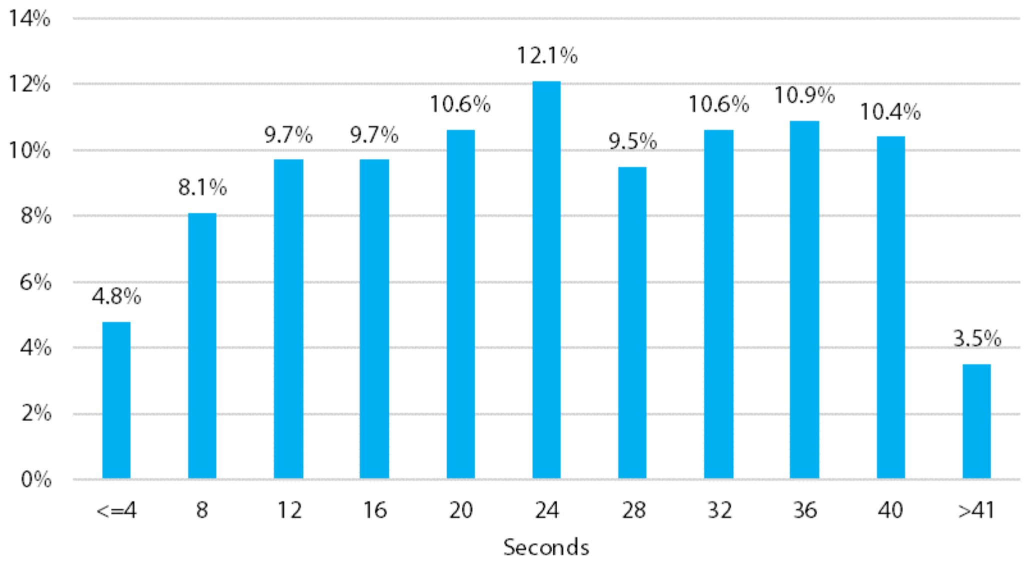


Figure 62: RA duration (in seconds).

16.7 Horizontal and vertical spacing at the time of RA

For an RA to be effective, it must be issued when sufficient horizontal and vertical spacing between the aircraft still exist and the pilot(s) have enough time to respond to the RAs. As shown in Figure 63, the majority of RAs were issued when the aircraft were still separated by over 800 feet vertically and 1.6 NM horizontally.

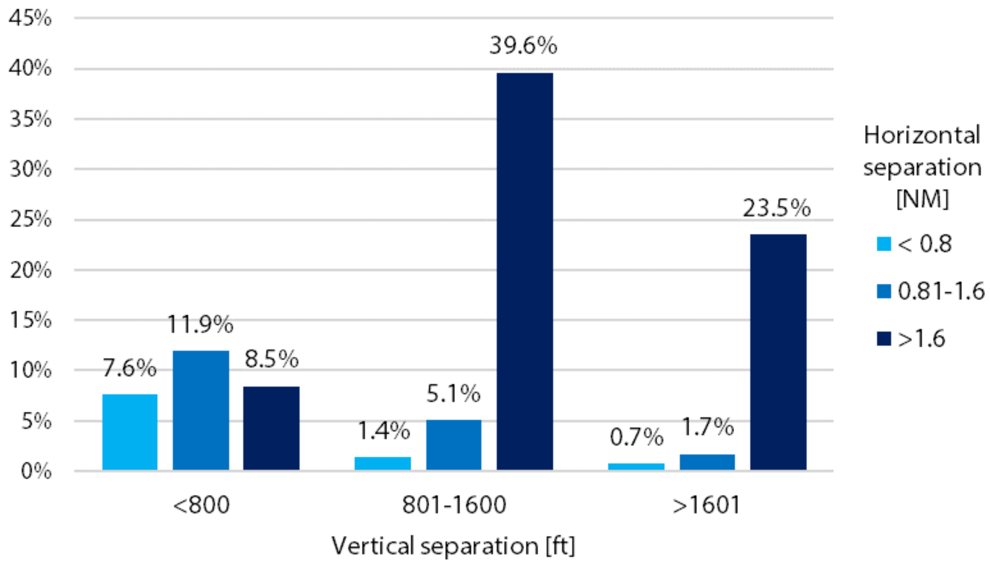


Figure 63: Horizontal and vertical spacing at the time of RA.

16.8 Horizontal and vertical miss distance at the Closest Point of Approach

Given the correct pilot responses to RAs, flight safety is increased by increasing the relative altitude between two conflicting aircraft, i.e., the Vertical Miss Distance (VMD) at the Closest Point of Approach (CPA). From the TCAS point of view, the greater the VMD, the better the level of safety that is achieved.

As illustrated in Figure 64, the achieved VMD was over 800 feet in the majority of cases. Only in 1.1% of cases, were the achieved VMD/HMD below 400 feet and 0.4 NM, respectively.

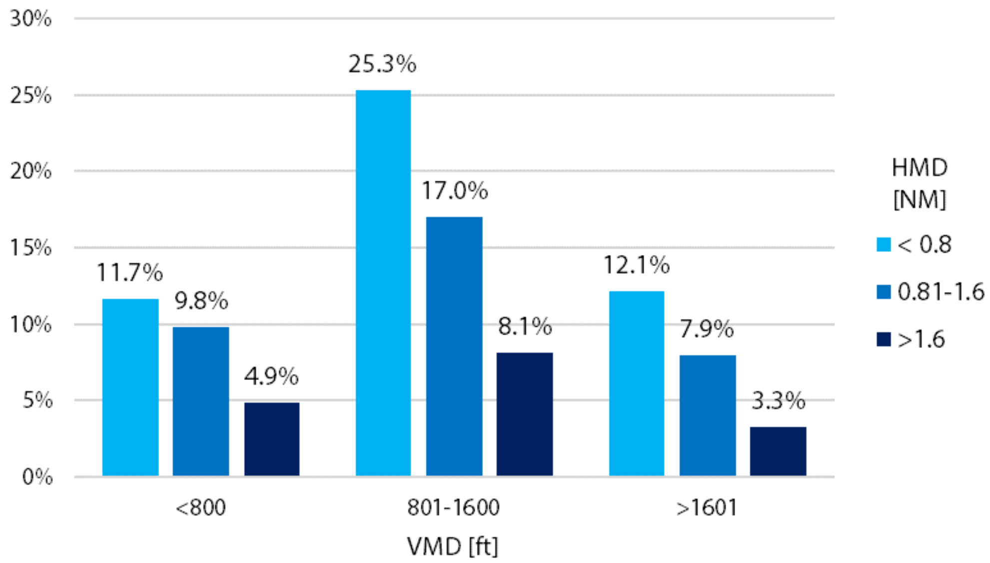


Figure 64: HMD and VMD at CPA.

16.9 Operational compliance

16.9.1 Pilot compliance with TCAS RAs

Correct and prompt pilot responses to RAs are essential to mitigate the risk of midair collision. Using Mode S radar recordings, EUROCONTROL has assessed pilot responses to RAs[145] using two different methods. Here the result of one of the methods are presented (so called *Method B*). This method takes into account the ability of a pilot to respond promptly, for example, to a Climb RA whilst in descent (i.e., taking into account the time needed to change the vertical direction of the aircraft). Under this method only initial RAs were analysed (i.e., strengthening, reversal, and weakening RAs were not analysed).

Only RAs that lasted 8 seconds or longer were taken into account, as shorter RAs may not give the pilot an opportunity to respond and change the aircraft's vertical rate as required. Also, the Monitor Vertical Speed RAs were not included in the compliance study, as these preventive RAs do not require any pilot response.

[145] EUROCONTROL: The assessment of pilot compliance with TCAS RAs, TCAS mode selection and serviceability using ATC radar data, EUROCONTROL, edition 2.2, 10 February 2022 – available on SKYbrary.

Each assessed RA has been classified as follows:

- **Followed:** the required vertical rate was achieved, or the pilot's reaction was consistent with a manoeuvre towards the required vertical rate;
- **Weak Response:** the pilot has made an adjustment in vertical speed in the required direction, but insufficient in vertical speed or acceleration to fulfil the requirement;
- **No Response or too weak response:** the vertical rate was not sufficient to achieve the required vertical rate;
- **Opposite:** the action performed by the pilot was in the opposite vertical sense compared to the RA;
- **Excessive:** the response exceeded the required vertical rate.

The results indicated that 55% of initial RAs were followed correctly at 8 seconds after the RA and 54% after 12 seconds. The remaining responses were either too weak, opposite or excessive – see Figure 65.

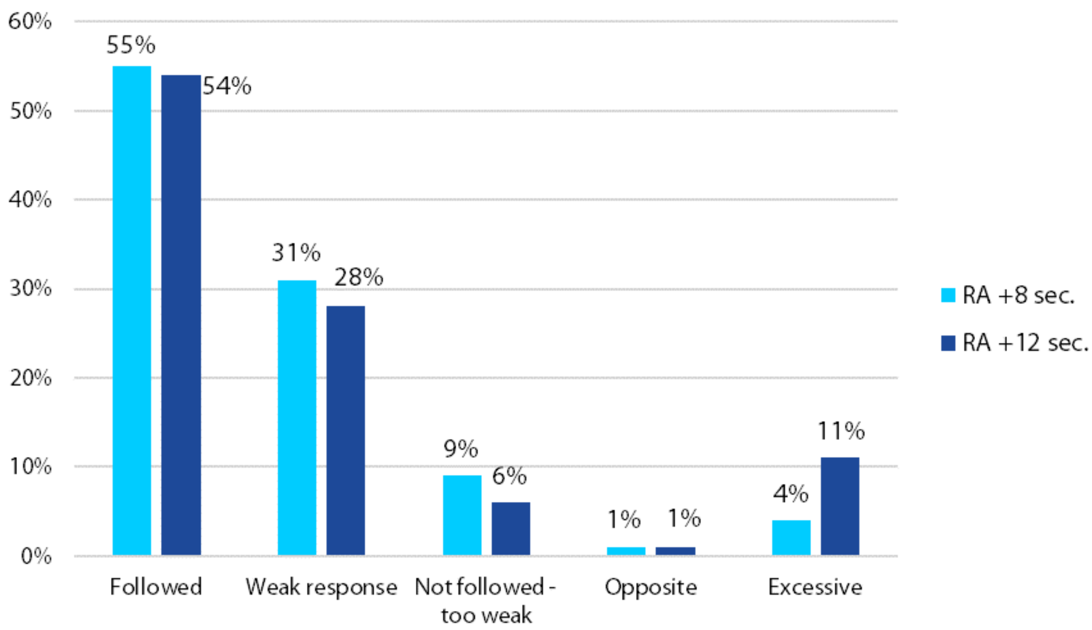


Figure 65: Pilot compliance with RAs after 8 or 12 seconds.

16.9.2 TA-only mode operations

The normal operating mode of TCAS II is TA/RA. In this mode TCAS II will provide full safety protection issuing TAs and RAs, as needed (see Section 9.12). A subset of data used for the above-mentioned study has been used to assess if the aircraft were operated in the TA-only mode.

To exclude any cases when TA-only mode is used for parallel approaches, only TA-only operations above FL100 were considered. It was found that approximately 0.6% of all flights were conducted in TA-only mode[146].

[146] For more information see Section 9 of *The assessment of pilot compliance with TCAS RAs, TCAS mode selection and serviceability using ATC radar data*, EUROCONTROL, edition 2.2, 10 February 2022 – available on SKYbrary.

While it is a small percentage of all operations, these aircraft did not benefit from the protection offered by TCAS II RAs. It is believed that the majority of these operations were due to incorrect mode selection by the crew. Technical malfunctions, like transponder fault or incorrect Mode S downlink, cannot be excluded, especially in the case of TA-only mode operations for more than one day. These malfunctions will most likely will be unknown to the crew.

While pilots may easily spot if TCAS is in standby mode as no surrounding traffic will be visible on the traffic display, the incorrect selection of TA-only might be more difficult to notice, as the surrounding traffic will be displayed.

16.9.3 TCAS II serviceability

Under the provisions of MEL (see Section 9.13) aircraft can be dispatched with TCAS II out of service. Using Mode S radar data, an assessment of TCAS II serviceability established that approximately 1.4% of flights in core European airspace are conducted with TCAS II out of service. To exclude any transient problems, only flights reporting unserviceable TCAS for more than 5 minutes were counted.

17. ACAS II OPERATIONAL ANOMALIES

17.1 Self-tracking RAs

> More information on equipment anomalies:
>
> ACAS Bulletin 23

Cases have been reported where TCAS II triggers an RA as a result of self-tracking, i.e., when an aircraft tracks itself as an intruder. Although an aircraft's suppression bus should prevent own transponder replying to interrogations, failures may occasionally occur. As TCAS II will not track Mode S intruders whose Mode S 24-bit address is the same as own aircraft, the pseudo-intruder is then seen as Mode A/C equipped aircraft at the same altitude and same position as own aircraft[147]. Self-tracking RAs are not preceded by a TA.

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.

17.2 Transponder testing on the ground

TCAS II and ACAS Xa interrogate, within their range, all Mode S and Mode A/C transponders. In addition, ACAS Xa will use ADS-B signals received from other aircraft. That will include ground-based transponders and ADS-B transmitters operated for testing or maintenance. If these transponders happen to respond with an altitude report close to that of an aircraft flying above in the vicinity, that aircraft's Traffic Display will show a 'ghost' target and could even generate TAs/RAs against such targets. These unnecessary alerts are disruptive to the flight crews 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 closed 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).

EASA AMC 20-13, § 14.1 provides the following advice on maintenance of transponders: "*Maintenance testing of altitude reporting transponders should be suitably screened to minimise the risk of nuisance traffic or collision resolution advisories in operating aircraft. When performing transponder testing which involves the use of the altitude changes, it is advisable to ensure the transponder is in 'standby' or 'off' whilst the air data system is set to the required altitude. The transponder should only be operated during the testing phase to minimise the risk of interference with other aircraft. Following completion of the testing, the transponder should be returned to 'standby' or 'off'. The air data system may then be returned to atmospheric pressure. Note: Before performing any transponder testing involving altitude changes the local Air Traffic Controller should be contacted and a 'safe test altitude(s)' agreed.*"

[147] In a Mode S RA downlink message, a self-tracking RA will typically display the intruder for the duration of the event at very close proximity (0.05–0.1 NM) to the RA-receiving aircraft and without a Mode S address.

17.3 False RAs

An RA caused by a false track or an ACAS II malfunction is a false RA. In rare situations, ACAS II may generate an RA due to surveillance or tracking anomalies when there is no threat. For instance, own aircraft may see another aircraft in the vicinity much closer than it really is, determine it is a threat and generate an RA against it.

For example, two aircraft operating in close proximity (i.e., formation flights – see Section 9.16), such as a pair of military fighters) equipped only with a Mode A/C transponder (rather than a Mode S transponder) can be acquired by ACAS II using Mode C only interrogation (*whisper shout* interrogations). As Mode C replies will be transmitted at about the same time, their replies will overlap causing garbling and the receiver may incorrectly decode the content of the replies and, consequently, incorrect altitude will be used.

Pilots, in real time, have no possibility to determine if the RA is false and, therefore, are expected to follow it and report to ATC.

An RA which is operationally unnecessary (nuisance) but generated according to the collision avoidance logic should not be classified as false RAs. Any suspicious RAs should be reported and investigated to determine whether there is an underlying problem with the ACAS II equipment or design.

17.4 Turbulence

ACAS II does not account for environmental factors such as turbulence. Turbulence can cause an aircraft to briefly deviate from its assigned altitude, as the autopilot may respond with pitch or power adjustments. If another aircraft is flying at an adjacent flight level, ACAS II may perceive it as a potential collision risk and consequently issue an RA.

An RA which is operationally unnecessary (nuisance) but generated according to the collision avoidance logic should not be classified as false RAs. Any suspicious RAs should be reported and investigated to determine whether there is an underlying problem with the ACAS II equipment or design.

17.5 Domino effect encounters

Rarely, a domino effect encounters may occur. In these cases, an ACAS II equipped aircraft responds to an RA to avoid a threat and that brings it into a conflict with a third aircraft which gets an RA, and so on. This may be expected to take place for example in a holding pattern. Although this type of scenario is operationally undesirable, ACAS II can handle multiple threats and resolve the situation.

17.6 Operationally unnecessary RAs during parallel approaches (*tau*-cap RAs)

17.6.1 Background information

Reports of operationally unnecessary TCAS II RAs have been received from a number of European airports as well as some airports outside Europe. Examples of horizontal and vertical trajectories are shown in the adjacent graphs in Figure 66.

In the reported cases, the aircraft were separated vertically by approximately 600 feet and horizontally by approximately 1 NM when they received coordinated TCAS II RAs, in some cases resulting in a missed approach by one of the aircraft.

17.6.2 *Tau*-cap mechanism

TCAS II diagnoses a risk of a midair collision on the basis of an estimated time to collision (i.e., assuming the worst-case scenario) and whether this falls below a certain time threshold (see Section 11.2.3 for more information). In order to be robust and remain independent of the means of separation provision, this estimate (known as *tau*) is based on a simple calculation derived only from the tracked range of the potential threat.

A consequence of the algebra of this simple calculation is that, if there is a significant miss distance at closest approach ("significant" from a collision avoidance perspective can be much closer than from a separation provision perspective), the estimated time to collision can rise to arbitrarily large values while the aircraft are still converging.

If the TCAS II algorithms ignored this effect, then an RA could be delayed or even prevented (depending on the altitude profiles) if the aircraft pass close to each other but remain on a straight course. However, if in this scenario one or other of the aircraft execute a late manoeuvre there will be insufficient time remaining before a potential collision for a timely and effective RA to be issued.

To overcome this deficiency the value of *tau* is "capped" (i.e., not allowed to increase) in encounters in which the aircraft are projected to pass close (from a collision avoidance perspective) to each other.

The *tau*-cap mechanism ensures that in close encounters in which there is a late manoeuvre, a timely and effective RA can be issued. The drawback is that in instances of planned proximity (such as parallel approaches) an RA can be issued even though there is not a late manoeuvre.

The *tau*-cap mechanism has been present in all operational versions of TCAS II logic, from version 6.02 (now obsolete), through version 7.1 (one of the versions currently mandated in Europe). The *tau*-cap mechanism is not used in ACAS Xa.

17.6.3 Threat detection

The TCAS II threat detection algorithms onboard own aircraft declare an alert if an intruder simultaneously satisfies two criteria referred to as passing the Range Test (see Section 11.2.3.1) and passing the Altitude Test (see Section 11.2.3.2).

The Range Test passes if, on the basis of tracked range and range-rate, the intruder is:

- currently close; or
- is projected to be close within some given time threshold.

The Altitude Test passes if, on the basis of tracked altitude and altitude-rate, the intruder is:

- currently close in altitude; or
- is projected to be close in altitude within some given time window.

In the Range Test 'close' (current or projected) means that the slant range between own aircraft and the intruder falls below a distance parameter known as *DMOD* (distance modifier) which depends on altitude ranging from 0.2 NM near the ground to 1.1 NM at higher levels ((see Section 11.2.3.1). The time threshold also depends on altitude ranging from 15 seconds near the ground to 35 seconds at higher levels (see Table 16). The projected time to closest approach (*tau*), and when the aircraft are not on a collision course (i.e., there is projected to be a significant separation, in collision avoidance terms, at closest approach) this will be an overestimate.

The ostensibly surprising aspect of some of the alerts that occur on parallel approaches is that analysis of flight data recordings and/or diagnostics in simulated encounters reveals that they occur when the range is greater than the appropriate value of *DMOD* and the calculated value of *tau* is greater than the appropriate value of the time threshold. The reason that in some circumstances the Range Test passes (and consequently, subject to the Altitude Test, an alert may be generated) is that the value of *tau* used in the Range Test has been 'capped' to a smaller value that was calculated earlier in the encounter. This capping is a consequence of the way in which a feature known as the Nuisance Alarm Filter is implemented in the TCAS II algorithms[148] and occurs whenever the separation of the two aircraft is less than 1.7 NM.

When *tau* is capped below the alert time threshold, the Range Test passes on every cycle, and it is only the behaviour of the Altitude Test that determines whether and when an alert will be generated. This will only occur in some cases of parallel approaches when the aircraft trajectories will be within the parameter window in which the *tau*-cap mechanism is triggered, and RAs are generated. The majority of aircraft on parallel approaches will not experience this phenomenon.

RAs due to *tau*-cap mechanism are more likely to occur at the airports located at higher elevations, as the involved aircraft on approach will be in a higher *SL* (see Section 11.1.3) and, consequently, wider parameters will be used.

17.6.4 Pilot and controller actions

Pilots cannot and should not attempt to assess in real time whether the RA is operationally needed. It can be done reliably in hindsight only through data analysis. 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.

Air traffic controllers and pilots are advised not to undertake any actions in an attempt to prevent the occurrence of these RAs, as the combination of factors that triggers them (altitude, distance, closing speed) are complex and impossible to correctly predict at the ATC radar display or TCAS traffic display.

It should not be assumed that all RAs occurring during parallel approaches[149] can be attributed to the *tau*-cap mechanism. The majority of aircraft on parallel approaches will not experience this phenomenon. Only very few parallel approaches will result in these operationally unnecessary RAs when the trajectories of the aircraft by coincidence fall within the narrow window in which the *tau*-cap mechanism RAs are generated. Each event needs to be investigated individually in order for conclusions to be drawn.

[148] The Nuisance Alarm Filter has been implemented to eliminate alerts in encounters in which the two aircraft ultimately pass with a significant separation.

[149] See Section 9.9 on ACAS II operations during closely spaced parallel approaches.

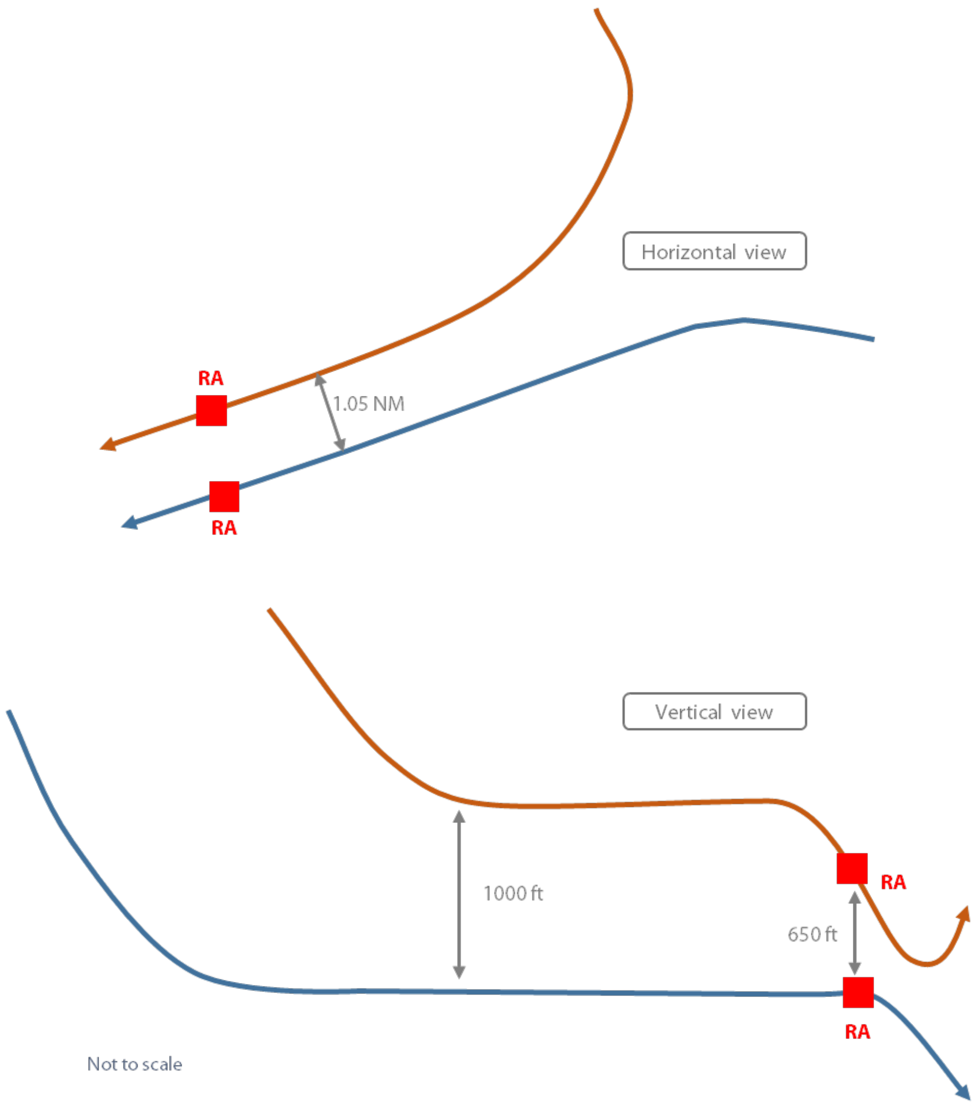


Figure 66: Example of parellel approach trajectory when unecessary RAs occur.

17.7 GNSS spoofing or jamming and ACAS systems

17.7.1 Background information

GNSS spoofing is a type of cyber attack in which a false Global Navigation Satellite System (GNSS) signal is transmitted to mislead an aircraft's navigation system.

GNSS jamming is transmitting a signal that prevents receivers from locking onto satellite signals, primarily rendering the GNSS system ineffective or degraded for all or some users in the affected area[150]. Some ADS-B systems remain corrupted even when jamming stops. See SKYbrary for more information.

TCAS II primarily relies on airborne transponder signals and uses ADS-B data only for hybrid surveillance (see Section 10.4) to reduce the number of Mode S surveillance interrogations. It is believed that GNSS spoofing or jamming in some rare cases might trigger RAs which otherwise would not be required. The same is applicable to the ACAS Xa and ACAS Xu systems. ADS-B reports are validated by independent active interrogations mitigating these risks. Nevertheless, if GNSS spoofing or jamming corrupts an aircraft's ADS-B position or timing data, other systems relying on ADS-B may present inaccurate traffic information, potentially leading to misinterpretation of surrounding traffic and inaccurate or unnecessary alerts.

ACAS sXu uses ADS-B as a primary surveillance source and may be directly affected by GNSS spoofing or jamming. If ADS-B data is compromised due to spoofing or jamming, these systems could issue inaccurate or unnecessary RAs.

It is important to note that GNSS spoofing or jamming can still indirectly affect ACAS II operations (see Section 17.7.2 below).

17.7.2 False GPWS or TAWS alerts supressing RAs

Additionally, GNSS spoofing or jamming may trigger unnecessary GPWS or TAWS alerts, even when the aircraft is in cruise and high above any terrain. That can have a direct impact on ACAS II operations. When GPWS or TAWS warnings have been activated, ACAS II will automatically be placed into TA-only mode with TA aural annunciation suppressed. Any RAs active at the time will be terminated, removed and replaced by a TA. ACAS II will remain in TA-only mode for 10 seconds after the GPWS or TAWS warning is removed. During this 10-second suppression period, the TA aural annunciation is not suppressed. See Table 10 for summary of alerts inhibitions.

[150] See EASA Safety Information Bulletin 2022-02R3 of 5 July 2024 for more information.

18. ACAS SAFETY AND SAFETY BENEFITS

18.1 ACAS II safety

After Phase 2 of the ACAS II implementation mandate was completed in Europe in 2005 (see Section 4.1) was completed, EUROCONTROL conducted ACAS II Post-implementation Safety Case (APOSC) to demonstrate that the safety of aircraft operations is substantially improved by ACAS. A structured safety argument was used supported by evidence from a safety assessment performed as part of the Safety Case as well as from external sources.

The ACAS II Post-implementation Safety Case report (released in 2011)[151] concluded that ACAS II provides a substantial net positive contribution to the reduction in the risk of a midair collision, as demonstrated by analysis of the design and implementation of the total ACAS II system.

18.2 Risk ratio

The safety benefits delivered by ACAS II are usually expressed in terms of the risk ratio: a comparison of the risk with and without ACAS II (i.e., does ACAS 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). The risk ratio is expressed by the following equation:

$$\text{Risk ratio} = \frac{\text{Risk of collision with ACAS II}}{\text{Risk of collision without ACAS II}}$$

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 ACAS II safety benefits, it is not sufficient to demonstrate that ACAS 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 ACAS 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 ACAS II resolution fails to resolve the collision;
- **induced risk of collision** – a situation in which there is no risk of collision and the ACAS II resolution creates it.

18.3 TCAS II

The recent study ACAS Xa validation study (see Section 18.4) calculated (for comparison purposes) the TCAS II (version 7.1) *logic risk ratio*[152] to be 4.9%, i.e., reducing the risk on midair collision by a factor of approximately 20[153].

[151] ACAS II Post-implementation Safety Case – EUROCONTROL, version 2.3, 25 November 2011 (available on SKYbrary).

[152] The term *logic risk ratio limits* the consideration to the effect of the collision avoidance system logic, omitting other factors, e.g., surveillance performance, that could affect the safety of the end-to-end ACAS system.

[153] It should be noted this is a theoretical calculation, based on models rather than on real traffic.

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 TCAS II equipage of other aircraft, the risk of collision for a specific aircraft can be reduced by a factor greater than three by fitting TCAS II[154].

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 midair collisions and midair collisions from taking place. However, it must be stressed that TCAS II cannot resolve every near midair collision and may induce a near midair 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.

18.4 ACAS Xa

ACAS Xa/Xo is designed to be safer than TCAS II, while improving operational suitability.

The FAA conducted safety studies during the ACAS Xa standardisation process[155] that indicate ACAS Xa provides overall safety and operational improvements. These studies indicate that ACAS Xa improves safety by 20% on the United States encounter model and reduces the overall alerting rate by 65% on recorded radar tracks in US airspace[156]. The improvement is most visible in case of preventive (Monitor Vertical Speed) RAs where 97% of TCAS II RAs were removed by ACAS Xa resulting in only an ACAS Xa TA. This is attributed to higher quality ADS-B data (used by ACAS Xa rather than active surveillance used by TCAS II) proving a better estimate of present and future state of intruder aircraft.

Safety and operational validation[157] has also been conducted in Europe. The results[158] indicate that there are several benefits of ACAS Xa compared to TCAS II:

- When pilots follow their RAs, ACAS Xa logic provides an increased safety benefit of between 16% and 24% (depending upon whether or not the intruding aircraft have ADS-B out);
- When one pilot does not follow their RA, ACAS Xa provides an increased safety benefit of about 47%;
- ACAS Xa reduces the overall number of RAs by about 60%.

[154] Source: EUROCONTROL ACASA Project, Final Report on Studies on the Safety of ACAS II in Europe, WP-1.8/210D, ACASA/02-014, March 2002.

[155] FAA TCAS Program Office, Post-FRAC Operational Validation Report, DO-385 V1R0, December 2018.

[156] Source: ICAO ACAS Manual, Doc 9863, 3rd edition.

[157] ACAS Xa CP1 (Change Proposal) version of logic was used in the study.

[158] European Airborne Collision Avoidance System (ACAS) Xa Change Proposal (CP)1 validation report – EUROCONTROL, version 1.0, 16 June 2022 (available on SKYbrary).

In some areas ACAS Xa did not perform quite as well as TCAS II:

- For encounters between 5000 and 13,500 feet where both aircraft have collision avoidance systems both ACAS Xa and TCAS II are effective, but TCAS II is more effective. This difference is an order of magnitude smaller than the overall benefit provided by ACAS Xa and is compensated by the better safety performance of ACAS Xa when one pilot does not follow their RAs.
- 85% of very close encounters trigger RAs on ACAS Xa rather than 97% with TCAS II. These 15% of encounters without RAs occur only in very slow convergence geometries. Safety simulations show that this does not have a negative safety impact and is intimately linked with the reduction in alert rate.
- There were more vertical deviations exceeding 300 feet with ACAS Xa. Based on the relatively low frequency of multi-threat encounters, these vertical deviations are expected to only rarely trigger RAs on proximate aircraft.
- There was a greater RA alert rate on board aircraft climbing/descending less than 1500 ft/min. in single 1000-foot level-off encounters.
- ACAS Xa did not issue a TA at least 5 seconds before an RA in 104 equipped vs. unequipped (with the collision avoidance system) encounters compared with 71 for TCAS II.

The safety and operational acceptance performance of ACAS Xa has been compared with TCAS II using fast time simulation of model encounters and recorded radar data. Results with statistical confidence above 95% were used as a threshold for comparisons with SESAR acceptability criteria[159]. Of ten *Priority 1* SESAR acceptability criteria, seven were within the threshold limits at least partially, two were outside the threshold limits at least partially and one showed no significant difference between TCAS II and ACAS Xa.

The European validation study concluded that ACAS Xa brings greater safety benefits than TCAS II even if this benefit is less than TCAS II for a few sub-classes of traffic. ACAS Xa improves the *logic risk ratio* to between 4.2% (ACAS Xa versus intruders without ADS-B out) and 3.7% (ACAS Xa versus intruders with ADS-B out). This amounts to a safety improvement of between 16% and 24%. In the simulated 12 million flight hours, the number of ACAS Xa RAs have been reduced by approximately 60% (from 1624 to 638 RAs).

[159] SESAR vision of European acceptability criteria for ACAS Xa development, Single European Sky Air traffic management (SESAR), D101, Edition 1.02, 30 November 2015.

19. ACAS II TRAINING

19.1 Pilots

ACAS 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 ACAS II advisories in a manner compatible with the system design. Many advisories involve more than one ACAS II equipped aircraft. In these coordinated encounters, it is essential that the flight crew on each aircraft respond in the expected manner. Therefore, initial and recurring pilot training and understanding of ACAS II operation is essential.

In pilot training, attention should be given to the differences between TCAS II and ACAS Xa systems as highlighted in Section 12.1. While the displays and alerts are similar, certain features like timing and type of alerts generated, ACAS Xo (see Section 12.3), AOTO mode (see Section 12.2.5) should be given particular attention.

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).

19.2 Controllers

ACAS 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 RAs occur, by understanding how collision avoidance systems work, interact with ATC, and by understanding the responsibilities of pilots and air traffic controllers during an ACAS event.

19.3 Training resources

EUROCONTROL and other organisations have produced a number of publications available free of charge to support ACAS II training and awareness. The list of these publications can be found in Section 20.

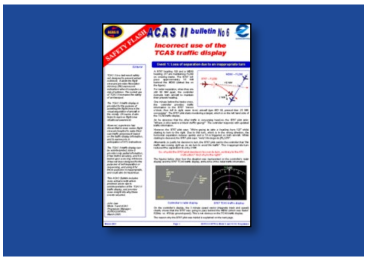
20. ADDITIONAL TRAINING AND INFORMATION RESOURCES

20.1 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.

All EUROCONTROL ACAS II Bulletins can be found on SKYbrary, where an index of topics is provided to facilitate the search of Bulletins for an article of interest The list below provides links to selected issues (click on a link or icon to access a specific Bulletin):

Index
A list of topics covered in
ACAS II Bulletins



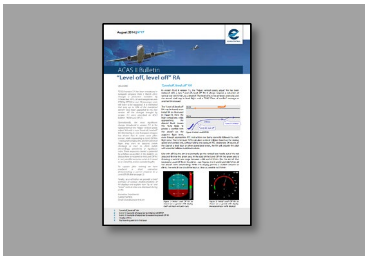
6 - Incorrect use of the TCAS
traffic display
(March 2005)

13 - Reversing to resolve
(September 2011)

14 - Version 7.1 is coming
(January 2012)

15 - Not so fast…
(May 2012)

16 - "Traffic, traffic" TCAS Traffic
Advisories
(December 2012)



17 - "Level off, level off" RA
(August 2014)

19 - ATC Matters
(February 2016)

20 - Low level event
(June 2016)

Continued overleaf…

21- Bizjets are amongst us (February 2017)

22 - ATC vertical rate instructions (November 2017)

23 - Equipment matters (June 2018)

24 - Investigating RAs (November 2018)

25 - Near collision over Yaizu (January 2022)

26 - TA-only mode (May 2022)

27 - No RAs in close encounter (September 2022)

28 - RAs with no loss of separation (September 2022)

29 - Aircraft without operational TCAS (November 2022)

30 – Level Off RA not followed (December 2022)

31 – Crossing RAs (May 2023)

32 – Manoeuvring based on traffic display (December 2023)

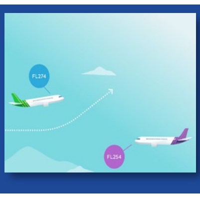
Note: The information contained in EUROCONTROL ACAS II Bulletins is accurate at the time of publishing but is subject to change.

20.2 EUROCONTROL training courses and presentations

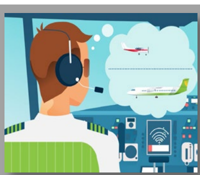
Click on a link or icon to access a specific course or publication:

Introduction to TCAS [ATC-I-TCAS] – e-learning course.
This course is aimed at ab-initio air traffic controllers who are completing their ATC initial training.

TCAS for Controllers [ATC-R-TCAS] – e-learning course
This refresher course is aimed at air traffic controllers who wish to enhance their knowledge of TCAS operations.

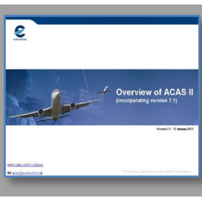


TCAS RA High Vertical Rate
A short animated video about a TCAS RA due to high vertical rates.



TCAS – Always follow the RA (SKYclip)
A short animated video about a TCAS RA against a VFR aircraft.

TCAS RA not followed (SKYclip)
A short animated video recreating an indecent in which an RA was not followed.



Overview of ACAS II (incorporating version 7.1)

TCAS II version 7.1 for air traffic controllers

TCAS II version 7.1 for pilots

20.3 Other training and information resources

Click on a link or icon to access a specific publication:

SKYbrary article on ACAS with links to several other training resources.

IATA/EUROCONTROL Guidance Material: Performance assessment of pilot compliance with Traffic Alert and Collision Avoidance System (TCAS) advisories using Flight Data Monitoring (FDM), 3rd Edition, January 2022 (note: downlink from IATA website, file size 99 MB).

Pilot TCAS RA compliance tool: Based on the above-mentioned IATA/EUROCONTROL Guidance Material, the RA Compliance Tool is intended for post-event operational evaluations of pilot compliance to RAs.

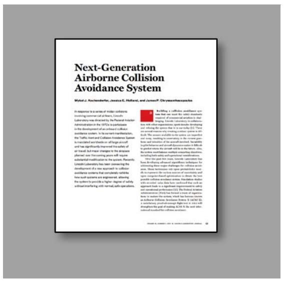
FAA Booklet – Introduction to TCAS II version 7.1 (February 28, 2011).

The Traffic Alert and Collision Avoidance System by James K. Kuchar and Ann C. Drumm – an article from the Lincoln Laboratory Journal (Volume16, Number 2, 2007).

20.4 ACAS X information resources

Click on a link or icon to access a specific publication:

SKYbrary article on ACAS X.


Next-Generation Airborne Collision Avoidance System

Next-Generation Airborne Collision Avoidance System by Mykel J. Kochenderfer, Jessica E. Holland, and James P. Chryssanthacopoulos.

EUROCONTROL Net*Alert* 17 newsletter on ACAS X.


THE NEW KID ON THE BLOCK

HindSight 22 – The new kid on the block.

21. GLOSSARY

***The glossary is provided for reference only** and it has been derived from the definitions published in ICAO Annex 10 Volume IV, ICAO PANS-OPS (Doc 8168), ICAO PANS-ATM (Doc 4444), ICAO ACAS Manual (Doc 9863), TCAS II MOPS (RTCA DO-185B and EUROCAE ED-143), ACAS Xa/Xo MOPS (RTCA DO-385A and EUROCAE ED-256A), ACAS Xu MOPS (RTCA DO-386 and EUROCAE ED-275), ACAS sXu MOPS (RTCA DO-396), Detect & avoid MASPS (EUROCAE ED-271A).*

ACAS – Airborne Collision Avoidance System is an aircraft system based on secondary surveillance radar transponder signals which operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft that are equipped with transponders.

ACAS I – *("ay-cas one")* **–** Airborne Collision Avoidance System that provides information as an aid to *see & avoid* action but does not include the capability for generating Resolution Advisories (RAs).

ACAS II – *("ay-cas two")* **–** Airborne Collision Avoidance System that provides vertical Resolution Advisories (RAs) in addition to Traffic Advisories (TAs).

ACAS III – *("ay-cas three")* **–** Airborne Collision Avoidance System that provides vertical and horizontal Resolution Advisories (RAs) in addition to Traffic Advisories (TAs)[160].

ACAS X – *("ay-cas eks")* **–** A family of new Airborne Collision Avoidance Systems currently under development. It takes advantage of recent advances in 'dynamic programming' and other computer science techniques. See Section 3.3 for more information.

Active surveillance – The use of interrogations and subsequent replies to derive range, bearing, and altitude. See also Passive surveillance.

ADS-B (Automatic Dependent Surveillance – Broadcast) – A means by which aircraft can automatically transmit and/or receive data such as identification, position and additional data in a broadcast mode via a data link. More information on SKYbrary.

ADS-B In – provides operators of properly equipped aircraft with weather and traffic position information delivered directly to the cockpit.

ADS-B Out – broadcast of information about an aircraft's location, altitude, ground speed and other data to ground stations and other aircraft, once per second.

ADS-R (Automatic Dependent Surveillance – Rebroadcast) – ADS-R is a service that relays ADS-B information transmitted by an aircraft broadcasting on one link to aircraft equipped with ADS-B In on the other link.

Aircraft (Mode S 24-bit) address – A unique combination of 24 bits that is assigned by States to all suitably equipped aircraft for the purpose of air-ground communications, navigation and surveillance. Also known as ICAO 24-bit Aircraft Address.

---

[160] ACAS III has not been covered in ICAO SARPs until now, as there has been no collision avoidance system capable of issuing horizontal avoidance manoeuvres. A new collision avoidance system for RPAS – ACAS Xu (see Section 13) – is the first collision avoidance system incorporating horizontal manoeuvres by utilizing modern surveillance methods, such as ADS-B (see Section 3.3). Consequently, ICAO is now undertaking the development of ACAS III SARPs.

Altitude crossing RA – A Resolution Advisory during which the own aircraft is expected to cross the altitude of the intruder before closest approach. An RA is considered crossing regardless of whether the word "crossing" is included in the aural annunciation. An RA is altitude crossing if own ACAS II aircraft is currently at least 100 feet below or above the threat aircraft for upward or downward sense advisories, respectively. See Section 11.4.1.1.

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

Blended RA – An RA issued by ACAS Xu or ACAS sXu independently in both vertical and horizontal dimensions. See Sections 13.4.2 and 14.2.3 for more information.

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 II 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 II.

Cooperative intruders – An aircraft that transmits surveillance and identification data that can be received by own aircraft. The intruder is equipped with a transponder, ADS-B or ADS-R that allows the own aircraft to receive state information (e.g., altitude) of the intruder. See Non-cooperative intruders.

Coordinated encounter – An encounter in which two ACAS II equipped aircraft contemporaneously receive RAs against each other.

Corrective advisory – An RA that requires a change in own aircraft's vertical rate, for example a Level Off RA when the aircraft is climbing. A Corrective advisory can be Positive or Negative. See also: Preventive advisory.

Crossing RA – See: Altitude crossing RA.

Detect & avoid (DAA) – A system consisting of airborne and ground-based equipment that together perform the functions which allow the remote pilot to detect and avoid hazards. This includes sensors, processing units and the interface with the remote pilot. See also: RWC and see & avoid.

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). See Section 11.2.3.1. Not used by ACAS Xa.

Downward sense RA – An RA with issued to ensure that own aircraft will pass below the threat (the RAC tells the other aircraft "do not pass below me"). See also: Upward sense RA.

Encounter – A situation when two or more aircraft are in proximity, so an RA is potentially triggered on at least one of them.

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

False advisory – An advisory caused by a false track or an ACAS II malfunction. See also: Missing RA, Nuisance RA, and Unnecessary RA.

Flight level (FL) – Altitude above sea-level in 100 feet units measured according to a standard atmosphere. E.g., FL250 = 25,000 feet. More information on SKYbrary.

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

Horizontal Resolution Advisory Complement (HRC) – Information provided by one capable collision avoidance system (e.g., ACAS Xu) to another via a coordination message to ensure complementary manoeuvres by restricting the choice of manoeuvres available to the system receiving the HRC. See also: VRC.

Hybrid surveillance – The combined use of active and validated passive surveillance data to update a track. See also: Active surveillance.

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.

Initial RA – First Resolution Advisory issued during an encounter. See also: Subsequent RA.

Intruder (aircraft) – An aircraft within the surveillance range of ACAS II for which ACAS II has an established track.

Master aircraft – For the purpose of ACAS II-ACAS II coordination, an aircraft with the lower Mode S 24-bit address. See also: Slave aircraft.

Miss Distance Filtering (MDF) – A process in the TCAS II threat detection logic which allows the suppression of nuisance RAs in encounters with a significant HMD (in suitable encounter geometries). The process can also allow the early removal of an RA before the closest point of approach. Not used by ACAS Xa.

Missing RA – A Resolution Advisory that does not occur or is late when a threat is present. See also: False RA, Nuisance RA, and Unnecessary RA.

Mode A transponder – A type of transponder that transmits an identifying code (squawk) only.

Mode C transponder – A transponder type that transmits both an identifying code (squawk) and altitude information (always based on the standard barometric pressure of 1013.2 hPa).

Mode S transponder – A transponder type that transmits an identifying code (squawk), altitude information, and unique 24-bit address. Furthermore, Mode S transponders can provide downlink of certain parameters to the ground and permits data exchange.

Mode S – A secondary surveillance radar process that allows selective interrogation of aircraft according to the unique 24-bit address assigned to each aircraft. More information on SKYbrary.

Mode S address – See: Aircraft (Mode S 24-bit) address.

Modified RA – See: Subsequent RA.

Multi-threat encounter – An encounter involving two or more threats against own aircraft being processed simultaneously by the logic.

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

Negative advisory – An RA that requires that a prescribed range of vertical rates must be avoided, such as Do Not Descend (announced as "*Monitor Vertical Speed*"). A Negative advisory can be Corrective or Preventive. See also: Positive advisory.

Non-cooperative intruders – An aircraft that does not transmit surveillance and identification data that can be received by own aircraft. The intruder is not equipped with a transponder, ADS-B or ADS-R that allows the own aircraft to receive state information (e.g., altitude) of the intruder. All state data must be determined by own aircraft onboard sensors, like an onboard air-to-air radar (ATAR). See Cooperative intruders.

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: False RA, Missing RA, and Unnecessary RA.

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

Passive surveillance – The use of ADS-B messages to update ACAS II tracks. See also Active surveillance and Hybrid surveillance.

Positive advisory – An RA that requires either a climb or a descent at a particular rate. 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 – An RA that does not require a change in own aircraft's vertical rate, for example a Do Not Climb RA (announced "*Monitor Vertical Speed*")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.

Radar or radio altimeter – A radar or radio altimeter is an airborne electronic device capable of measuring the height of the aircraft above terrain immediately below the aircraft. More information on SKYbrary.

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.

Remain Well Clear (RWC) – The ability to detect, analyse and manoeuvre to avoid potential conflicting traffic by applying adjustments to the current flight path in order to prevent the conflict from developing into a collision hazard. Applicable to RPAS. See also: DAA.

Remotely piloted aircraft system (RPAS) – A remotely piloted aircraft, its associated remote pilot station(s), the required command and control links and any other components.

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

Resolution Advisory Complement (RAC) – Information provided by one ACAS II to another via a Mode S interrogation in order to ensure complementary manoeuvres by restricting the choice of manoeuvres available to the ACAS II receiving the RAC. See also: Downward sense RA and Upward sense RA.

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. See Section 18.1.

Secondary Surveillance Radar (SSR) – A surveillance radar system which uses transmitters/receivers (interrogators) and transponders. More information on SKYbrary.

See & avoid – A recognised method for avoiding collision when weather conditions permit. It requires that pilots actively search for potentially conflicting traffic, especially when operating in airspace where all traffic is not operating under the instructions of ATC. More information on SKYbrary. See also *Detect & avoid*.

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. For TA and RA selection, sensitivity levels are not used in ACAS Xa.

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

Squitter – Spontaneous transmission generated by Mode S transponders.

Slave aircraft – For the purpose of ACAS II – ACAS II coordination, an aircraft with the higher Mode S 24-bit address. See also: Master aircraft.

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.

Subsequent RA – Any modified RA issued during an encounter after the initial RA but before a Clear of Conflict indication. A subsequent RA can be weakening, strengthening, or reversed sense RA.

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

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

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

Threat (aircraft) – An intruder that has satisfied the threat detection criteria and requires an RA.

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. More information on SKYbrary.

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: False RA, Missing RA, and Nuisance RA.

Upward sense RA – An RA with issued to ensure that own aircraft will 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 ACAS II to another via a coordination message to ensure complementary manoeuvres by restricting the choice of manoeuvres available to the ACAS II receiving the VRC. See also: HRC.

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 decreasing 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.

22. Abbreviations

ACAS	Airborne Collision Avoidance System
ACASA	ACAS Analysis (EUROCONTROL project in support of the mandate for the carriage of ACAS II in Europe)
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-R	Automatic Dependent Surveillance – Re-broadcast
AGL	Above Ground Level
AIP	Aeronautical Information Publication
ALIM	Altitude Limit – Vertical Threshold for Corrective Resolution Advisory (TCAS II)
AMC	Acceptable Means of Compliance
ANSP	Air Navigation Service Provider
AOTO	ADS-B Only TA Only mode (ACAS Xa)
AP/FD	Autopilot/Flight Director (Airbus)
ASAS	Airborne Separation Assurance Systems
ATC	Air Traffic Control
ATAR	Air-to-Air Radar
ATM	Air Traffic Management
BCAS	Beacon Collision Avoidance System
CAS	Collision Avoidance System
CPA	Closest Point of Approach
CSPO-3000	Closely Spaced Parallel (runway) Operations (3000-foot spacing between parallel runways)
DAA	Detect & avoid
DMOD	Distance Modification (TCAS II)
DNA	Designated No Alerts mode (ACAS Xo)
EASA	European Union Aviation Safety Agency
EFIS	Electronic Flight Instrument System
EICAS	Engine Indication and Crew Alerting System
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration (USA)
FDM	Flight Data Monitoring
FL	Flight Level
ft	Feet (approximately 0.305 meters)
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 (atmospheric pressure unit)
HRC	Horizontal Resolution Advisory Complement (ACAS Xu)
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions

IVSI	Instantaneous Vertical Speed Indicator
kg	Kilogram(s)
kt	Knots (NM/hour)
m	Meter(s)
MASPS	Minimum Aviation System Performance Specification
MEL	Minimum Equipment List
MHz	Megahertz
MOPS	Minimum Operational Performance Standards
m/s	Metres per second
m/sec	Metres per second
NAR	Non-Altitude Reporting [target]
NM	Nautical Mile (approximately 1,852 meters)
NMAC	Near Midair Collision
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
RWC	Remain Well Clear
SARPs	Standards and Recommended Practices (ICAO)
sec	Second(s)
SESAR	Single European Sky ATM Research Programme
SKYbrary	An online repository of safety knowledge related to ATM and aviation safety in general
SL	Sensitivity level (TCAS II)
STCA	Short Term Conflict Alert (ATC)
STM	Surveillance and Tracking Module (ACAS X)
TA	Traffic Advisory
tau	Warning Time (TCAS II)
TAWS	Terrain Avoidance and Warning System
TCAP	TCAS Alert Prevention (Airbus)
TCAS	Traffic alert and Collision Avoidance System
TRM	Threat Resolution Module (ACAS X)
TVTHR	Time (Vertical) Threshold – Reduced Time to Co-altitude Threshold (TCAS II)
UAS	Unmanned Aircraft Systems
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
XPNDR	Transponder
ZTHR	Z Threshold – Vertical Threshold for Resolution Advisory (TCAS II)
ZTHRTA	Z Threshold – Vertical Threshold for Traffic Advisory (TCAS II)

23. Bibliography

Note: A list of publications and links below are provided here for reference only and are current on 1 December 2024 and are subject to change.

23.1 ICAO publications

ICAO publications are available for purchase directly from ICAO.

ICAO Annex 2 – Rules of the Air (Tenth edition – 2005, amendment 46, date applicable: 8 November 2018).

ICAO Annex 6 – Operation of Aircraft – Part I – International Commercial Air Transport – Aeroplanes (Twelfth edition – 2022, amendment 48, dates applicable: 29 December 2022 & 1 January 2025).

ICAO Annex 10 – Aeronautical Telecommunications – Volume IV – Surveillance Radar and Collision Avoidance Systems (Fifth edition – 2014, amendment 91, date applicable: 3 November 2022).

ICAO Doc 4444 – PANS-ATM – Procedures for Air Navigation Services – Rules of the Air and Air Traffic Services (Sixteenth edition – 2016, amendment 11, date applicable: 3 November 2022).

ICAO Doc 8168 – PANS-OPS – Procedures for Air Navigation Services – Aircraft Operations – Volume III – Aircraft Operating Procedures (First edition – 2018, amendment 2, date applicable: 3 November 2022).

ICAO Doc 9863 – Airborne Collision Avoidance System (ACAS) Manual (Third edition – 2021).

23.2 RTCA publications

RTCA publications are available for purchase directly from RTCA.

RTCA DO-185B – Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System (TCAS II) Airborne Equipment[161], change 2, March 2013.

RTCA DO-300A (change 1) – Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System (TCAS II) TCAS II Hybrid Surveillance, December 2015.

RTCA DO-317C – Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System, June 2020.

RTCA DO-337 – Recommendations for Future Collision Avoidance Systems, March 2012.

RTCA DO-365B – Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems, March 2021.

RTCA DO-385A – Minimum Operational Performance Standards for Airborne Collision Avoidance System X (ACAS X) (ACAS Xa and ACAS Xo), June 2023.

RTCA DO-386 – Minimum Operational Performance Standards for Airborne Collision Avoidance System Xu (ACAS Xu), December 2020.

RTCA DO-396 – Minimum Operational Performance Standards for Airborne Collision Avoidance System sXu (ACAS sXu), December 2022.

[161] Superseding DO-185A (TCAS II version 7.0 MOPS).

23.3 EUROCAE publications

EUROCAE publications are available for purchase directly from EUROCAE.

EUROCAE ED-143 – Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II)[162], change 2, April 2013.

EUROCAE ED-221A – Minimum Operational Performance Standards MOPS for Traffic Alert and Collision Avoidance System II (TCAS II) Hybrid Surveillance, December 2015.

EUROCAE ED-224 – Minimum Aviation System Performance Specification (MASPS) for Flight Guidance System (FGS) Coupled to Alert and Collision Avoidance System (TCAS), March 2014.

EUROCAE ED-256A – Minimum Operational Performance Standards for Airborne Collision Avoidance System X (ACAS X) (ACAS Xa and ACAS Xo)[163], June 2023.

EUROCAE ED-258 – Operational Services and Environment Description for Detect & Avoid [Traffic] in Class D-G Airspaces under VFR/IFR, January 2019.

EUROCAE ED-264 – Minimum Aviation System Performance Standards (MASPS) for the Interoperability of Airborne Collision Avoidance Systems (CAS), September 2020.

EUROCAE ED-271A – Minimum Aviation System Performance Standard for Detect and Avoid (Traffic) in Class A-C airspaces, November 2024.

EUROCAE ED-275 – Minimum Operational Performance Standards for Airborne Collision Avoidance System Xu (ACAS Xu)[164], December 2020.

23.4 EASA & European Union publications

Easy Access Rules for Standardised European Rules of the Air (SERA) – European Union Aviation Safety Agency, February 2023

EU-OPS-1 – European Commission Regulation (common technical requirements and administrative procedures applicable to commercial transportation by aeroplane). 20 September 2008.

Applicable sections:

- **EU-OPS 1.668:** Airborne collision avoidance system
- **EU-OPS 1.398:** Use of airborne collision avoidance system (ACAS)

ETSO C119c (European Technical Standard Order) – Traffic alert and Collision Avoidance system (TCAS), Airborne Equipment, TCAS II. 8 December 2009.

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.

Commission Implementing Regulation (EU) 2016/1185 – of 20 July 2016 amending Implementing Regulation (EU) No 923/2012 as regards the update and completion of the common rules of the air and operational provisions regarding services and procedures in air navigation (SERA Part C) and repealing Regulation (EC) No 730/2006.

---

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

[163] Jointly published with RTCA and commensurate with DO-385A.

[164] Jointly published with RTCA and commensurate with DO-386.

Commission Regulation (EU) No 2025/343 – of 17 February 2025 amending Regulation (EU) No 1332/2011 and Implementing Regulation (EU) 2017/373 as regards airborne collision avoidance systems published in the Official Journal of the European Union on 18 February 2025.

EASA (European Union Aviation Safety Agency) – ED Decision 2012/018/R – Acceptable Means of Compliance and Guidance Material to Part-CAT. 25 October 2012.

EASA (European Union Aviation Safety Agency) – ED Decision 2016/023/R – Acceptable Means of Compliance and Guidance Material to the rules of the air. 14 October 2016.

EASA (European Union Aviation Safety Agency) Safety Information Bulletin 2013-11R1 – (ACAS II – Manoeuvres based on Visual Acquisition of Traffic). 20 January 2020.

EASA (European Union Aviation Safety Agency) Easy Access Rules for Generic Master Minimum Equipment List (CS-GEN-MMEL). February 2018.

23.5 FAA Publications

TSO C119e (Technical Standard Order) – Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, TCAS II with Optional Hybrid Surveillance, 30 June 2016.

TSO C219a (Technical Standard Order) – Airborne Collision Avoidance System (ACAS) Xa/Xo, 1 December 2023.

AC 20-151C (Advisory Circular) – Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II), Versions 7.0 & 7.1 and Associated Mode S Transponders, 21 July 2017.

AC 20-131A (Advisory Circular) – Airworthiness and Operational Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders, 29 March 1993.

AC 90-120 (Advisory Circular) – Operational Use of Airborne Collision Avoidance Systems, 20 November 2024.

Introduction to TCAS II version 7.1 – 28 February 2011.

23.6 EUROCONTROL publications

ACAS II Bulletins – EUROCONTROL (2002-2023).

ACAS Safety Studies – EUROCONTROL (2001-2011).

Assessment of Pilot Compliance with TCAS RAs, TCAS Mode Selection and Serviceability Using ATC Radar Data – EUROCONTROL, edition 2.2, 10 February 2022.

European Airborne Collision Avoidance System (ACAS) Xa Change Proposal (CP)1 validation report – EUROCONTROL, version 1.0, 16 June 2022.

Performance assessment of pilot compliance with Traffic Alert and Collision Avoidance System (TCAS) advisories using Flight Data Monitoring (FDM) – IATA and EUROCONTROL, 3rd edition, January 2022 (note: downlink from IATA website, file size 99 MB).

Traffic Alert and Collision Avoidance System (TCAS) – Selected Statistical and Performance Data in Core European Space – EUROCONTROL, 9 April 2021.

24. Appendix – Relevant ICAO Provisions

Note: Extracts from ICAO documents are provided here for reference only and are current on 1 December 2024 and are subject to change.

24.1 Annex 2

3.2 Avoidance of collisions
Nothing in these rules shall relieve the pilot-in-command of an aircraft from the responsibility of taking such action, including collision avoidance manoeuvres based on resolution advisories provided by ACAS equipment, as will best avert collision.
Note 1.— It is important that vigilance for the purpose of detecting potential collisions be exercised on board an aircraft, regardless of the type of flight or the class of airspace in which the aircraft is operating, and while operating on the movement area of an aerodrome.

[…]
ATTACHMENT A.
3. Interception manoeuvres
[…]
3.2. An aircraft equipped with an airborne collision avoidance system (ACAS), which is being intercepted, may perceive the interceptor as a collision threat and thus initiate an avoidance manoeuvre in response to an ACAS resolution advisory. Such a manoeuvre might be misinterpreted by the interceptor as an indication of unfriendly intentions. It is important, therefore, that pilots of intercepting aircraft equipped with a secondary surveillance radar (SSR) transponder suppress the transmission of pressure-altitude information (in Mode C replies or in the AC field of Mode S replies) within a range of at least 37 km (20 NM) of the aircraft being intercepted. This prevents the ACAS in the intercepted aircraft from using resolution advisories in respect of the interceptor, while the ACAS traffic advisory information will remain available.

24.2 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.

24.3 Annex 10 – Volume IV

4.3.4.6 *Validation of ADS-B tracks for RA generation.* For ACAS X-compliant systems: If ADS-B tracks fail validation via active interrogation and reply, ACAS shall revert back to using active surveillance for threat resolution logic.
Note.— Only validated ADS-B is used in the generation of RAs.
4.3.4.7 *Designation of aircraft for do not alert (DNA).* For ACAS X-compliant systems with Xo functionality: If an intruder aircraft is designated as do not alert (DNA), no alerts for the intruder aircraft shall be issued to the flight crew of the own aircraft.
Note. — ACAS Xo provides additional modes with modified threat detection criteria in respect of designated intruders. For more details on ACAS Xo, refer to RTCA/DO-385 or EUROCAE/ED-256.

4.3.5.1 *RA generation.* For all threats, ACAS shall generate an RA except where it is not possible to select an RA that can be predicted to provide adequate separation either because of uncertainty in the diagnosis of the intruder's flight path or because there is a high risk that a manoeuvre by the threat will negate the RA.

4.3.5.1.2 *RA cancellation.*
4.3.5.1.2.1 For TCAS 7.1-compliant systems: Once an RA has been generated against a threat or threats it shall be maintained or modified until tests that are less stringent than those for threat detection indicate on two consecutive cycles that the RA may be cancelled, at which time it shall be cancelled.
4.3.5.1.2.2 For ACAS X-compliant systems: Once an RA has been generated against a threat or threats it shall be maintained until the intruder or intruders of the RA cease to be a threat.

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, EUROCAE/ED-143 or airborne collision avoidance system X (ACAS Xa and Xo) as specified in RTCA/DO 385 or EUROCAE/ED-256.

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.

24.4 PANS-ATM – Doc 4444

24.4.1 Procedures regarding ACAS equipped aircraft

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.

24.4.2 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;

24.5 PANS-OPS – Doc 8168 (Volume III)

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. […]

24.6 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.

5.2.1.14.1 ATC may have older altitude data than ACAS and does not know when ACAS issues RAs, unless notified by the pilot. It is possible for ATC to unknowingly issue instructions that are contrary to the ACAS RA indications. When one aircraft manoeuvres opposite the vertical direction indicated by ACAS and the other aircraft manoeuvres as indicated by ACAS, a collision may occur. Do not manoeuvre contrary to the RA based solely upon ATC instructions.

5.2.1.14.2 ATC may not be providing separation service to the aircraft causing the RA or the intruder may not be known to ATC, e.g. military operations in some States.

5.2.1.21 Pilots are expected to operate ACAS while in flight in all airspace.

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.

25. Relevant European Regulation and Guidance Material

Note: Extracts from European regulatory documents are provided here for reference only and are current on 1 December 2024 and are subject to change.

25.1 Regulation

SERA.11014 ACAS resolution advisory (RA)

ACAS II shall be used during flight, except as provided in the minimum equipment list specified in Commission Regulation (EU) No 965/2012[1] in a mode that enables RA indications to be produced for the flight crew when undue proximity to another aircraft is detected. This shall not apply if inhibition of RA indication mode (using traffic advisory (TA) indication only or equivalent) is called for by an abnormal procedure or due to performance-limiting conditions.

(b) In the event of an ACAS RA, pilots shall:

(1) respond immediately by following the RA, as indicated, unless doing so would jeopardise the safety of the aircraft;
(2) follow the RA even if there is a conflict between the RA and an ATC instruction to manoeuvre;
(3) not manoeuvre in the opposite sense to an RA;
(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;
(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.

(c) When a pilot reports an ACAS RA, the controller shall not attempt to modify the aircraft flight path until the pilot reports 'CLEAR OF CONFLICT'.

(d) 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 to all the affected aircraft when:

(1) the controller acknowledges a report from the flight crew that the aircraft has resumed the current clearance; or
(2) 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.

[1] Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council (OJ L 296, 25.10.2012, p. 1).

25.2 Guidance Material

GM1 SERA.11014 ACAS resolution advisory (RA)
Nothing in the procedures specified in SERA.11014 should 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.

GM2 SERA.11014 ACAS resolution advisory (RA)
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.

GM3 SERA.11014 ACAS resolution advisory (RA)
Pilots should not manoeuvre their aircraft in response to traffic advisories (TAs) only.

GM4 SERA.11014 ACAS resolution advisory (RA)
Visually acquired traffic may not be the same traffic causing an RA. The visual perception of an encounter may be misleading, particularly at night.

GM5 SERA.11014 ACAS resolution advisory (RA)
In the case of an ACAS–ACAS coordinated encounter, the RAs complement each other in order to reduce the potential for a 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.

GM6 SERA.11014 ACAS resolution advisory (RA)
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.

GM7 SERA.11014 ACAS resolution advisory (RA)
Pilots should use appropriate procedures by which an aeroplane climbing or descending to an assigned altitude or flight level 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. These procedures are intended to avoid unnecessary ACAS II RAs in aircraft at or approaching adjacent altitudes or flight levels. For commercial operations, these procedures should be specified by the operator.

Source: Easy Access Rules for Standardised European Rules of the Air (SERA) – European Aviation Safety Agency, March 2022.

*****

Intentionally left blank

SUPPORTING
EUROPEAN
AVIATION

www.eurocontrol.int