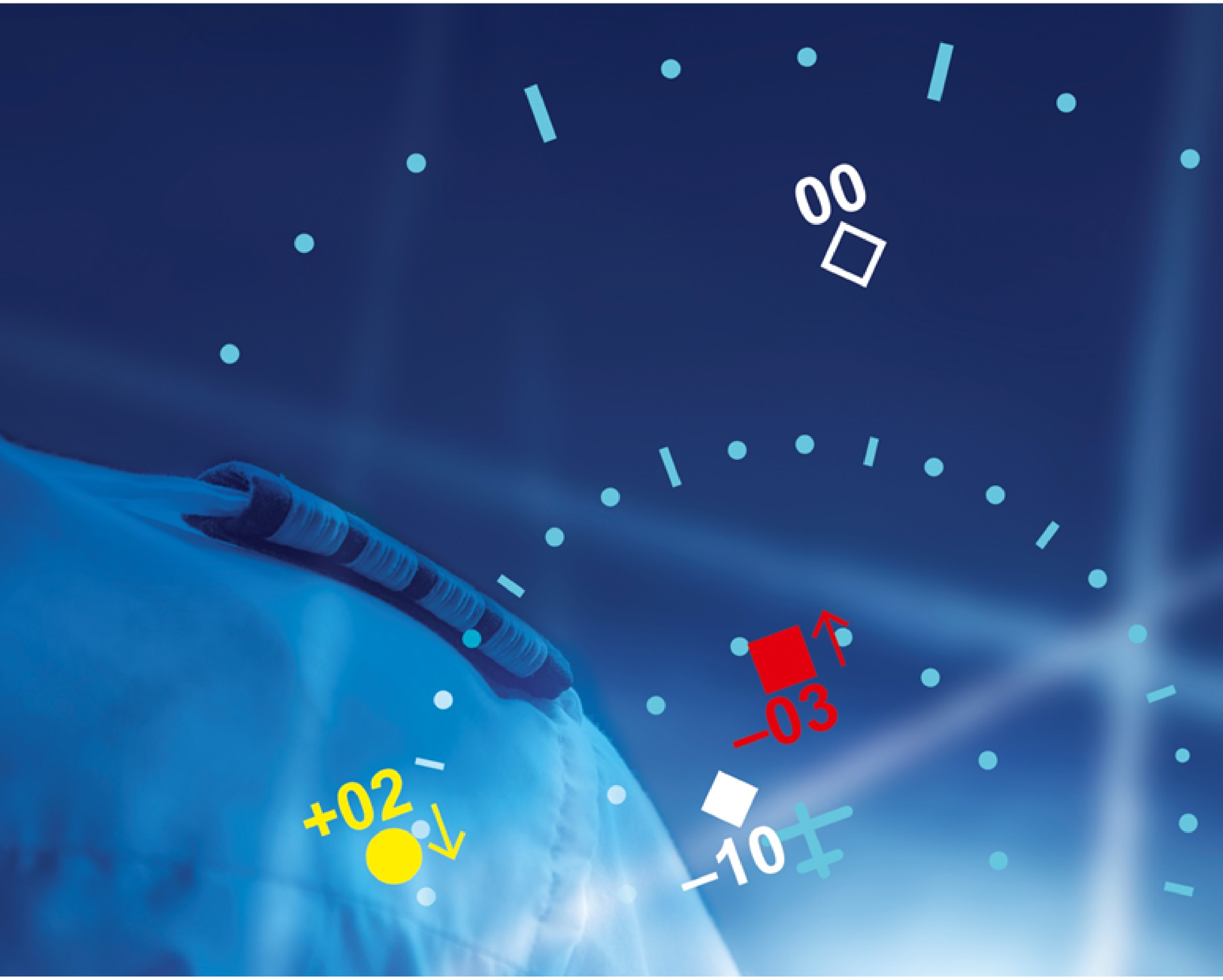
ACAS Guide

Airborne Collision Avoidance Systems

March 2022



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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 concentrates on operational principles as well as technical details of TCAS II version 7.1, as it is the version currently mandated and operated in Europe. The previous TCAS II versions 6.04a and 7.0, as well as TCAS I system, are also briefly described. Moreover, the forthcoming ACAS Xa/Xo system is extensively covered but it should be noted that, at the time of publication of this ACAS Guide, this system has not yet 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 publishing 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* booklet.

HISTORY OF CHANGES

Edition number	Edition date	Reason for change	Pages affected
1.0	12 January 2012	First edition.	All
2.0	20 April 2015	Major changes.	All
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

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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.

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 and the forthcoming family of airborne collision avoidance systems – known as ACAS X – is introduced to provide the Reader with a complete picture. A list of additional training resources and applicable ICAO provisions are provided as well.

Collision avoidance functions for Remotely Piloted Aircraft Systems (drones), like Detect and Avoid as well as ACAS Xu (collision avoidance system for unmanned aircraft) are not covered in this Guide. Also, non-standardised traffic awareness systems intended for general aviation or military aircraft, like FLARM, and Portable Collision Avoidance System (PCAS) are not covered.

2 INTRODUCTION

2.1 Historical background

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

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

To compensate for any limitations of "see and avoid" and ATC performance, an airborne collision avoidance system, **independent** of any ground systems and acting as a last resort, has been considered from the 1950s. In 1956, an American scientist Dr John S. Morrel (1901-1974) of Bendix Aviation Corporation proposed[1] 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) [2]. The CPA is the occurrence of minimum slant range between own aircraft and the other aircraft.

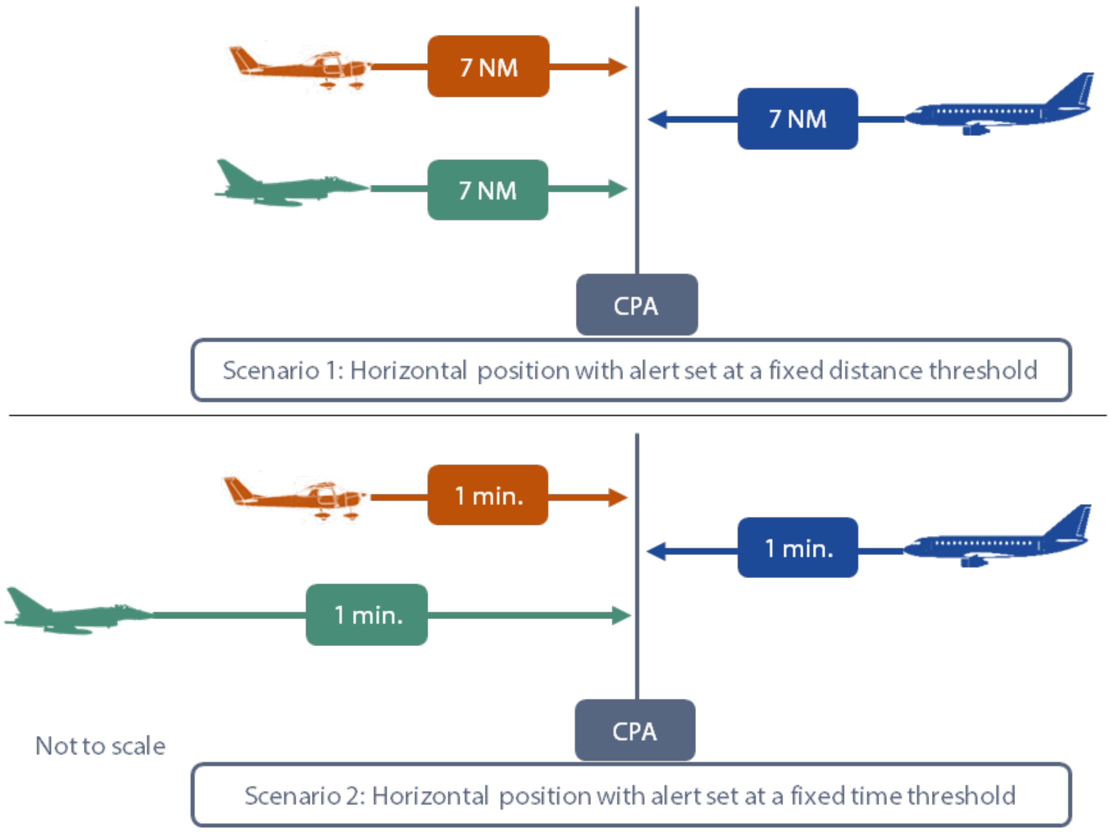

Figure 1: Alerting at fixed distance vs. alerting at fixed time to CPA.

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

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

The difference between using alerting at a fixed position threshold vs. alerting at a fixed time threshold is illustrated in Figure 1. 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 1) the alert is triggered at a specific 'distance-to-go' until estimated Closest Point of Approach. The two intruders 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.

2.2 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[3], 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[4] range and altitude.

In 1978, the collision between a light aircraft and an airliner over San Diego, California[5] led the US Federal Aviation Administration to initiate, three years later, the development of TCAS (Traffic alert and Collision Avoidance System) utilizing the basic BCAS design for interrogation and tracking with some additional capabilities.

[3] 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 degrees. 128 people were killed. More information on Aviation Safety Network.

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

[5] 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.

In 1986, the collision between an airliner and a light aircraft over Cerritos, California[6] resulted in a US Congressional mandate that required some categories of US and foreign aircraft to be equipped with TCAS II for flight operations in US airspace.

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

2.3 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.

Currently, TCAS II version 7.1 is the only implementation that fully meets the ACAS ICAO Standards and Recommended Practices (SARPs)[7]. At the time of writing, the work is ongoing at ICAO to update the relevant Provisions to include ACAS Xa (see Sections 3.3 and 11 for more information about ACAS X). Once these updates have been approved by member states and are effective, ACAS Xa would become another ICAO recognised airborne collision avoidance system[8].

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** and **ACAS Xo** are used when referring to the implementation of ACAS Xa and ACAS Xo respectively;
- **ACAS X** is used when referring to the ACAS X concept or family of systems.

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[6] 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 the controlled airspace and both crews could not see each other due to the geometry of the conflict. 67 people onboard plus 15 on the ground were killed. More information on Aviation Safety Network.

[7] ICAO Annex 10, Volume IV.

[8] In April 2020, ICAO published a state letter outlining ACAS X-related changes to Annex 10, Volume IV.

2.4 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.

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

ACAS II can issue two types of alerts:

- **Traffic Advisories (TAs)**, which aim to help the pilots in the visual acquisition of the intruder aircraft, and to alert them to be ready for a potential resolution advisory.
- **Resolution Advisories (RAs)**, which are avoidance manoeuvres recommended to the pilot. An RA will tell the pilot the range of vertical rates within which the aircraft should be flown to avoid the threat aircraft. An RA can be generated against all aircraft equipped with an altitude reporting transponder (Mode S or Mode A/C); the intruder does not need to be fitted with ACAS II. When the intruder aircraft is also fitted with an ACAS II system, both systems coordinate their RAs through the Mode S data link, in order to select complementary resolution senses. ACAS II does not detect non-transponder equipped aircraft or aircraft with a non-operational transponder[9].

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[10]. 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 21) of this ACAS Guide.

[9] 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 Stand-by. 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.

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

2.5 ACAS Standards

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

- **ACAS I** provides information as an aid to "see and avoid" action but does not include the capability for generating RAs;
- **ACAS II** provides vertical RAs in addition to TAs;
- **ACAS III** provides vertical and horizontal RAs in addition to TAs[11].

So far, ACAS III has not materialised due to limitations that conventional surveillance systems have with horizontal tracking and, consequently, issuing horizontal avoidance manoeuvres. ACAS III has been mentioned as a future system in the current edition of ICAO Annex 10[12] but there have been no ICAO standards for ACAS III. A new collision avoidance system for Remotely Piloted Aircraft Systems (RPAS) or drones – ACAS Xu – incorporates 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.

The TCAS II, ACAS Xa/Xo and ACAS Xu Minimum Operational Performance Standards (MOPS) have been developed jointly by RTCA[13] and EUROCAE[14], as indicated in Table 1 below. A list of current RTCA and EUROCAE MOPS versions is available in Sections 20.2 and 20.3, respectively. Any ACAS equipment must meet the standards specified in the MOPS in order to be certified.

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

System	RTCA		EUROCAE	
	Document	**First published**	**Document**	**First published**
TCAS II version 7.1	DO-185B	June 2008	ED-143	September 2008
ACAS Xa/Xo	DO-385	September 2018	ED-256	October 2018
ACAS Xu	DO-386	December 2020	ED-275	December 2020

Currently, TCAS II equipment is available from four vendors, all of them based in the USA[15]. 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.

[11] Sometimes referred to as TCAS IV.

[12] Fifth edition – 2014, amendment 90.

[13] RTCA Inc. A USA-based non-profit organisation that develops technical standards for regulatory authorities (formerly Radio Technical Commission for Aeronautics).

[14] European Organisation for Civil Aviation Equipment.

[15] 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*[16] or proximity to an intruder aircraft, using two sensitivity levels[17]. 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).

ACAS I is not covered further in this Guide.

[16] See Section 10.2.3 for more information on *tau*.

[17] See Section 10.1.3 for more information on sensitivity level.

3.2 TCAS II

3.2.1 Versions 6.02 and 6.04a

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

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

As a result of the evaluation a number of improvements were suggested. That led to the development and release of version 6.04a in 1993[18]. The new version aimed to reduce the number of nuisance alerts, which were occurring at low altitudes and during level-off encounters.

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

Version 6.02 is 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).

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[19] 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[20];
- 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); however, as of 1 January 2017 only version 7.1 complies with ICAO SARPs. ACAS Xa may become the next system also complying with ICAO SARPs[21].

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).

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

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

[20] The carriage and operation of TCAS II is not an RVSM requirement in itself. For information about equipage mandates, see Section 4.2.

[21] Pending approval at the time of writing.

3.2.3 Version 7.1

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

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[22];
- **level busts** when pilots following the Reduce Climb and Reduce Descent RAs flew through their cleared level, often causing a follow up RA for the other aircraft above or below, and disrupting ATC operations.

To address these issues, in version 7.1 the Reduce Climb/Descent RAs have been replaced with a new "Level off, level off" RA. The "Level off, level off" RA requires a reduction of vertical rate to 0 ft/min. The level off is to be achieved promptly, not at the next standard flight level (e.g. FL200, FL210, etc.). The "Level off, level off" RA may be issued as an initial RA (as illustrated in Figure 2) 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 3). The aural message "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).

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>
> See ACAS Bulletin 17 for more information on Level Off RAs

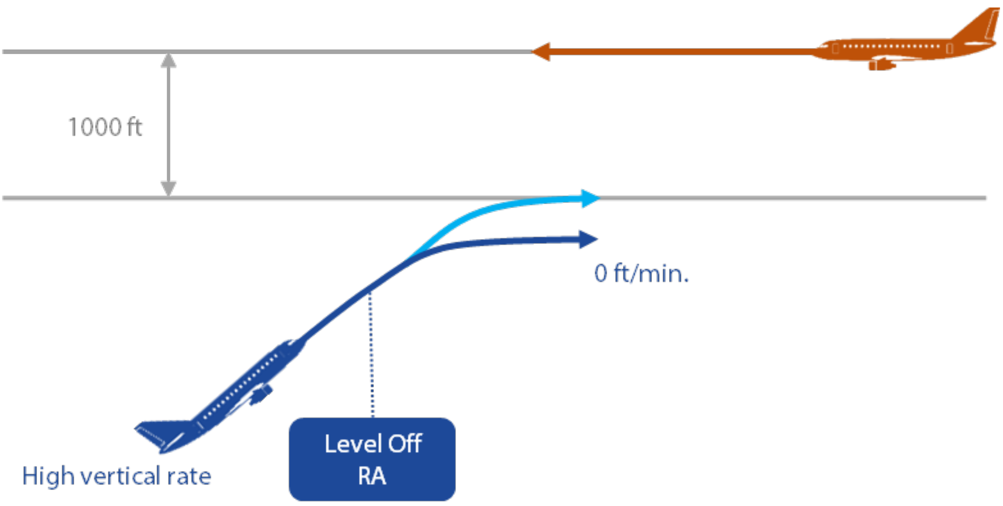

Figure 2: Level Off RA as an initial RA.

[22] 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).*

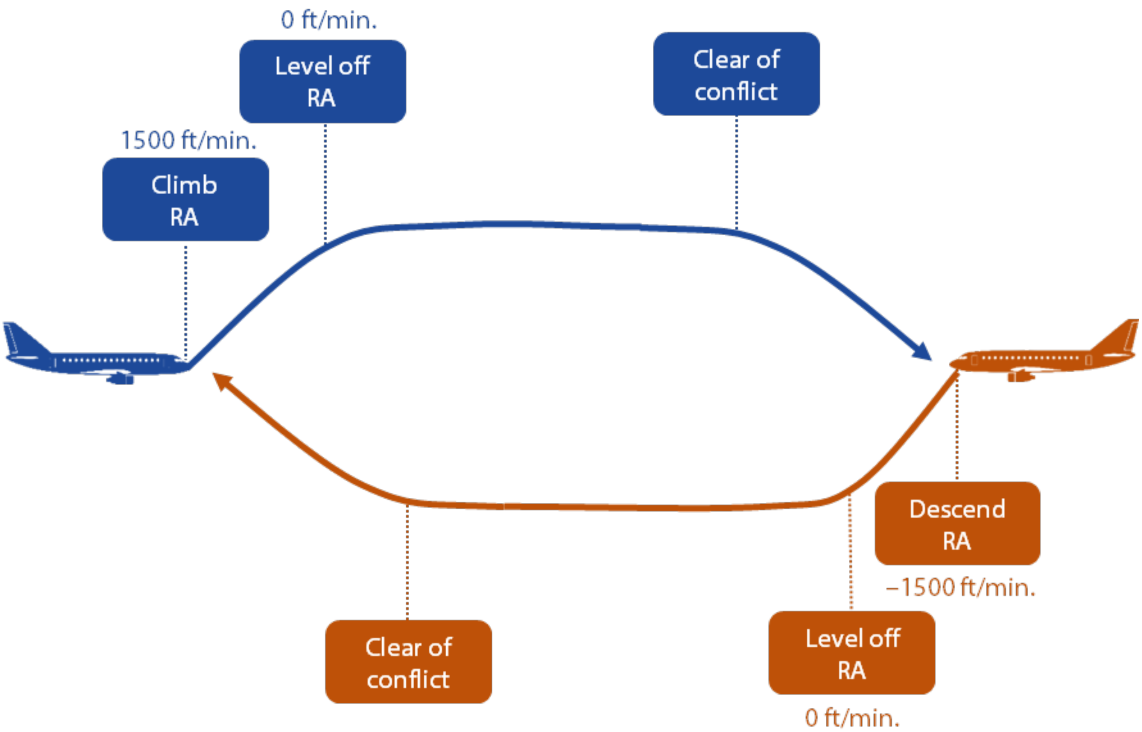

Figure 3: Level Off RA as a weakening RA.

3.2.3.2 Improved reversal logic

The design of TCAS II version 7.0 allowed for reversal RAs (i.e. "Climb, climb NOW" and "Descend, 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 4). 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[23] and the Überlingen (Germany) midair collision in 2002[24]. In 5 years following the Überlingen collision, eight other occurrences have been observed in European airspace[25].

[23] 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. More information in ACAS II Bulletin no. 25 and on SKYbrary.

[24] 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.

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

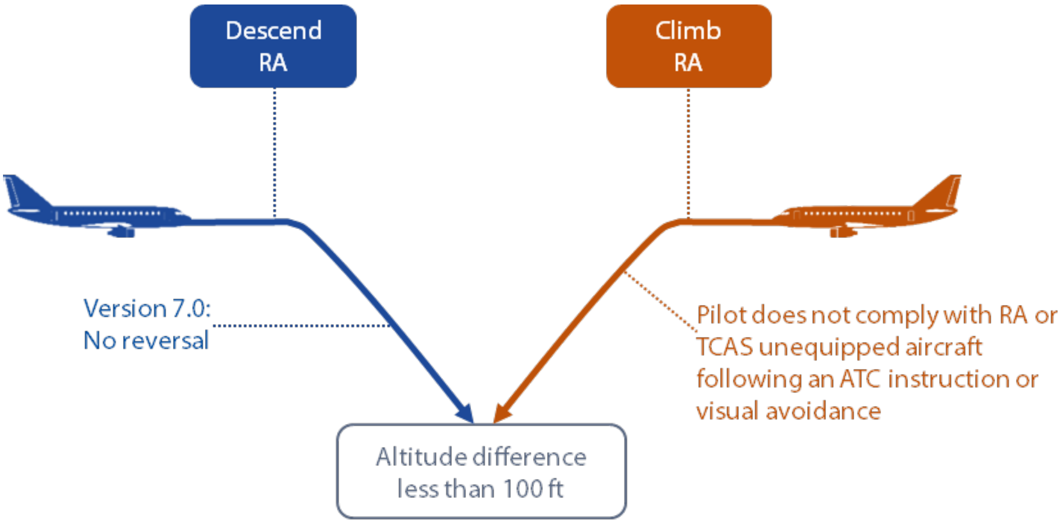

Figure 4: Geometry in which version 7.0 did not reverse an RA.

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 4). 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).

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[26] (i.e. "Climb, climb NOW" or "Descend, descend NOW" RA) and will change the sense of RA issued to the aircraft that is not responding correctly to be compatible with the reversal, e.g. "Maintain vertical speed, maintain" RA (see Figure 5). 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 6).

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

See ACAS Bulletin 14 for more information on TCAS II version 7.1

[26] 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).

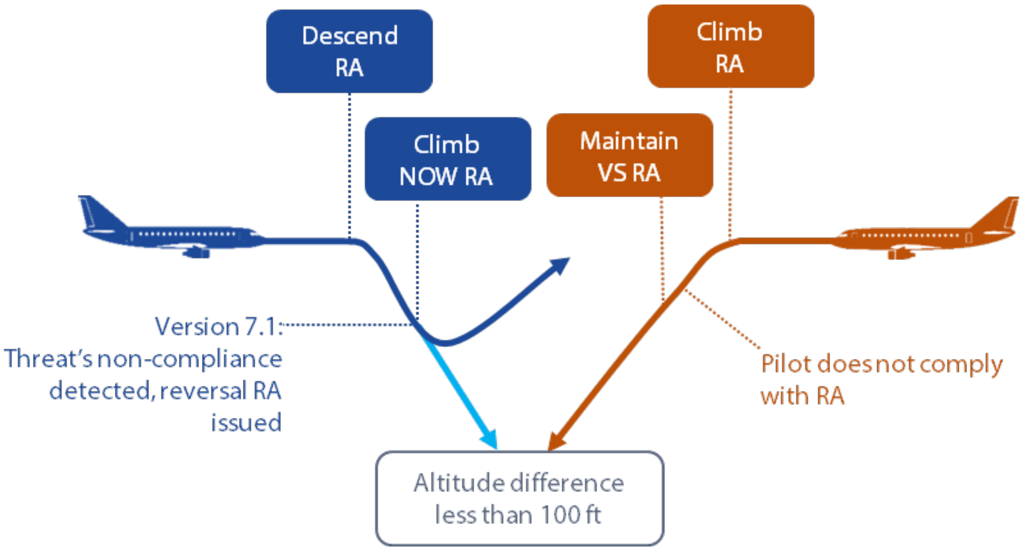

Figure 5: Improvement of reversal logic in version 7.1 (both aircraft equipped[27]).

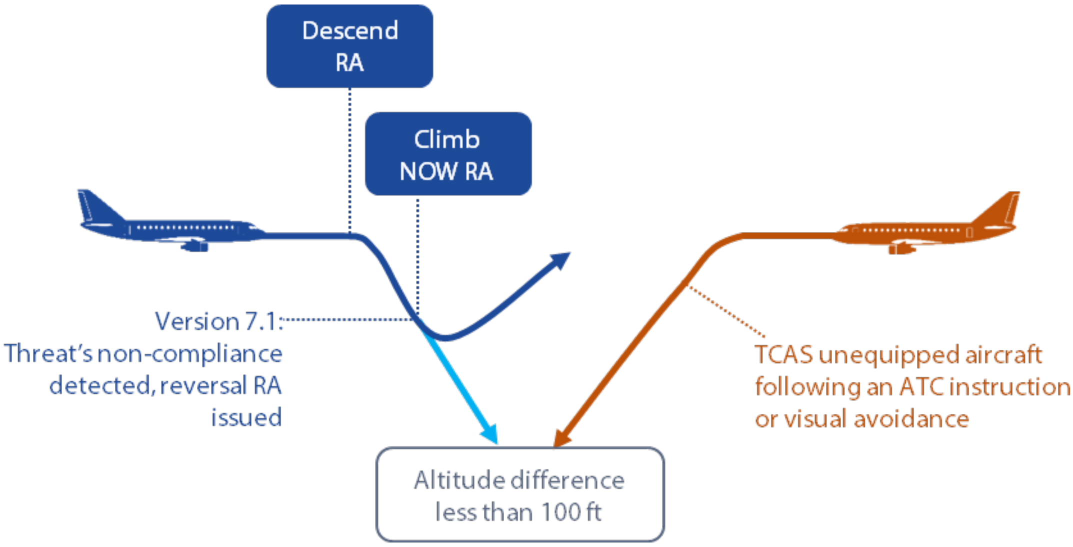

Figure 6: Improvement of reversal logic in version 7.1 (only one aircraft equipped).

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[28]) since 2008. This new approach takes advantage of recent advances in 'dynamic programming' and other computer science techniques (which were not available when TCAS II was first developed) to generate alerts using an off-line optimisation of RAs.

[27] 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.

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

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.

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 '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

The following collision avoidance systems form the ACAS X family:

- **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[29]. At the time of writing, work is ongoing at ICAO to update the relevant Provisions to include ACAS Xa. ACAS Xa may become operational in the early 2020s[30]. ACAS Xa is expected to be compliant with ACAS II ICAO SARPs[31]. Although ACAS Xa is an acceptable alternative to, and interoperable with, 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. See Section 11.1 for more information.

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

[30] TCAS II version 7.1 (at the time of writing) remains the only approved airborne collision avoidance system in European airspace. The EU implementing rules will need to be changed to allow ACAS Xa/Xo (as well as other future variants of ACAS X) to be operated in European airspace.

[31] ACAS Xa inclusion into ICAO Annex 10, Volume IV is pending at the time of writing.

- **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. It is not currently known when ACAS Xo will become operational. See Section 11.4 for more information.
- **ACAS Xu** (**u**nmanned aircraft) – Designed for Remotely Piloted Aircraft Systems (RPAS), incorporating horizontal resolution manoeuvres. Work on ACAS Xu Standards started in 2016 and the MOPS were published in December 2020[32].
- **ACAS sXu** (**s**mall **u**nmanned aircraft) – An extension of ACAS Xu intended for small Remotely Piloted Aircraft Systems (RPAS), with wing span less than 50 feet (approximately 15 meters). Work on ACAS sXu Standards has already started and is expected to be completed in 2022.
- **ACAS Xr** (**r**otorcraft) – A future version of ACAS X intended for rotorcraft (helicopters). At the time of writing, the Standards are expected to be developed by 2024.
- **ACAS Xp** (**p**assive surveillance) – A future version of ACAS X that relies solely on passive ADS-B to track intruders and does not make active interrogations. It is intended for general aviation aircraft (that are not currently required to fit TCAS II).

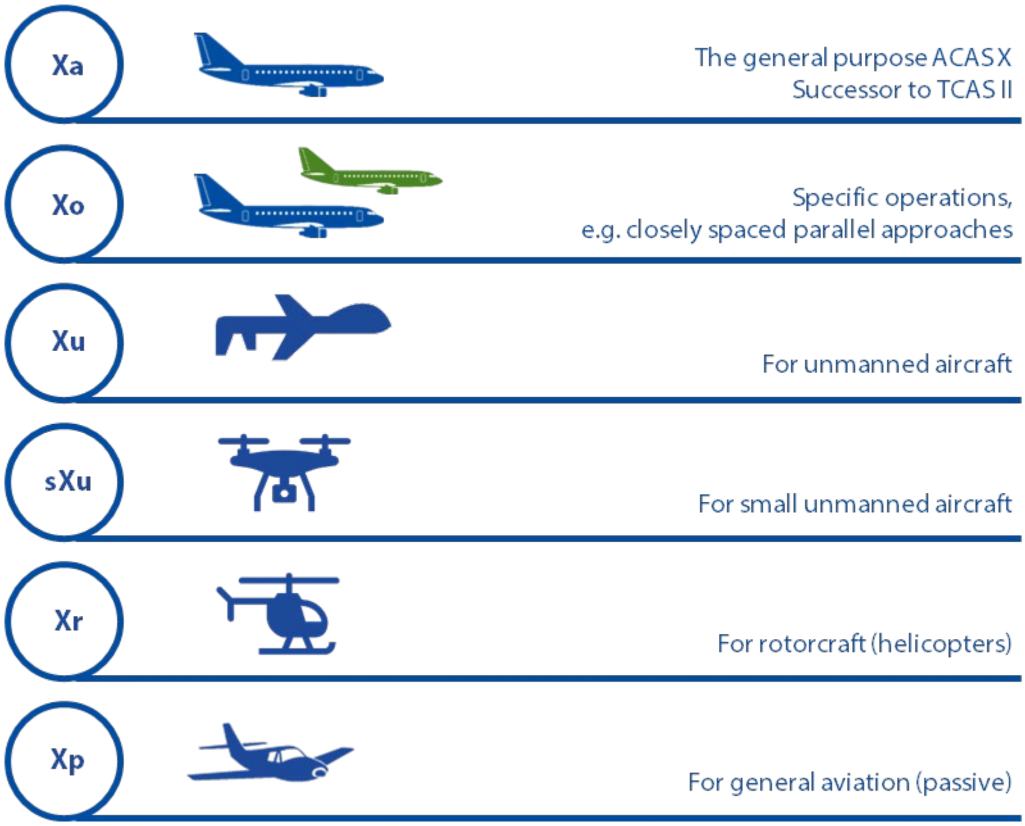

Figure 7: ACAS X variants.

[32] 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.

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[33] and NextGen[34] 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 Unmanned Aircraft Systems (UAS) or Remotely Piloted Aircraft Systems (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 17.4.

3.4 Other traffic awareness and collision avoidance systems

There are several traffic awareness and collision avoidance systems for general aviation and 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 as well as Detect and Avoid systems are not covered in this ACAS Guide.

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[33] 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.

[34] 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 II Carriage Mandates

4.1 History of carriage mandate

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

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

In 1995, the following schedule for ACAS II implementation in Europe was adopted:

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

This gradually increasing implementation of the use of ACAS II, arising from the perceived safety benefits of the equipment, and the 1996 midair collision over Charkhi Dadri (India)[35] initiated the ICAO proposal for worldwide mandatory ACAS II carriage.

In order to guarantee the complete effectiveness of ACAS II, ICAO has phased in, based upon the rules of applicability in the European policy, a worldwide 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[36], 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.

[35] 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.

[36] 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 and European ACAS II equipage mandates

Amendment 85 to ICAO Annex 10, Volume IV, published in October 2010, introduced a provision[37] stating that all ACAS units shall be compliant with version 7.1 **after 1 January 2017**.

Version 7.1 has been mandated within European Union earlier than the dates stipulated in ICAO Annex 10. On 20 December 2011, the European Commission published an Implementing Rule[38], subsequently amended on 16 April 2016[39], mandating the carriage of ACAS II (TCAS II) version 7.1 within **European Union airspace from 1 December 2015 by all aeroplanes with a maximum certified take-off mass exceeding 5700 kg or authorised to carry more than 19 passengers**, with the exception of unmanned aircraft systems.

The above mandate applies only to civil aircraft. However, the Military Authorities of the ECAC (European Civil Aviation Conference) 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[40].

Currently, the European Union mandate does not cover ACAS Xa. For ACAS Xa to be operated in European airspace, the above-mentioned Implementing Rule will need to be amended.

4.3 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, 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 above-mentioned Implementing Rule) 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[41].

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[42].

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

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[37] See Section 21.3 for the full text of ICAO Annex 10 provision.

[38] 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.

[39] Commission Regulation (EU) No 2016/583 of 15 April 2016 amending Regulation (EU) No 1332/2011 laying down common airspace usage requirements and operating procedures for airborne collision avoidance published in the Official Journal of the European Union on 16 April 2016.

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

[41] Source: EASA website.

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

4.4 Equipage exemptions

The EU Implementing Rule does not provide for equipage exemptions that would permit continued operations or a single flight without the required ACAS II equipment, except for the ACAS II equipped aircraft temporarily operating without the serviceable ACAS II equipment under the MEL exemption (see Section 8.12)[43].

[43] For more information refer to EASA website.

5 SYSTEM COMPONENTS

5.1 TCAS II system components

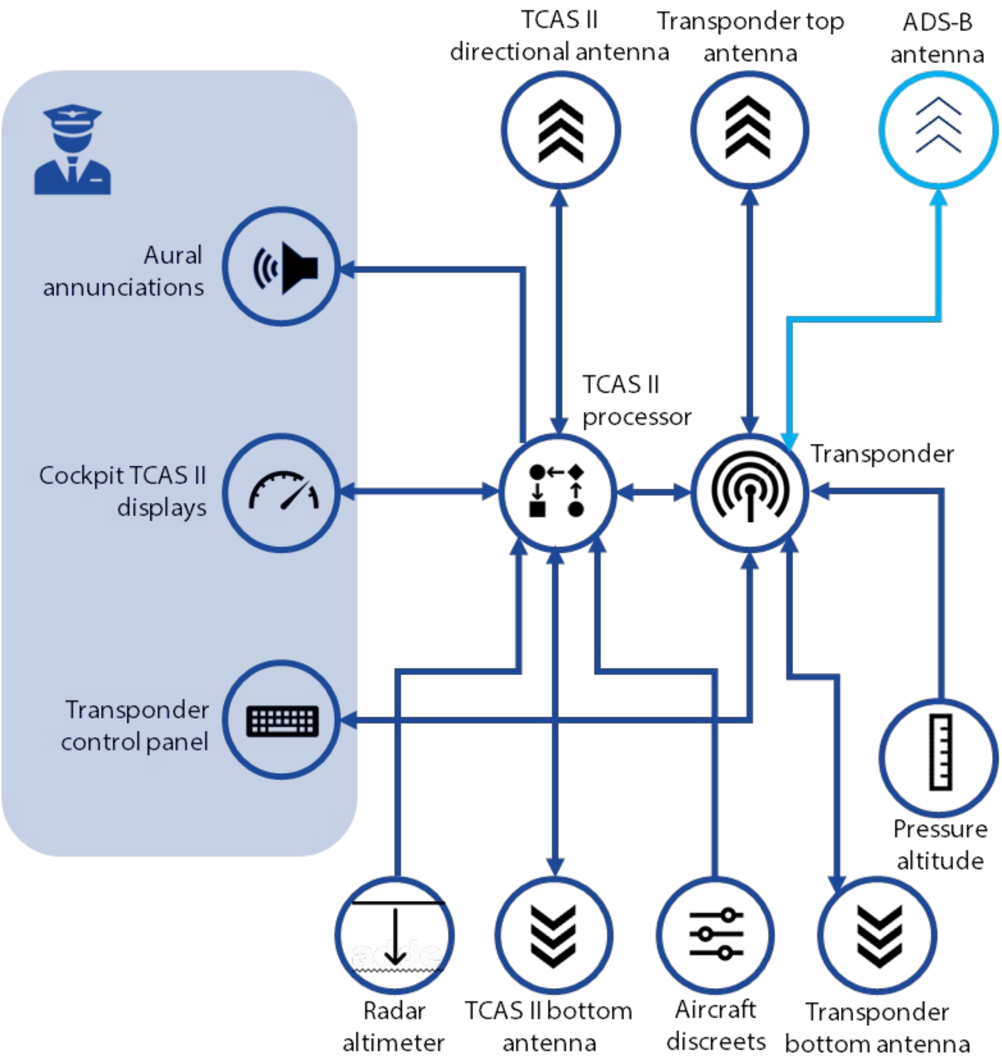


Figure 8: TCAS II installation schematic diagram.

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).

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[44], 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.

[44] An exception here is the Airbus AP/FD (Autopilot/Flight Director) TCAS capability. See Section 8.15.1 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[45].

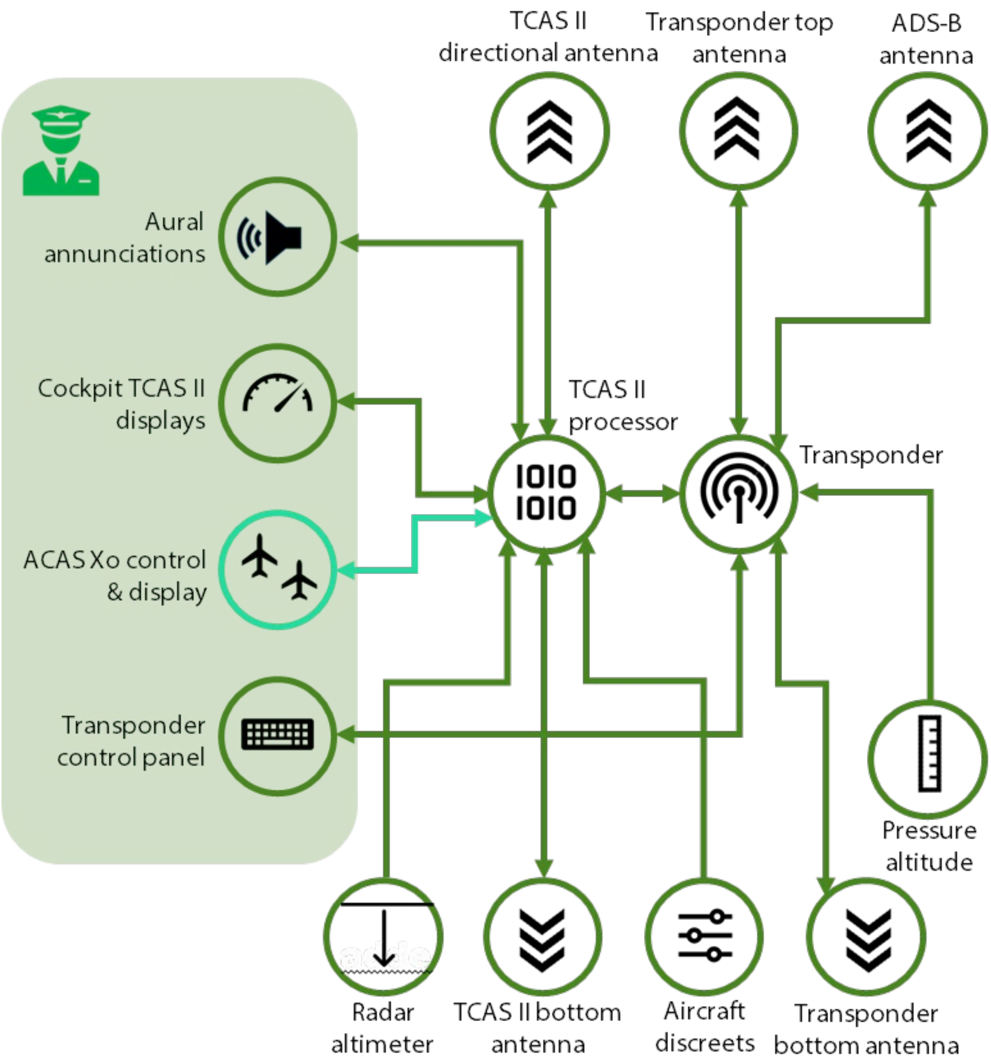


Figure 9: ACAS Xa installation schematic diagram.

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 Stand-by.

[45] 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 11 and Figure 12). Typically, the following modes are available (implementations may vary):

- **STAND-BY:** 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 Stand-by.
- **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.

See Section 10.1.4 for information about mode of operations.

See Figure 11 and Figure 12 for illustration of TCAS/transponder control panels on the Boeing 737-700 and Airbus A320.

Operating mode	Stand-by (STBY)	XPNDR	ALT RPTG OFF	TA-only	TA/RA or AUTOMATI
Transponder	Off	On	On, but no altitude reporting	On	On
ACAS	Off	Off	Off	On	On
Own aircraft	No alerts	No alerts	No alerts	TA only	TA &. RA
Intruder	No alerts	TA & RA (uncoordinated)	NAR TAs[46]	TA & RA (uncoordinated)	TA & RA
ATC	No detected	Full detection	Detected, without altitude info	Full detection	Full detection

Figure 10: ACAS and transponder modes of operations.

[46] See Section 6.9 for more information regarding NAR (non-altitude reporting) TAs.

Figure 11: Example of TCAS/transponder panel on a Boeing 737-700.

Figure 12: 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.

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

See ACAS Bulletin 6 for information on the usage of traffic display

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.

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 implementation may also provide flight identification next to the traffic symbol based on ADS-B In applications.

Examples of traffic displays are shown in figures below.

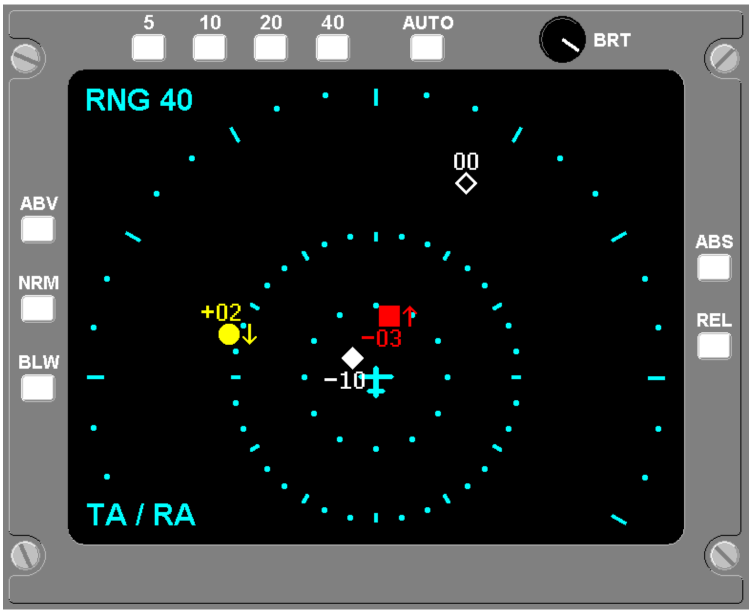


Figure 13: Traffic display example – dedicated display.

Figure 14: Traffic display example – IVSI combined with traffic display.

Figure 15: Traffic display example – Electronic Flight Instrument System (EFIS).

Figure 16: Actual traffic display implementation on Airbus A320.

Figure 17: Actual traffic display implementation on Boeing 737-800.

5.4.2 Traffic display symbology

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

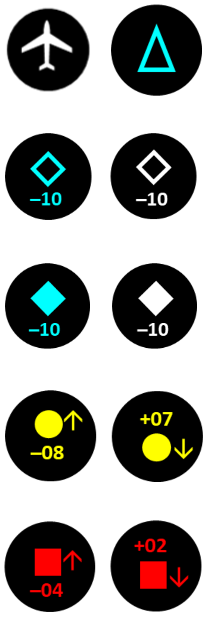
The background to the display is dark. The traffic display symbols are shown in Figure 18 below. Targets are displayed by different symbols, according to their threat status.

The vertical trend arrow and relative altitude will be shown next to each symbol (in the matching colour)[47]. 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.

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.

For ACAS Xo equipped aircraft, once a pilot has designated the DNA or CSPO-3000 function on a target, the designation will be indicated on the traffic display (i.e. a special symbol will be assigned to the target).

[47] Except for non-altitude reporting (NAR) targets. See Section 6.9 for more information.



White or cyan (light blue) aircraft-like symbol or a triangle	Own aircraft
Hollow cyan (light blue) or white diamond	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[48]	Traffic advisory Typically generated 20-48 seconds before CPA
Solid red square	Resolution advisory Typically generated 15-35 seconds before CPA

Figure 18: Traffic display symbology.

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

Vertical data is also shown next to the relevant symbol (when the intruder is reporting altitude). The relative altitude is displayed in hundreds of feet, above the symbol if the intruder is above own aircraft and below the symbol in the opposite case. 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 Figure 19).

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[49]: 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, 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.

[48] If ACAS Xa AOTO feature is enabled (see Section 11.3.5), then the AOTO TA symbol will be different from the symbol presented here.

[49] Bearing information is also used for manoeuvre detection in the Miss-Distance Filter (see Threat Detection in Section 10.2.3).

Figure 19: Trend arrow symbology.

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 are prohibited.

5.4.3 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 14. A 2-NM radius circle is shown by dots or lines around the own aircraft symbol.

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

Table 2 and Table 3 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 20). An example of implementation on a Boeing 737-800 is shown in Figure 22;
- **display on the Vertical Speed Indicator (tape)** – the RA is displayed in the same way as in "classic" cockpits. A red area marks the range of vertical rates to be avoided, a green area indicates to the pilots the required vertical rate (see Figure 21). An example of implementation on an Airbus A320 is shown in Figure 23.

Table 2 and Table 3 show how ACAS II advisories are shown on an EFIS instrumentation.

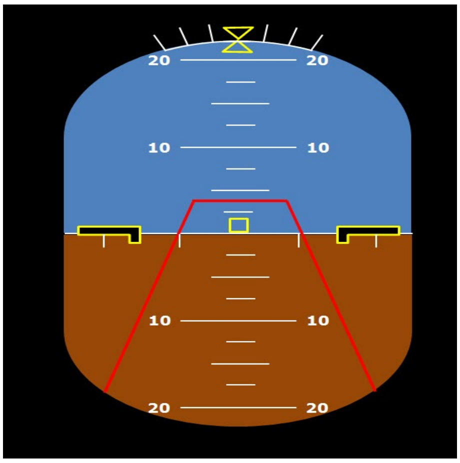


Figure 20: RA pitch cue on PFD.

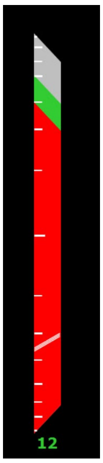


Figure 21: Vertical Speed Tape.

Figure 22: PFD with pitch cue display indicating a Climb RA on a Boeing 737-800.

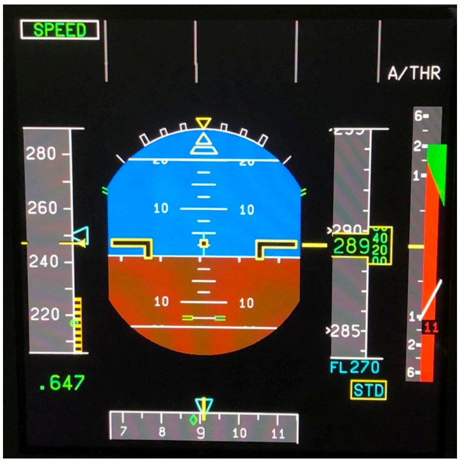


Figure 23: PFD with vertical speed tape indicating a Climb RA on an Airbus A320.

Figure 24: 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.

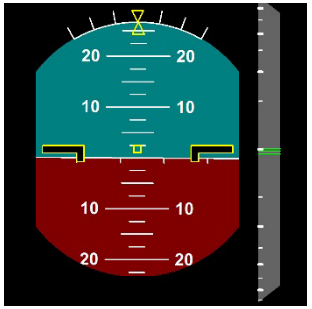
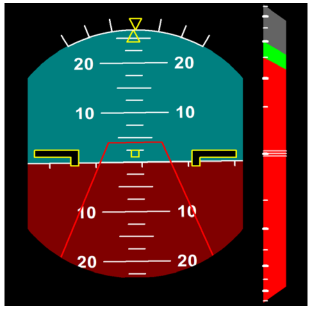
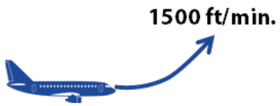
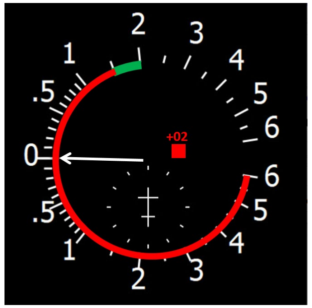
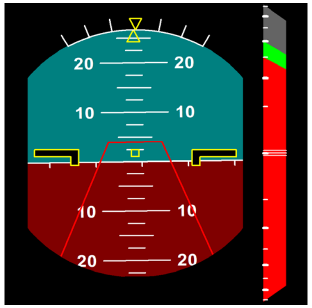
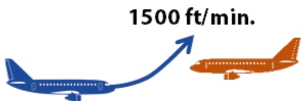
All aural annunciations are inhibited below 500 feet (±100 feet) AGL or when GPWS or TAWS or wind shear detection warnings are active (see Section 7.2).

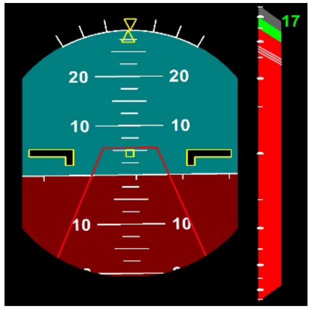
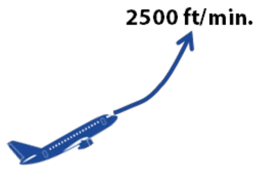
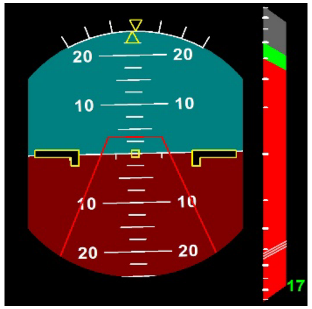
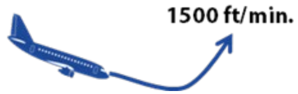
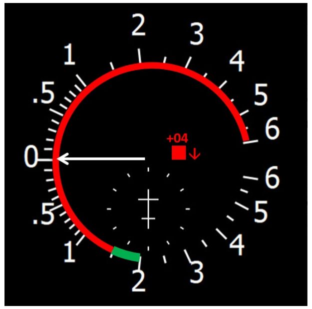
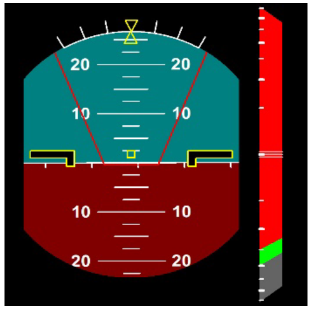
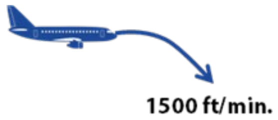
The TCAS II version 7.1 and ACAS Xa aural annunciations are shown in Table 2 and Table 3.

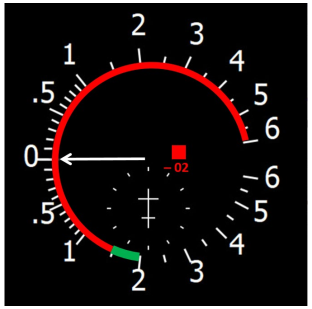
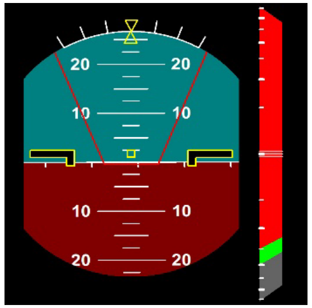
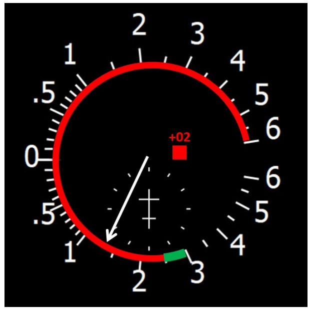
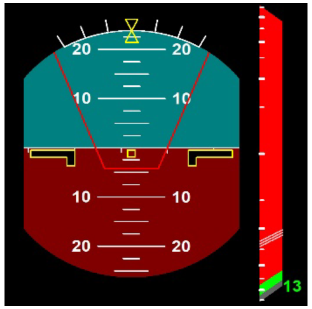
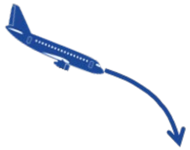
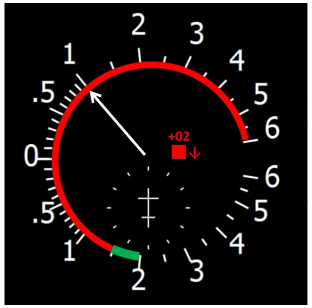
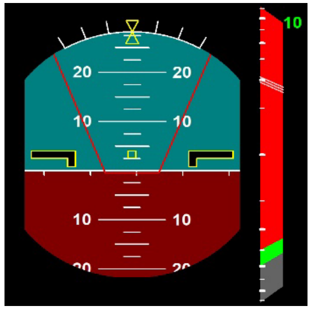
5.7 Status and Failure Annunciations

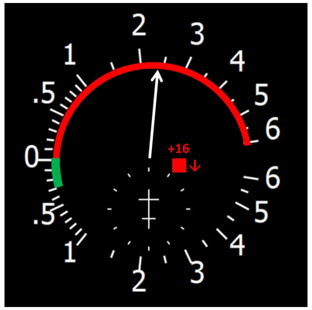
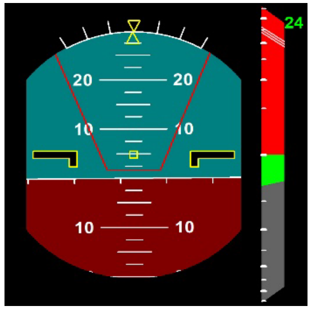
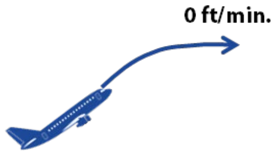
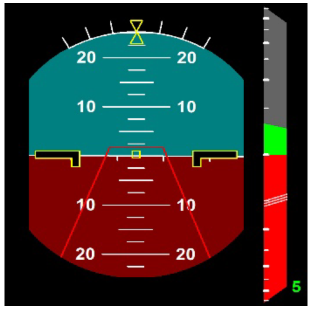
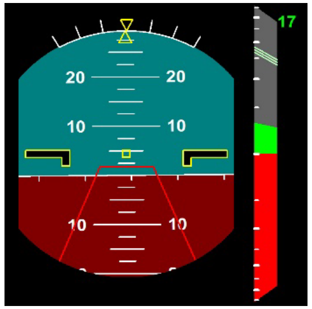
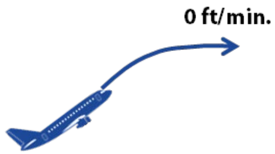
Visual annunciations are provided to indicate the normal operating and the failure modes of TCAS II and ACAS Xa. The Traffic Display and RA display will show the following operating modes and failure conditions: TCAS/ACAS in Standby or turned off, operating mode is the TA-Only mode, TCAS/ACAS has failed, Traffic Display/RA display has failed and a Self-Test is in progress.

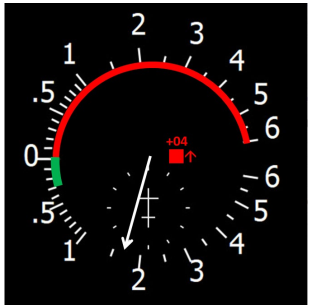
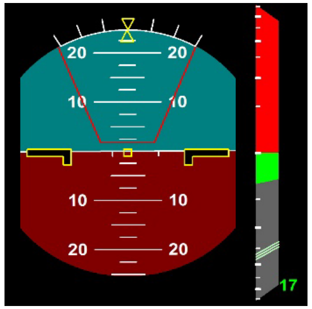
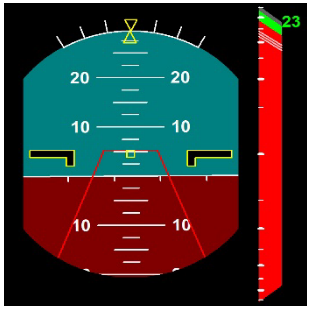
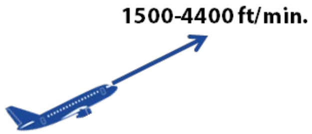
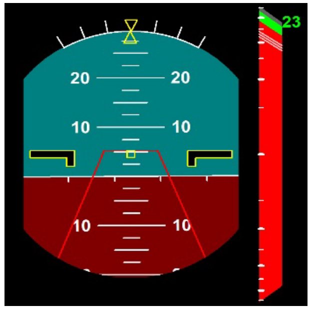
Table 2: TCAS II version 7.1 and ACAS Xa advisories aural annunciations and display as shown on (generic) IVSI and EFIS displays (single threat encounters).

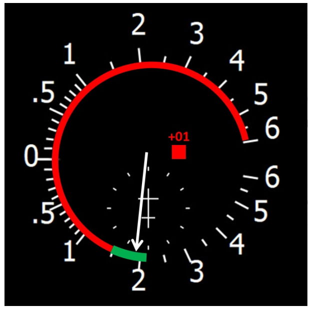
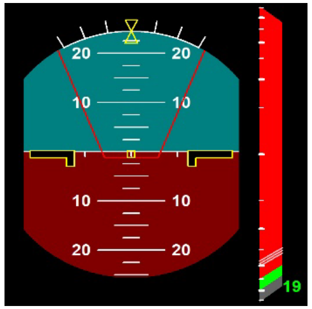
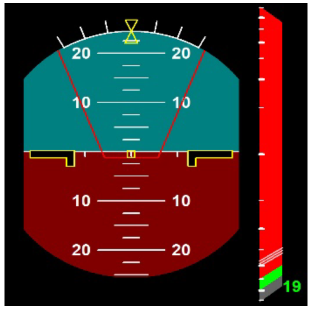
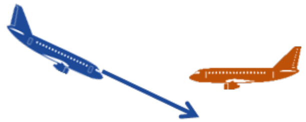
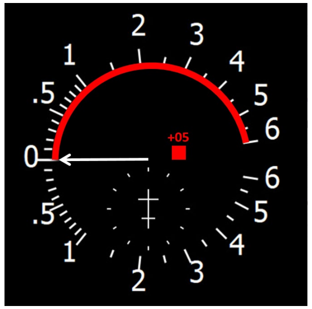
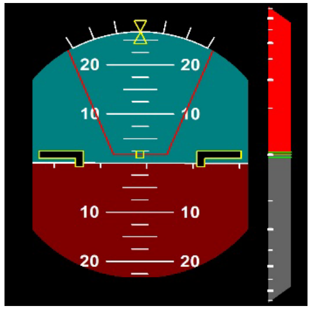
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Traffic Advisory	Traffic, traffic **TCAS II ver. 7.1** Traffic, traffic **ACAS Xa**			No manoeuvring
Climb	Climb, climb **TCAS II ver. 7.1** Climb, climb **ACAS Xa**			
Crossing Climb	Climb, crossing climb; climb crossing climb **TCAS II ver. 7.1** Climb, crossing climb; climb crossing climb **ACAS Xa**			

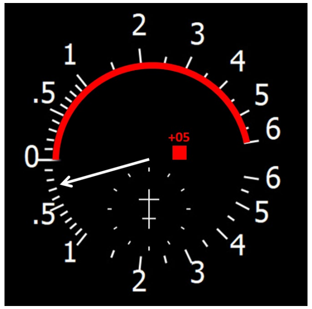
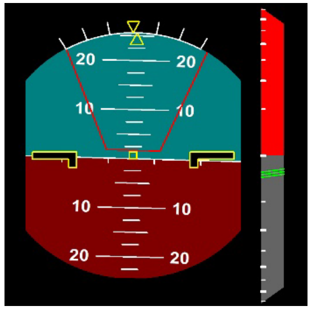
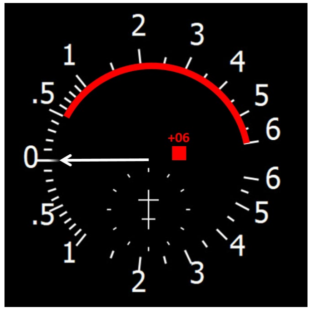
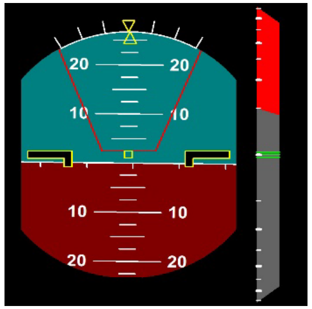
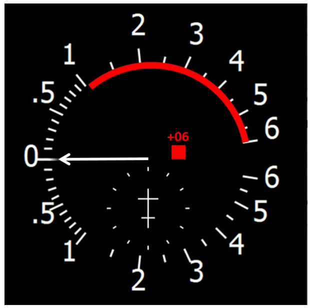
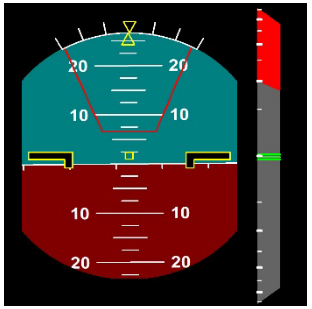
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Increase Climb Not possible as an initial RA	Increase climb, increase climb **TCAS II ver. 7.1** Increase climb, increase climb **ACAS Xa**			
Reversal Climb Not possible as an initial RA	Climb, climb NOW **TCAS II ver. 7.1** Climb, climb NOW **ACAS Xa**			
Descend	Descend, descend **TCAS II ver. 7.1** Descend, descend **ACAS Xa**			

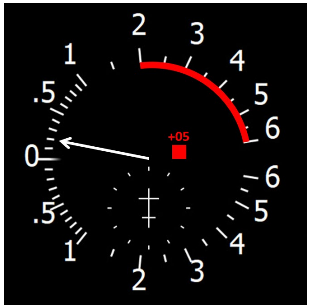
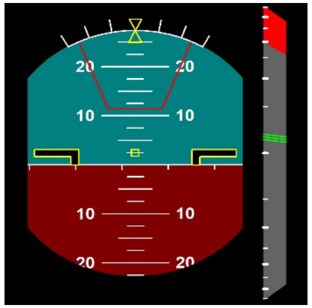
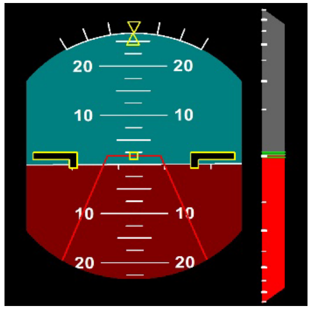
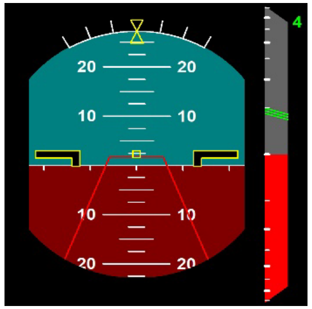
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Crossing Descend	Descend, crossing descend; descend crossing descend **TCAS II ver. 7.1** Descend, crossing descend; descend crossing descend **ACAS Xa**			 **1500 ft/min.**
Increase Descent Not possible as an initial RA	Increase descend, increase descend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

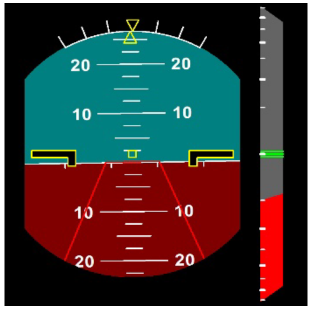
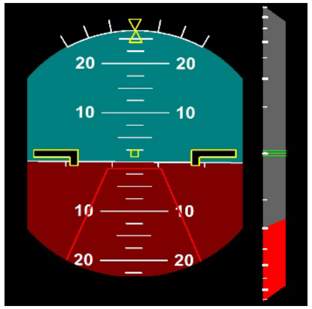
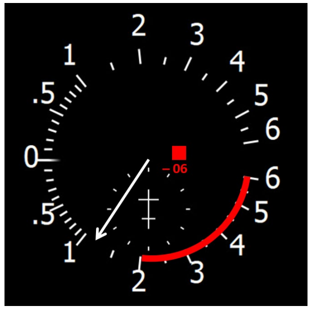
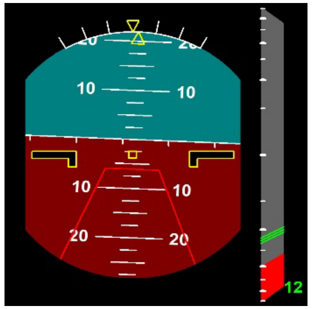
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Level Off (downward) Initial RA issued while climbing	Level off, level off TCAS II ver. 7.1 Level off, level off ACAS Xa			
Level Off (upward) Initial RA issued while descending	Level off, level off TCAS II ver. 7.1 Level off, level off ACAS Xa			
Level Off (downward) Weakening 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 (upward) Weakening 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**			
Maintain Vertical Speed Issued while climbing	Maintain vertical speed, maintain **TCAS II ver. 7.1** Climb, climb **ACAS Xa**			
Crossing Maintain Vertical Speed Issued while climbing	Maintain vertical speed, crossing maintain **TCAS II ver. 7.1** Climb, crossing climb; climb crossing climb **ACAS Xa**			

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Maintain Vertical Speed Issued while descending	Maintain vertical speed, maintain **TCAS II ver. 7.1** Descend, descend **ACAS Xa**			 **1500-4400 ft/min.**
Crossing Maintain Vertical Speed Issued while descending	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	Monitor vertical speed **TCAS II ver. 7.1** Monitor vertical speed **ACAS Xa**			No manoeuvre required. Climb is prohited.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Do Not Climb Weakening RA issued after maintain descend 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 prohited
Limit Climb 500 ft/min. TCAS II ver. 7.1 only	Monitor vertical speed TCAS II ver. 7.1 n/a ACAS Xa			No manoeuver required. Climb with the rate greater than 500 ft/min. is prohited.
Limit Climb 1000 ft/min. 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 prohited.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Limit Climb 2000 ft/min. 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 prohited.
Do Not Descend	Monitor vertical speed TCAS II ver. 7.1 Monitor vertical speed ACAS Xa			No manoeuvre required. Descent is prohited.
Do Not Descend Weakening 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. Descend is prohited.

Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
Limit Descend 500 ft/min. 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 prohited.
Limit Descend 1000 ft/min. 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 prohited.
Limit Descend 2000 ft/min. 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 prohited.

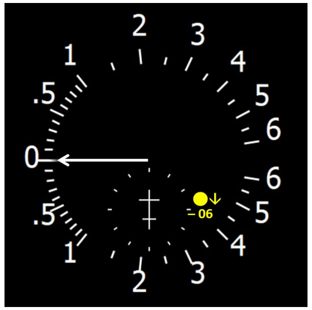
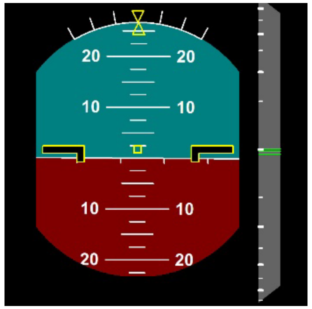
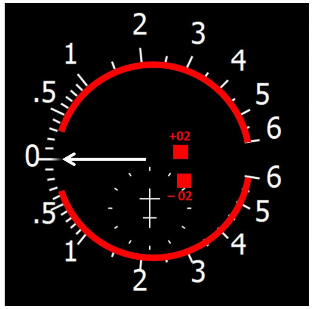
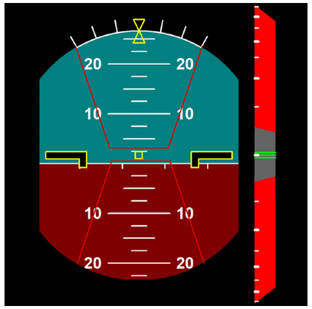
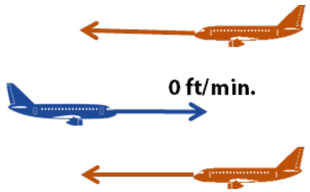
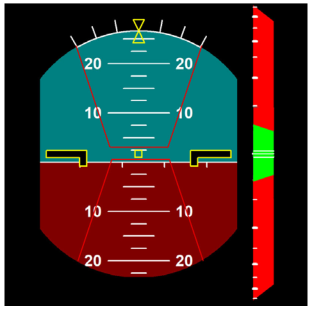
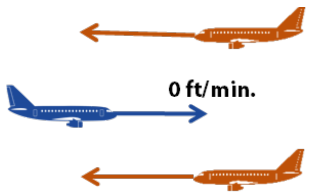
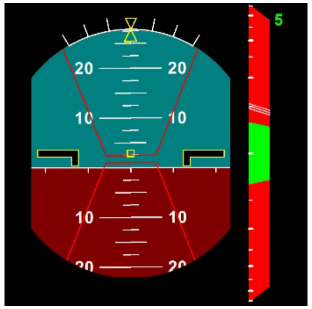
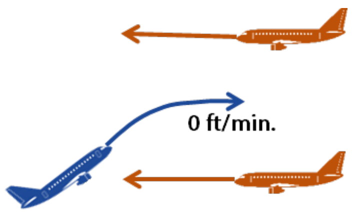
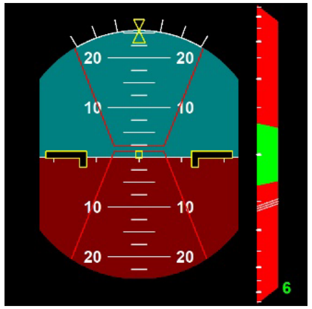
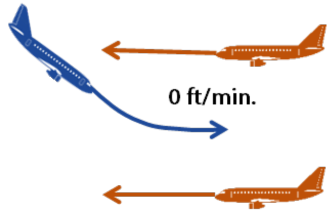
Advisory	Aural annunciation	IVSI	EFIS	Manoeuvre
RA Termination	Clear of conflict **TCAS II ver. 7.1** Clear of conflict **ACAS Xa**			Return to the last ATC clearance.

Table 3: TCAS II version 7.1 and ACAS Xa advisories aural annunciations and display as shown on (generic) IVSI and EFIS displays (examples of multi-threat encounters).

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[50]	Maintain vertical speed, maintain **TCAS II ver. 7.1**			
	Level off, level off **ACAS Xa**			

[50] 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.

<table>
<tr><th>Advisory</th><th colspan="2">Aural annunciation</th><th>IVSI</th><th>EFIS</th><th>Manoeuvre</th></tr>
<tr><td rowspan="2">Multi-threat encounter
Issued while climbing</td><td>Level off, level off</td><td>TCAS II ver. 7.1</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Level off, level off</td><td>ACAS Xa</td></tr>
<tr><td rowspan="2">Multi-threat encounter
Issued while descending</td><td>Level off, level off</td><td>TCAS II ver. 7.1</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Level off, level off</td><td>ACAS Xa</td></tr>
</table>

6 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.

Table 2 lists all ACAS II alerts for single threat encounters, while Table 3 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 11.3.4.

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 8.1 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 2. See Section 8.2 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 or a downward Maintain Vertical Speed RA (in TCAS II) can be reversed to a Climb NOW 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.

See ACAS Bulletin 13 for more information on reversal RAs

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 7.2.1).

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 25). 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.

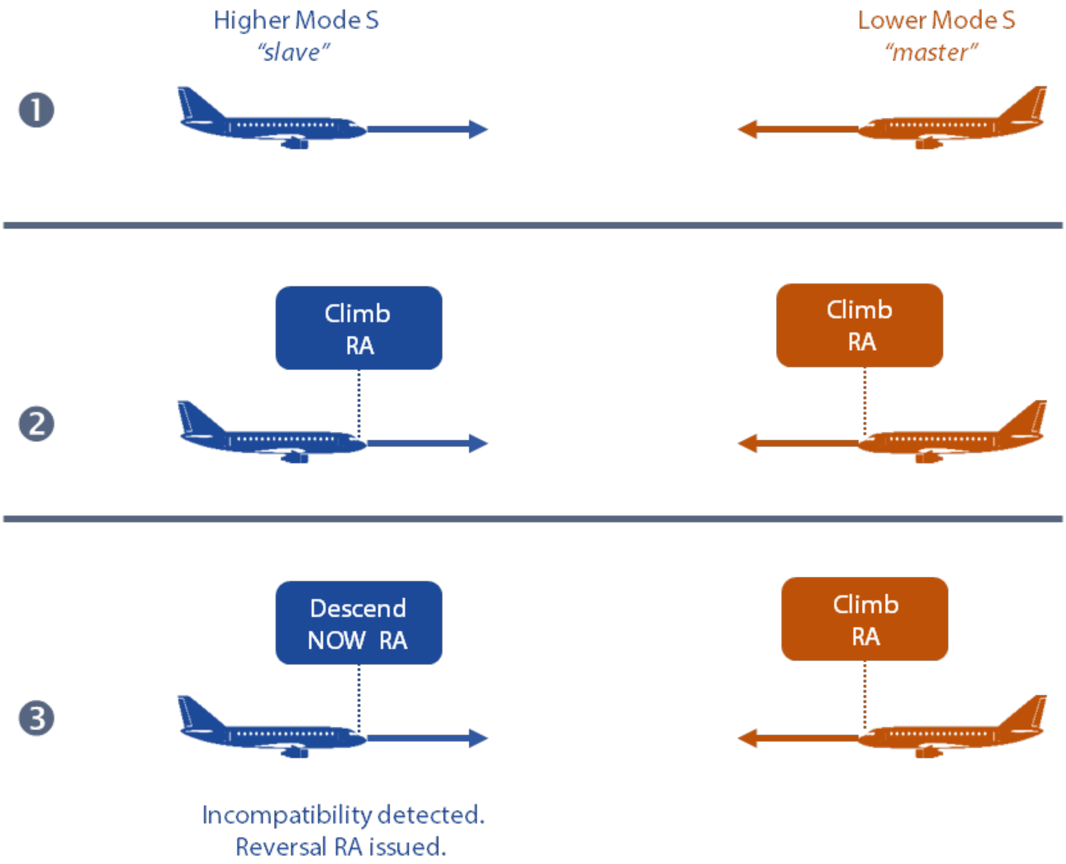


Figure 25: Coordination (tie-break) reversal in case of simultaneous threat declaration.

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 26).

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[51].

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[52].

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

See Section 8.2 on pilot actions on the receipt of a reversal RA.

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 8.2 on pilot actions on the receipt of a strengthening RA.

[51] 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.

[52] ICAO Doc 9863 Section 3.15.14.3.

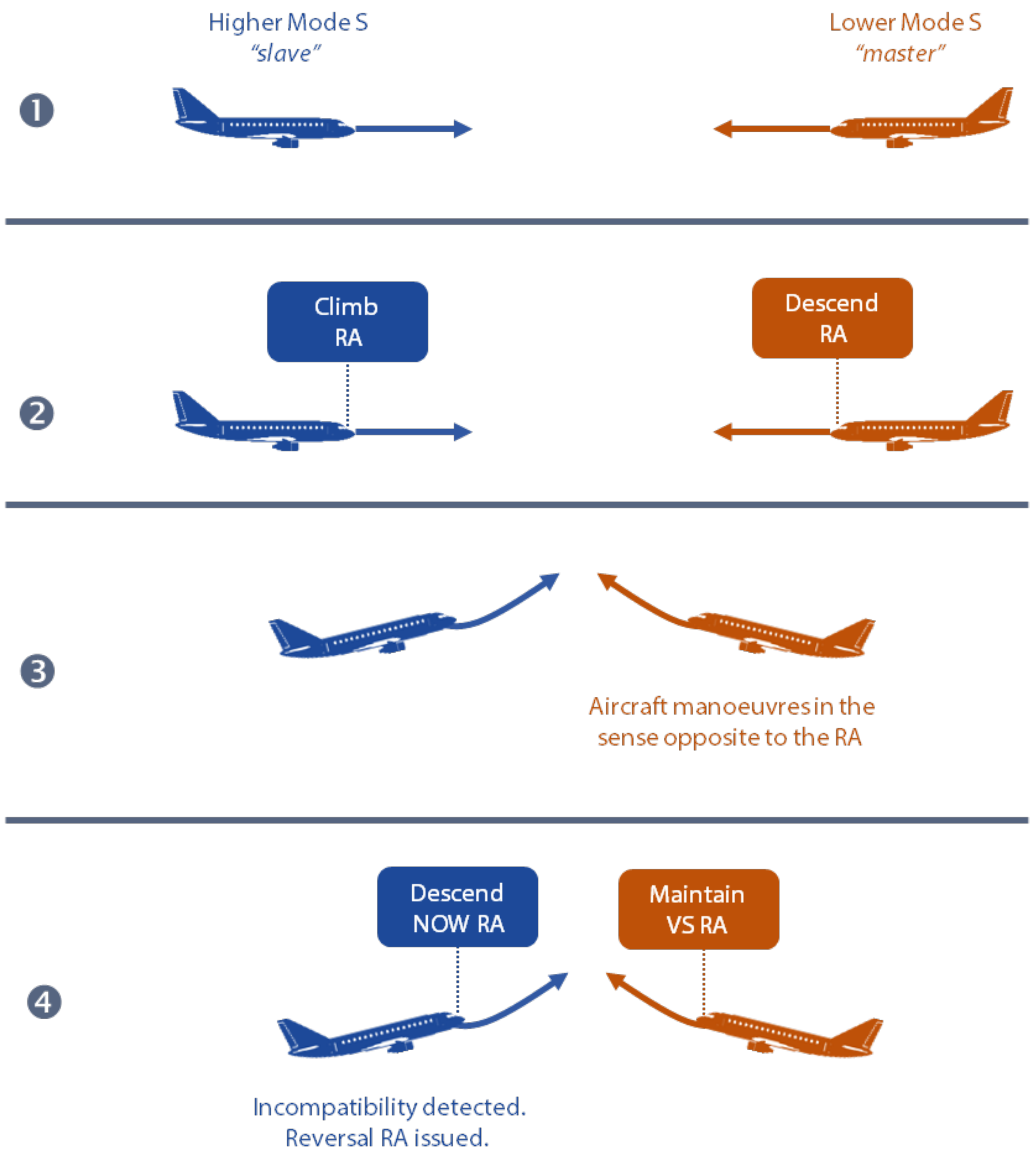


Figure 26: Geometric reversal.

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.

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.

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 an impression that they are being wrongly directed towards the other aircraft.

6.7 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.

6.8 Multi-threat RAs

Multi-threat encounters are rare. 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 3.

6.9 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 or own aircraft has passed below the RA inhibition altitude, i.e. 1000 feet (±100 feet) AGL (see Section 7.2 information about RA inhibitions).

6.10 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 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, when own aircraft is below FL155. Neither an altitude data tag nor a trend arrow will be shown with the traffic symbol for an intruder that is not reporting altitude.

TCAS II will generate TAs against non-altitude reporting aircraft when the range test 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 non-altitude reporting target will trigger the generation of a TA if the range test is satisfied and own aircraft is below FL155, on the basis of the same *tau* values associated with the RA (in *SL*2 where no RAs are issued the *SL*3 threshold of 15 seconds is used).

ACAS Xa will also generate TAs against non-altitude reporting aircraft above FL155 using the dedicated algorithm for this type of intruders[53].

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

7 ACAS II Functional Description

7.1 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.

7.2 RA inhibitions

7.2.1 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 (see Table 4 and Figure 27). 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 and Descend RAs are inhibited below 1550 and 1100 feet respectively 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 be 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).

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 when own aircraft is on the ground while for ACAS Xa these intruders will 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 4: 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.

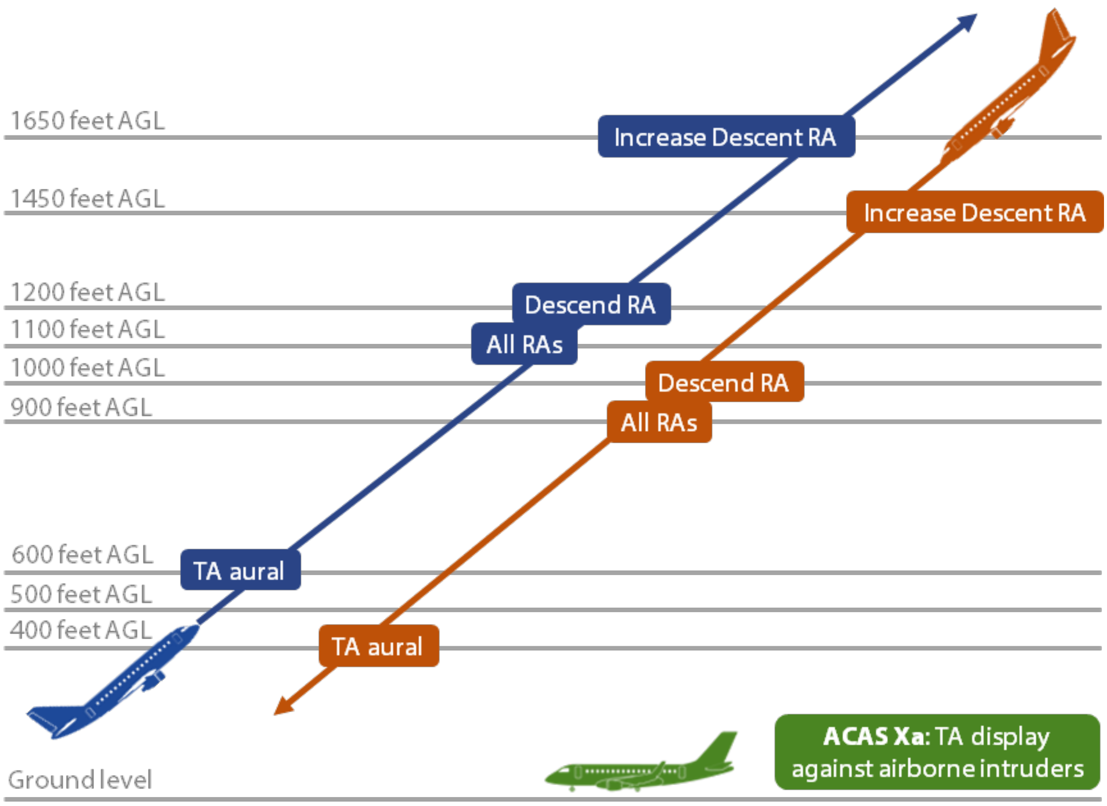


Figure 27: Illustration of ACAS II alert inhibitions.

7.2.2 Priority alert inhibitions

Some higher priority flight alerts, like GPWS (Ground Proximity Warning System), TAWS (Terrain Avoidance and Warning System) or wind shear detection warning take precedence over ACAS II alerts. When a GPWS/TAWS or wind shear detection warning have been activated, ACAS II will automatically be placed into TA-only mode with TA aural annunciation suppressed. 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.

7.2.3 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.

7.2.4 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.

7.3 ACAS-ACAS coordination

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 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 9.5 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[54]. 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.

[54] 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).

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.

7.4 ACAS-ACAS encounters

TCAS II monitoring indicates (see Section 12.2) 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).

7.5 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.

7.6 Threat detection limitations

7.6.1 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 depending on the threat type is shown in Table 5. 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 5: ACAS II levels of protection.

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

* Optional feature. See Section 11.3.5 for more information.

7.6.2 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.

7.7 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). 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[55]. As illustrated in an example below (Figure 28), 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 7.2.1).

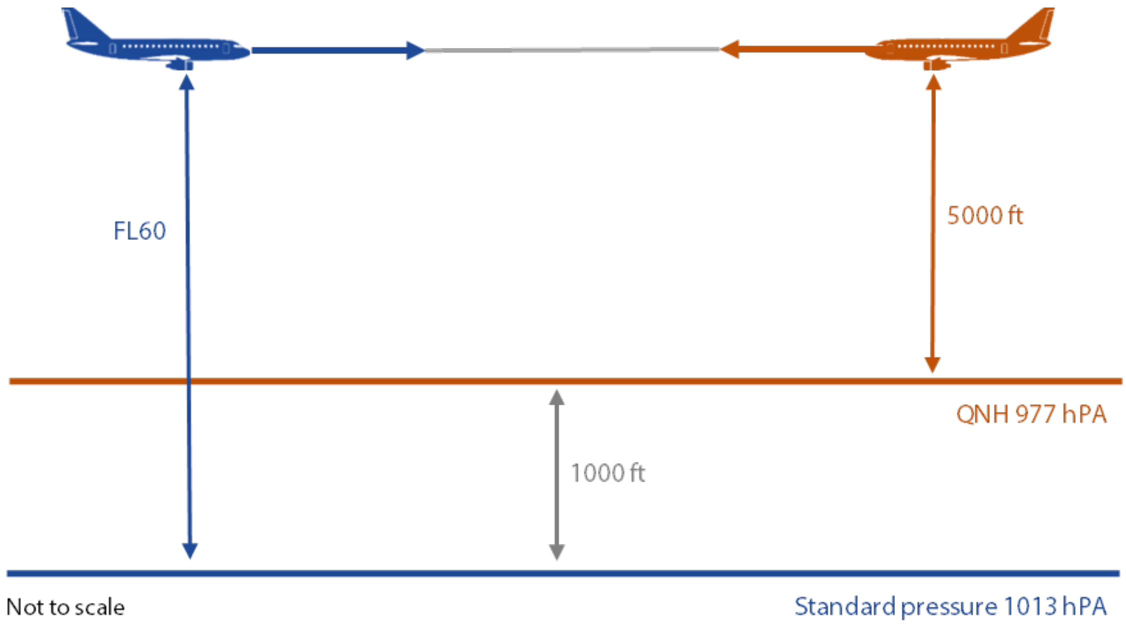


Figure 28: ACAS II altitude is automatically referenced to the standard pressure setting.

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

8 ACAS II Operations

8.1 Traffic Advisories – 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 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.

See ACAS Bulletin 16 for more information on Traffic Advisories

8.2 Resolution Advisories – 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. 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[56] 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 2 and Table 3). The threat aircraft symbol on the traffic displays changes to a red solid square and the ranges of the vertical rates to be avoided and the required vertical rate are displayed on appropriate instruments (implementation dependent).

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

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

For corrective RAs, the response should be initiated in the proper direction within 5 seconds of the RA being displayed. The change in vertical speed should be accomplished with an acceleration of $^1/_4\,g$.

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 $^1/_3\,g$.

[56] An exception here is the Airbus AP/FD (Autopilot/Flight Director) TCAS capability. See Section 8.15.1 for more information.

Practical advice on how to achieve the required acceleration is provided in EASA's Guidance Material [57]: *"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.

–10	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
–10	Proximate traffic * Aircraft within 6 NM and 1200 feet of own aircraft			
–08	Traffic advisory Typically generated 20-48 seconds before CPA	Visual acquisition Prepare for possible RA		
–04	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
–09	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.

Figure 29: ACAS II traffic display symbology and pilot associated actions.

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).

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

Figure 29 shows Traffic Display symbology and associated alerts and associated pilot actions. See Section 8.3 for information regarding RA reporting.

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

8.3 Interaction with ATC during RA – reporting RAs

An RA has important consequences for 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, ATC is required not to attempt to modify the flight path of the aircraft involved in the encounter. Hence, the pilot is expected to "follow the RA" (even though this does not yet always happen in practice).

Those RAs that require a deviation from the current ATC clearance or instruction are to be reported to ATC as soon as aircrew workload permits using the following phraseology[58]:

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

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).

If an ATC clearance or instruction contradictory to the ACAS II RA is received (i.e. 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.

Note – the phraseology is using 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.

If requested by the crew, air traffic controllers must 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. The implementation does not relieve the pilots from reporting RAs using the above-mentioned phraseology. ICAO has not published any provisions for operations of RA downlink.

[58] See Section 21.4.2 for the full text of ICAO PANS-ATM provision.

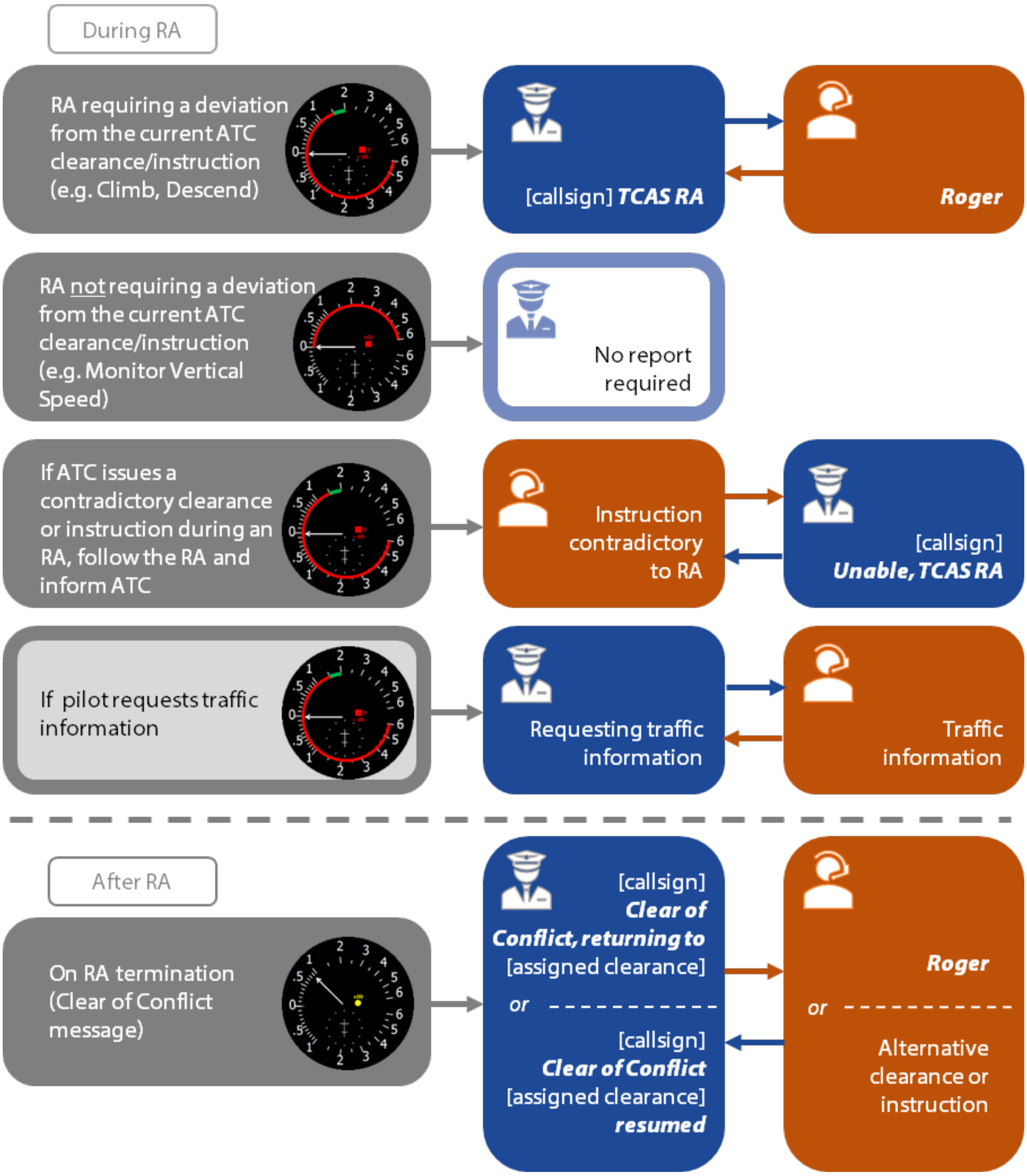


Figure 30: Pilot – ATC communication during and after an RA.

8.4 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 8.5 for more information).

ICAO Annex 10 states that 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. 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.

8.5 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.

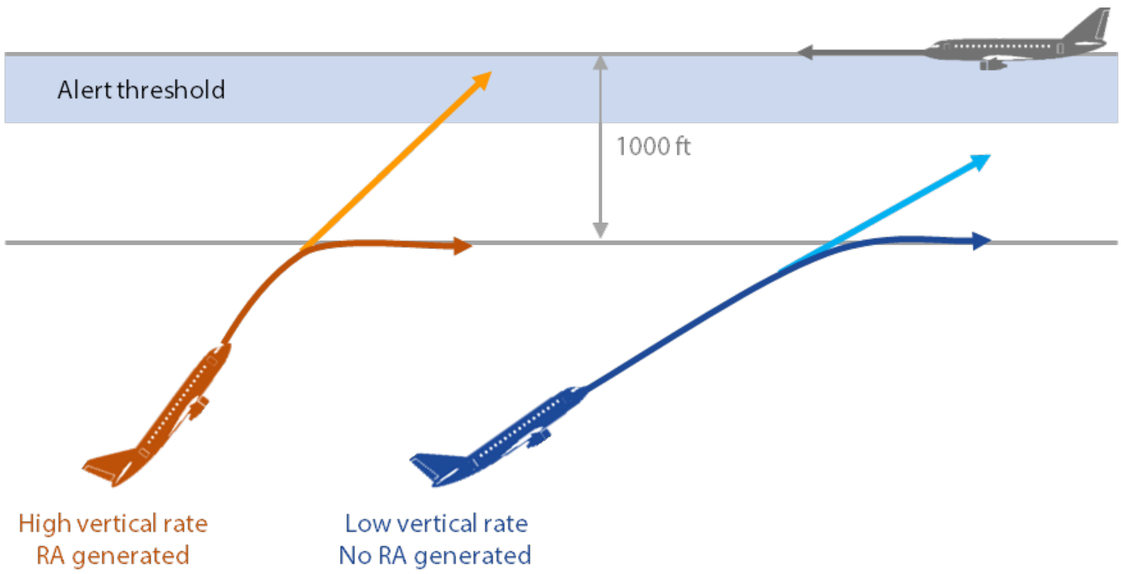


Figure 31: Approaching the cleared level with high vs. low vertical rate.

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.

ICAO Annex 6 (see Section 21.2) 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. However, pilots must comply with ATC instructions[59]. Even when the ICAO vertical speed reduction recommendation are followed, in some geometries these RAs may occur.

See ACAS Bulletin 15 for more information on high vertical rates

[59] Air traffic controllers use vertical rate instructions to ensure that all aircraft remain separated while traffic is flowing efficiently.

8.6 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[60] are quite clear that in the event of an RA, the pilot must respond immediately by following the RA unless doing so would jeopardise the safety of the aircraft. That provision applies in all airspace classes and all meteorological conditions (i.e. VMC and IMC). In real-time the pilot has little chance to assess whether the traffic acquired visually is in fact the one against which the RA has been generated. Also, the European Aviation Safety Agency (EASA) in their Safety Bulletin highlighted the fact that avoidance manoeuvres based on visual acquisition of traffic may not always provide the appropriate means of avoiding conflicting traffic[61].

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

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

8.7 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 12.9.1 for statistical data concerning inappropriate pilot responses.

8.8 Closely spaced parallel approaches

As recommended by ICAO[62], 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. 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 11.4) can prevent unwanted RAs during parallel approaches with runways 3000 feet apart or more.

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[60] See Section 21.5 for the full text of ICAO PANS-OPS provision.

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

[62] See the quotes from ICAO PANS-OPS in Section 21.5 and ICAO ACAS Manual in Section 21.6.

8.9 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) 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.*"

8.10 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.

8.11 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 5).

See Section 12.9.2 for statistical data concerning TA-only operations.

8.12 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[63]. 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.

[63] German AIP GEN 1.5 para. 5 dated 21 July 2016.

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 the role of ATC to police ACAS II serviceability[64]. See Section 12.9.2 for statistical data concerning TCAS II serviceability.

8.13 ACAS II/transponder operations on the ground

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

The modes of ACAS II/transponder operations are explained in and illustrated in Figure 32.

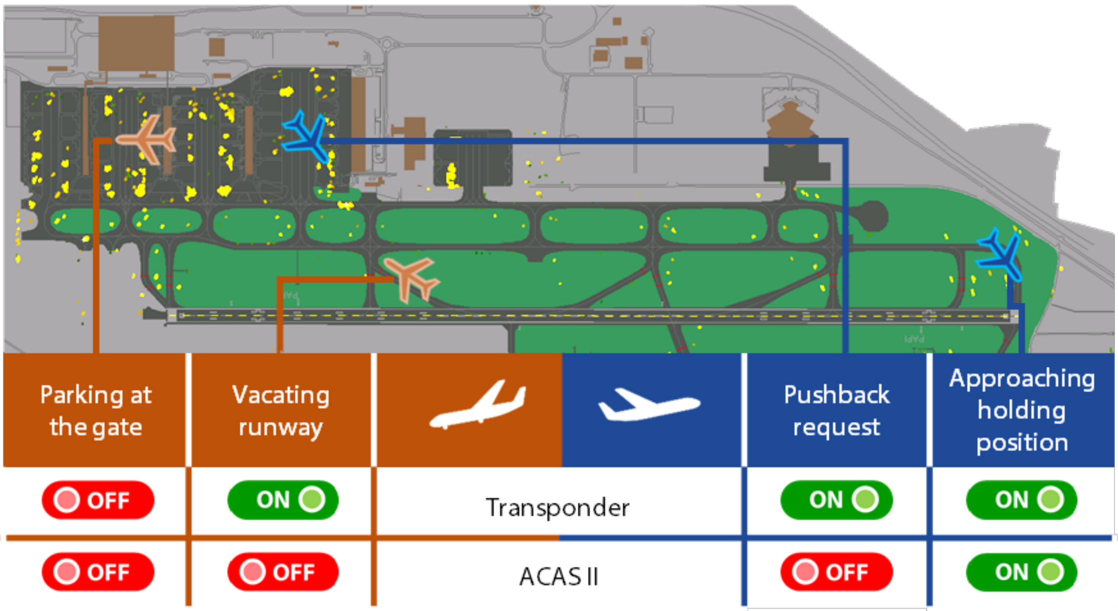


Figure 32: ACAS II/transponder operation on the ground.

[64] 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".

8.14 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.

8.14.1 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[65]. 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 8.14.2.

Figure 33: Demonstrative interception of ACAS II equipped aircraft.

8.14.2 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.

[65] For more information, see Section 6.9 on non-altitude reporting intruders.

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.

8.15 Additional ACAS II capabilities

8.15.1 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[66]. 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[67].

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

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 35.

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).

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

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

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 7.2.1).

The AP/FD mode RAs should be reported to ATC following the same principles as manually flown RAs (see Section 8.3).

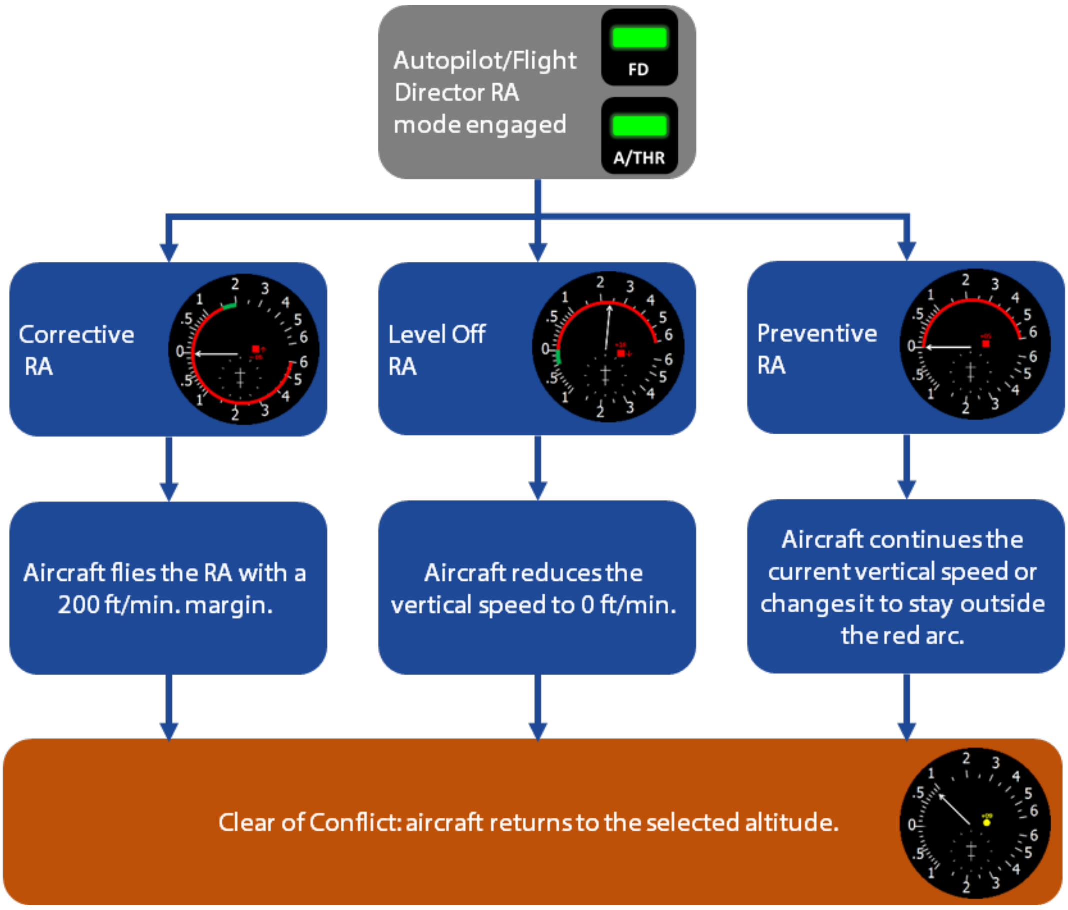


Figure 35: Airbus AP/FD mode.

8.15.2 Airbus TCAS Alert Prevention (TCAP) functionality

A TCAP (**TC**AS **A**lert **P**revention) functionality has been introduced by Airbus to prevent the generation of RAs in 1000-foot level-off geometries[68]. 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[69]. The functionality uses a new altitude capture law for flight guidance computers, which decreases aircraft's vertical rate approaching the selected altitude, once a TA has been generated and the auto-pilot and/or flight director are engaged (see Figure 36).

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

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

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

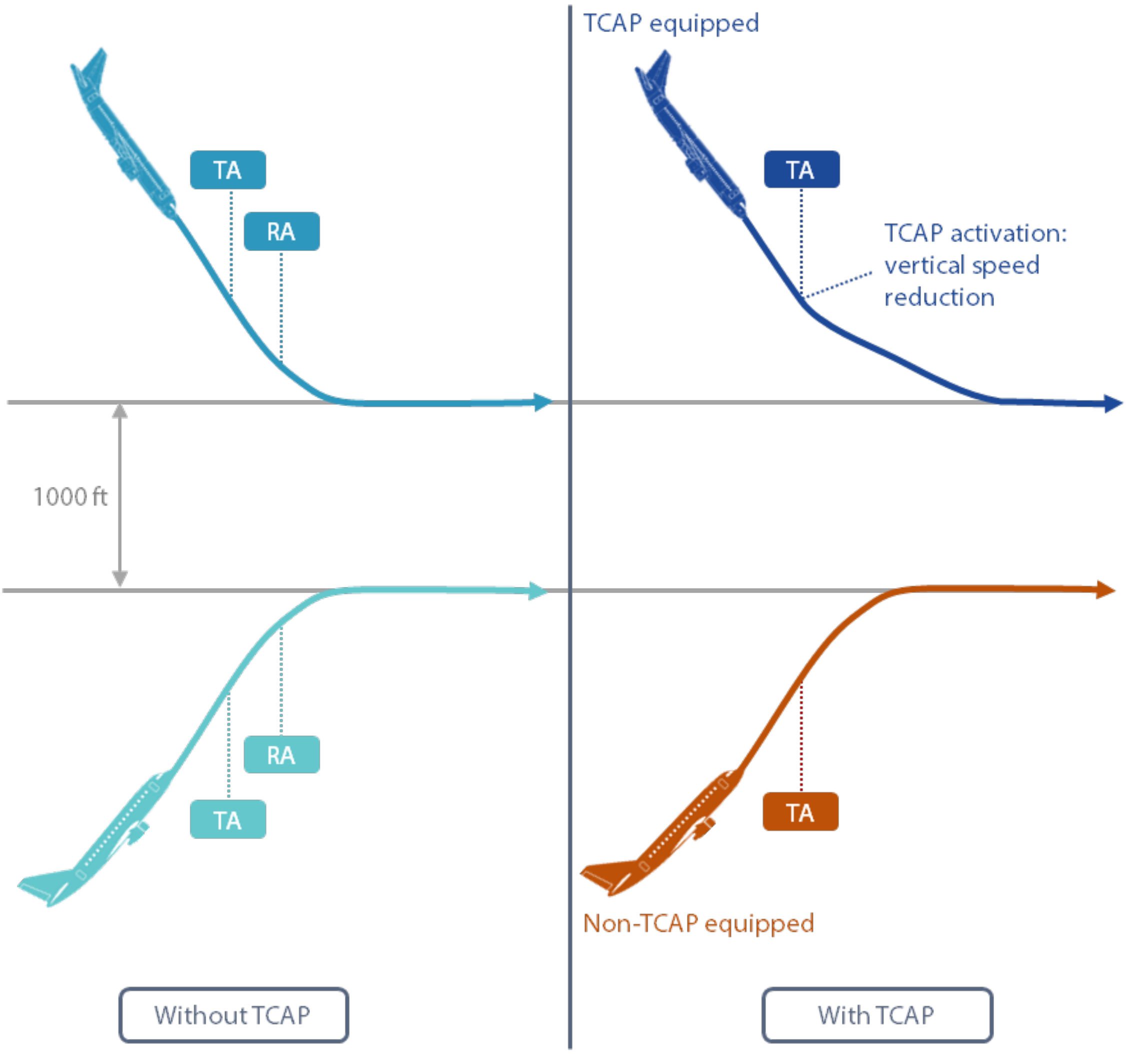


Figure 36: Illustration of an encounter without and with TCAP functionality.

8.16 ACAS II operational performance monitoring

ACAS II performance must be monitored in order to ensure that ACAS II deliver its safety benefits and to detect any latent design shortcomings and operational or training problems.

Ground based Mode S radars are used to receive ACAS capability report and RA downlink messages. The former provides information about the ACAS version and operational mode (off, TA-only, TA/RA), the latter provides information that can be used to determine the type of RA issued and the identity of the other aircraft involved. RA downlink messages provide information on RAs as they occurred on the aircraft (with a latency of up to the time of radar rotation cycle, assuming perfect radar detection). The format for Mode S RA downlink messages is different for TCAS II and ACAS Xa. Although, the same set of bits is used, they have been assigned differently. Additionally, omni-directional receivers can be used to intercept RA broadcast or coordination messages. 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. To assist aircraft operators with the assessment of pilot compliance with RAs, IATA (International Air Transport Association) and EUROCONTROL have jointly publish the Guidance Material[70] on such assessments.

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

8.17 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 full picture of all the data. Pilots can occasionally misinterpret the aural warnings. Consequently, drawing conclusions on the usefulness or correctness of RAs can be reliably done only in hindsight through investigation and examination of recordings and other objective data.

i

See ACAS Bulletin 24 for more information on investigating RAs

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 training shortcomings or operational errors. The conclusion may also reveal previously unknown problems with the equipment.

8.18 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[71].

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.

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 8.5).

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).

i

See ACAS Bulletin 19 & ACAS Bulletin 22 for more information

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.

[71] See the quote from ICAO PANS-ATM (Doc 4444) in Section 21.4.1.

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 8.3 on RA reporting.

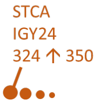
8.19 ACAS II and ground-based Short Term Conflict Alert (STCA)

Air traffic controllers are assisted by Short Term Conflict Alert (STCA), a ground-based system that generates alerts warning of a potential or actual infringement of separation minima. ACAS II and STCA operate independently which provides redundancy and minimises single points of failure (the only common source of data is the altitude reports from aircraft transponders). ACAS II and STCA are not entirely compatible with each other. Whilst the desired behaviour is that STCA alerts at least 30 seconds before the first RA, STCA sometimes will trigger significantly later (sometimes even after the RA). This is a result of the differences listed in Table 6. Providing sufficient warning time is not always possible, particularly in the case of sudden, unexpected manoeuvres.

STCA and TCAS II have no, or limited, knowledge[72] of controller and pilot intentions and actions. Hence, when a controller provides an instruction(s) to avoid a loss of separation, STCA and/or TCAS II alerts may still be triggered, even if the pilot has already initiated a manoeuvre corresponding to the controller's instruction.

[72] Some STCA systems use aircraft downlinked parameters (like Selected Flight Level) to optimise alerting behaviour and to reduce the number of operationally unwanted alerts.

Table 6: 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.

9 ACAS II SURVEILLANCE

9.1 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 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).

9.1.1 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[73], 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 6.10 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.

[73] Whilst that should not occur (as Mode S 24-bits 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.

9.1.2 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.

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 target (NAR) – see Section 6.10 for more information.

9.1.3 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 9.4 on Hybrid Surveillance). Additionally, ACAS Xa will use ADS-B messages to estimating range, altitude and bearing for collision avoidance purposes (as long as the active surveillance information is valid).

9.1.4 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 will track ADS-B only aircraft; however, only TAs but no RAs will be generated against such aircraft. See Section 11.3.5 for more information.

9.1.5 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.

9.2 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[74], 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".

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).

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

9.3 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 trigger effective collision can limited.

9.4 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 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 GNSS and received on own aircraft by the use of Mode S extended squitter, i.e. 1090 MHz ADS-B, also known as 1090ES[75].

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 Figure 37).

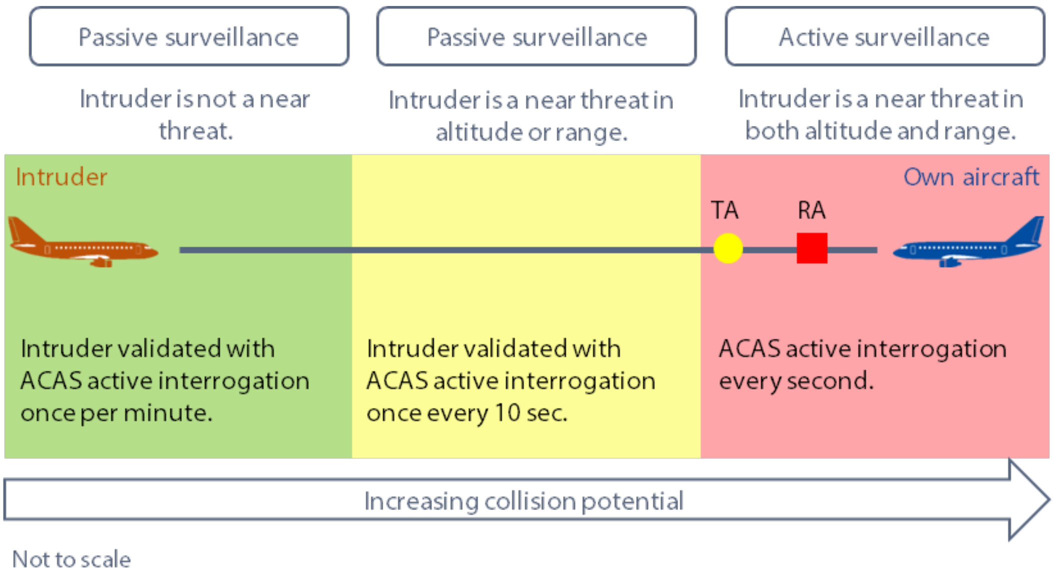


Figure 37: Hybrid surveillance – transition from passive to active surveillance.

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

9.5 Air-ground and air-air communications

The ACAS air-ground and air-air communication messages (as depicted in Figure 38) 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)[76].

9.5.1 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 7.3 for more information about ACAS-ACAS coordination.

9.5.2 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.

9.5.3 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[77]. 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.

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[76] RA downlink display to controllers has been implemented only by a small number of ANSPs. ICAO has not published any provisions for operations of RA downlink.

[77] A change to TCAS II MOPS (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.

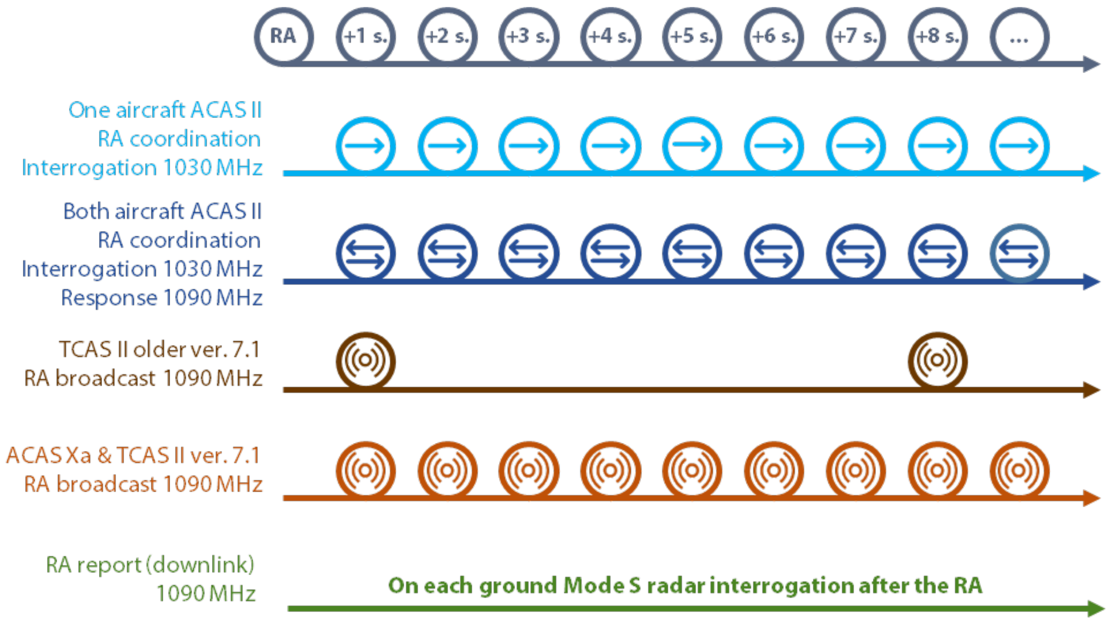

Figure 38: Air-ground and air-air communications timeline.

10 TCAS II SYSTEM

10.1 TCAS II collision avoidance logic

10.1.1 Concept

The TCAS II collision avoidance logic, or CAS (Collision Avoidance System) logic is based on two basic concepts: the warning time (see Section 10.1.2) and the sensitivity levels (see Section 10.1.3). 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.

10.1.2 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 10.2.3 for more information about threat detection.

10.1.3 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 40) around each TCAS II equipped aircraft. The sensitivity level depends on the altitude of own aircraft and varies from 1 to 7 (see Table 7 and Figure 39). 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[78]; however, *ALIM* (the threshold for corrective RAs – see Table 8) 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 10.2.3 for more information about threat detection.

[78] 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*.

10.1.4 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 **"STAND-BY"** 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. A "TA-only" aircraft will be treated by other TCAS II aircraft as unequipped. *SL2* is assumed. See Section 8.11 for more information on TA-only operations.
- When the pilot selects **"AUTOMATIC"** or **"TA/RA"** mode, TCAS II automatically selects the *SL* based on the current altitude of own aircraft. *SL*2 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 *SL*s 3 through 7, TAs and RAs are provided. To determine the sensitivity level required above 2600 feet AGL, the logic uses the standard pressure altitude (altimeter setting 1013.25 hPa) indicated by the barometric altimeter. Table 7 provides the altitude threshold at which TCAS II automatically changes *SL* and the associated *SL* for that altitude band.

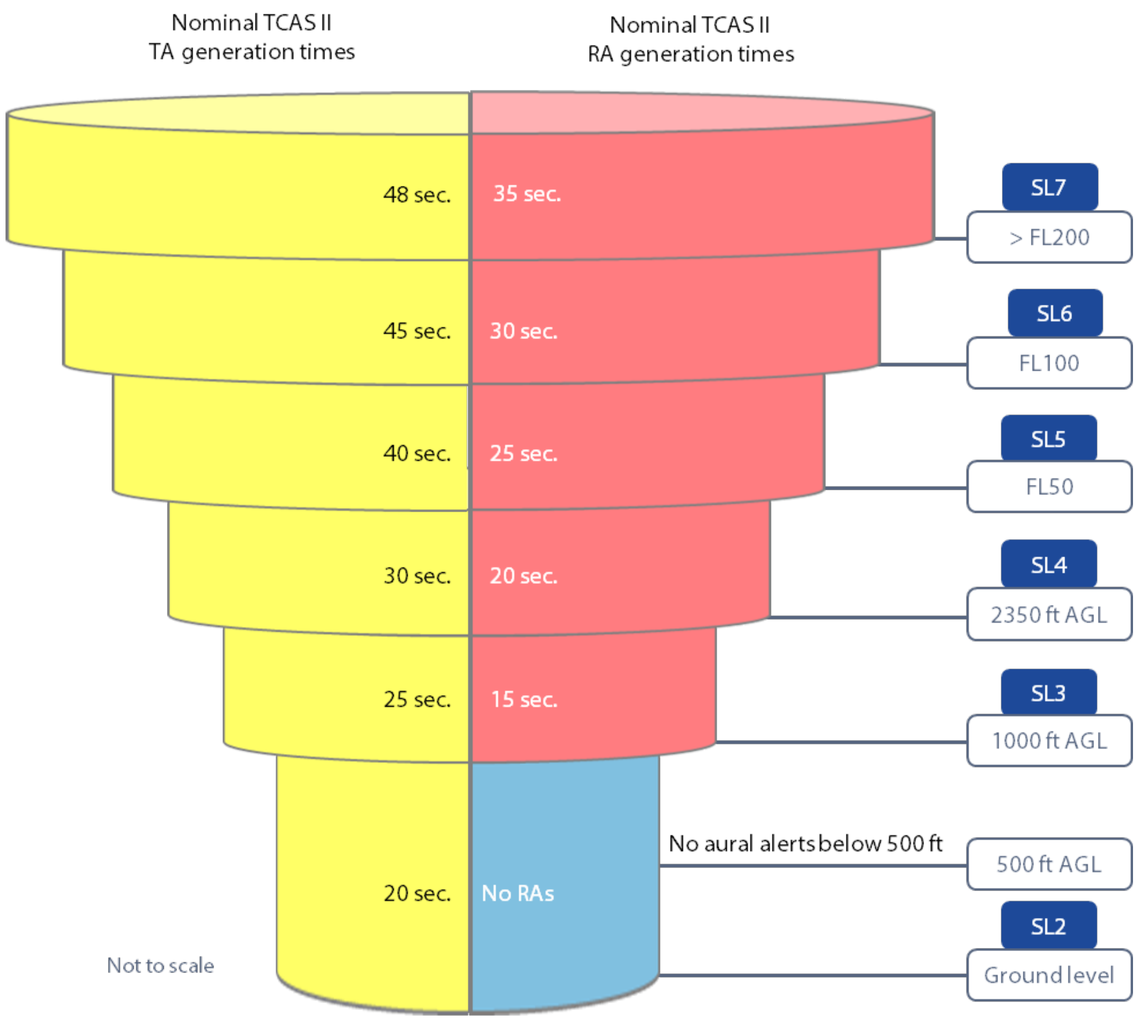

Figure 39: TCAS II nominal warning times and sensitivity levels.

Table 7: TCAS II sensitivity levels.

Own Altitude	Sensitivity levels (*SL*)
Stand-by 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

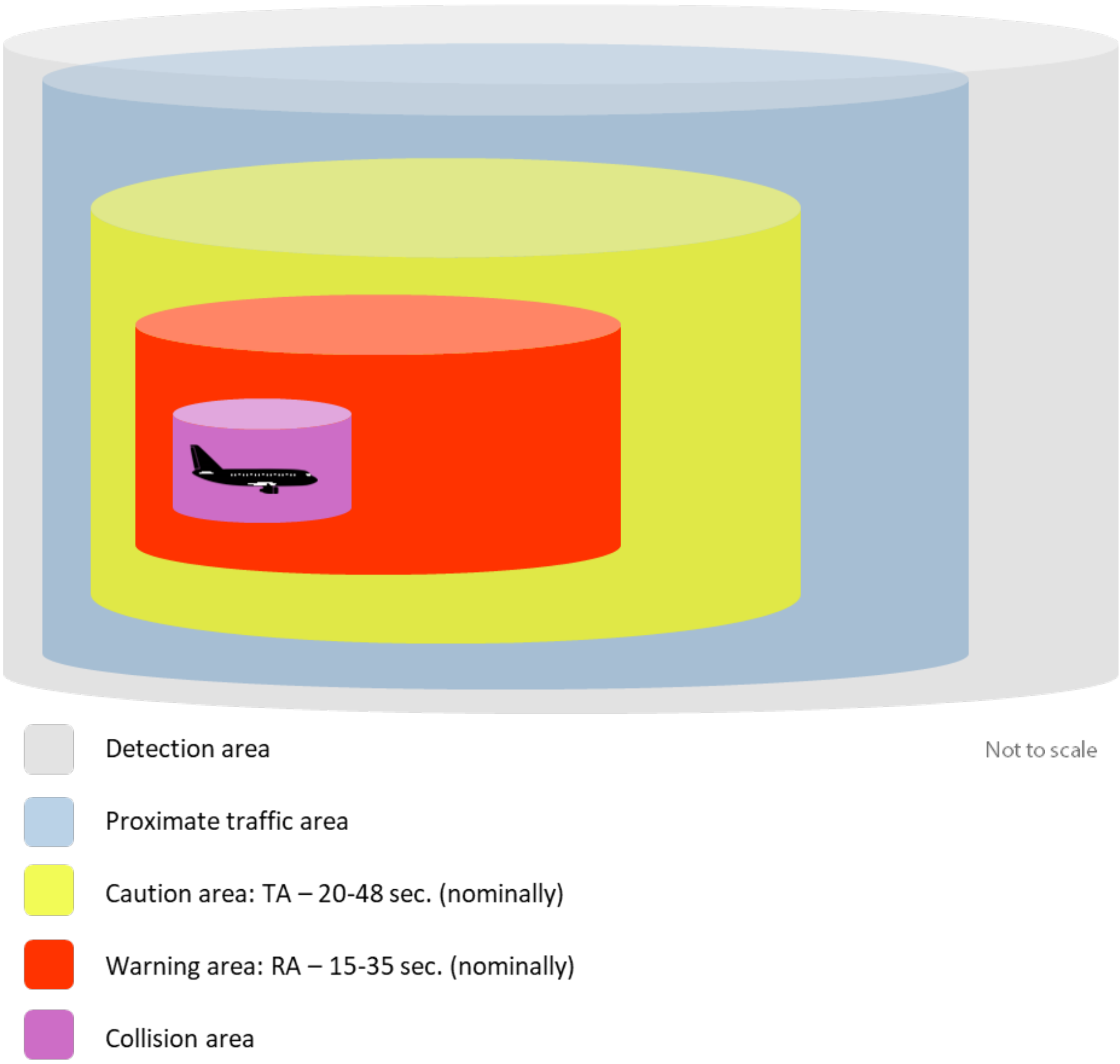

Figure 40: TCAS II protected volume (side and plan views).

10.2 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 41. 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.

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).

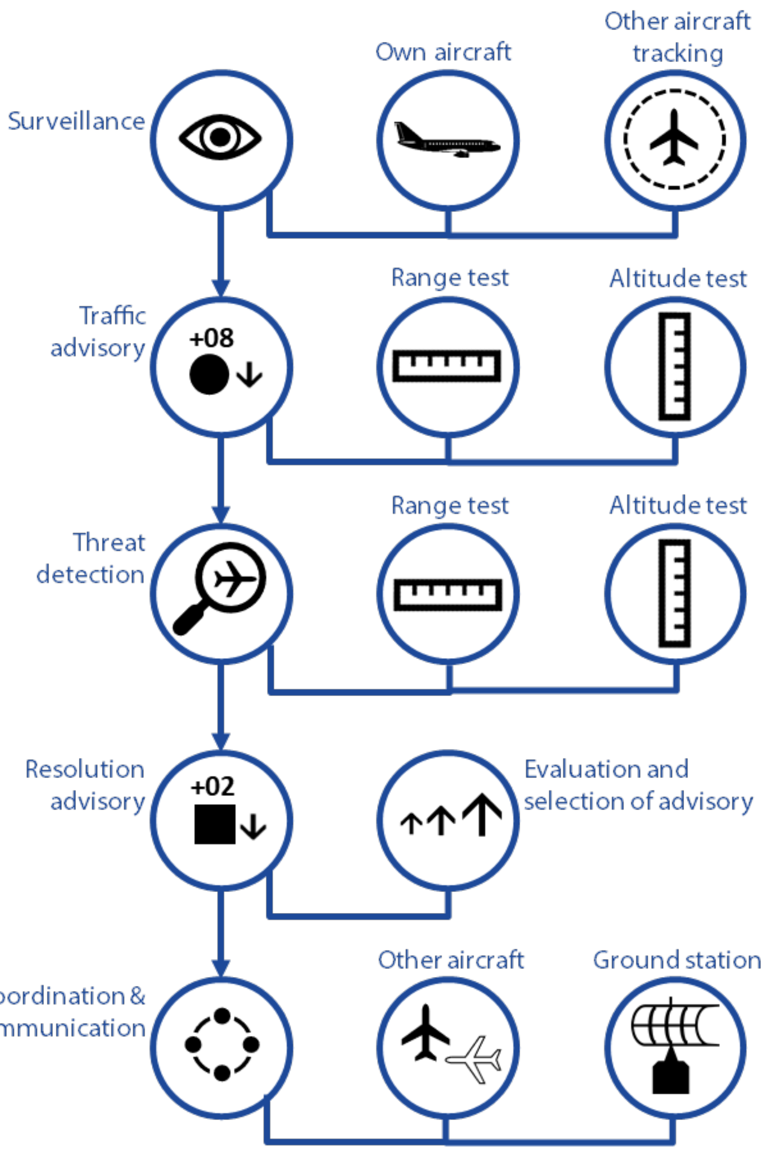

Figure 41: TCAS II logic functions.

10.2.1 Tracking

Using the surveillance reports (slant range, bearing[79] 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)[80] 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 42). 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.

[79] 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 10.2.3).

[80] 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.

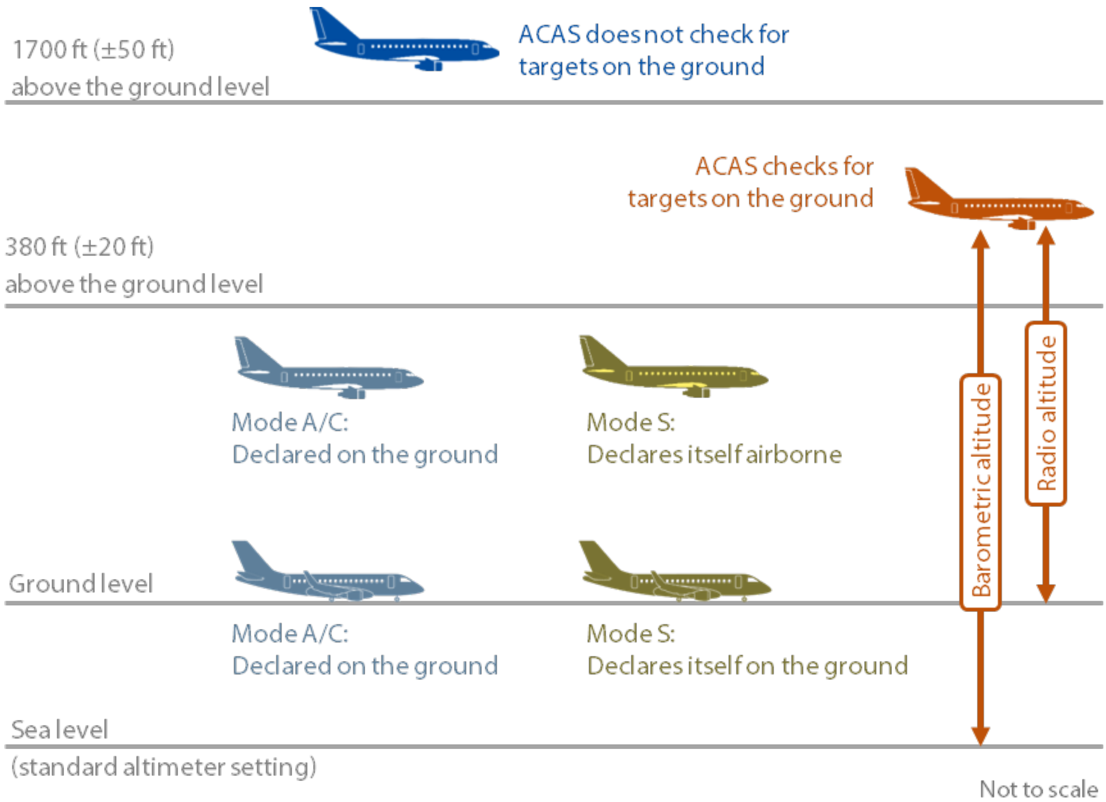

Figure 42: Target on-the-ground determination.

10.2.2 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.

10.2.3 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)[81] has been received from the threat.

10.2.3.1 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*[82]. 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 when the relative bearing of other aircraft is used in the collision avoidance logic.

10.2.3.2 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).

[81] See Section 7.3 for more information on Resolution Advisory Complement.

[82] 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).

10.2.3.3 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 40) 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 8. A further parameter, *ALIM*, (used when selecting the RA strength and direction: see below) is a function of altitude and is also shown in Table 8.

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 8).

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 8: 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

10.3 TCAS II TAs

The traffic advisory function uses a simplified algorithm, similar to the RA generation logic but with greater alert thresholds (see Table 8). 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).

10.4 TCAS II RAs

The full range of TCAS II RAs and associated cockpit presentation, as well as aural messages, are presented in Table 2 for single threat encounters and in Table 3 for multi-threat encounters. The Sections below explain how RAs are selected, changed and terminated.

10.4.1 Advisory selection

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

10.4.1.1 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 43 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 $^{1}/_{4}$ *g*). The CAS logic computes the predicted vertical separation for each of the two cases and normally selects the sense, which provides the greater vertical distance.

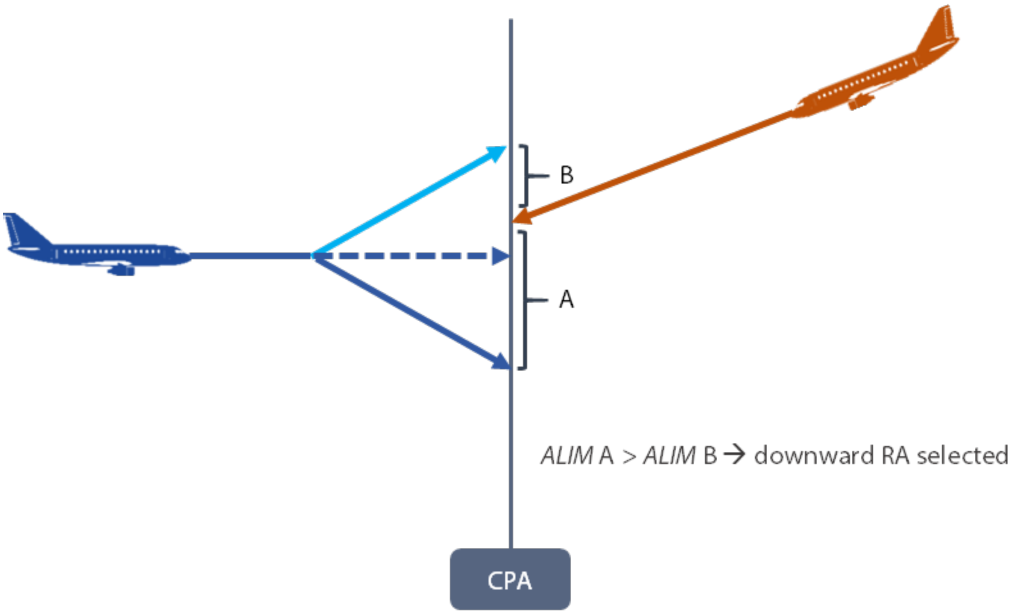

Figure 43: RA sense selection.

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 44 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 45).

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.

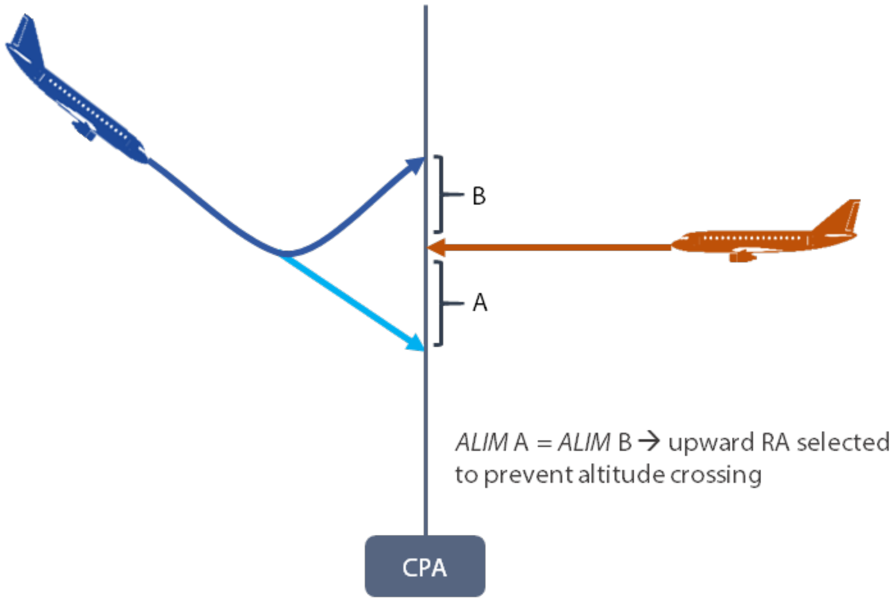

Figure 44: Non-crossing RA.

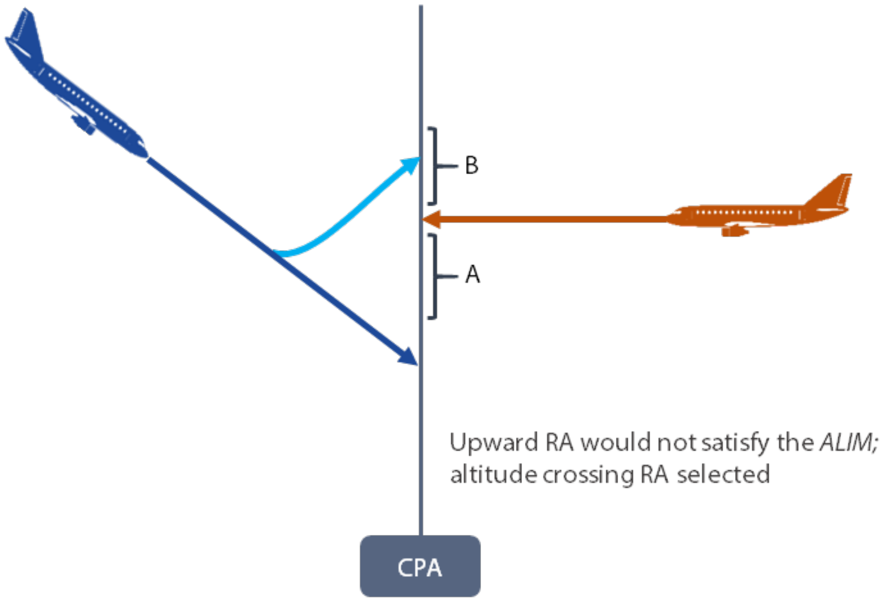

Figure 45: Crossing RA.

10.4.1.2 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 46), 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.

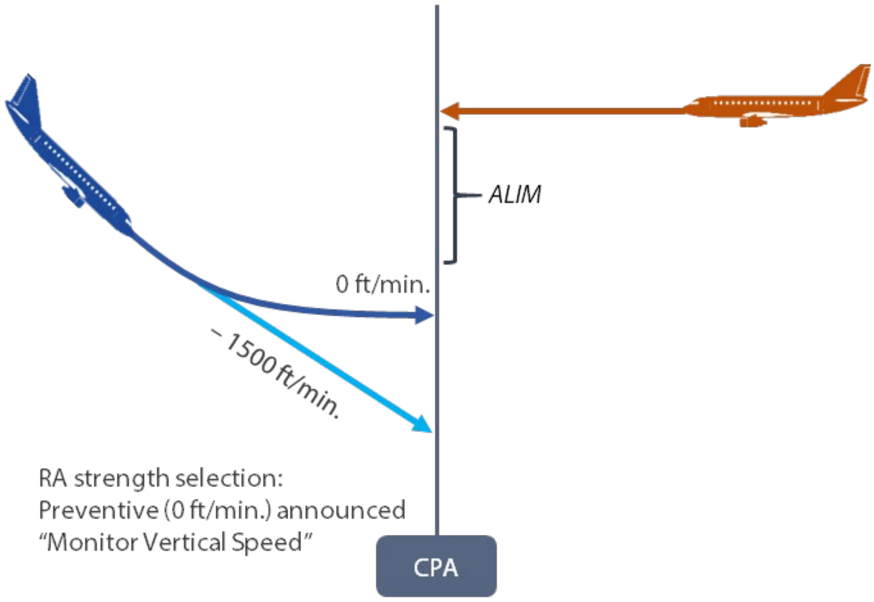

Figure 46: RA strength selection.

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 10.4.2).

10.4.2 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*.

10.4.2.1 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 47, 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).

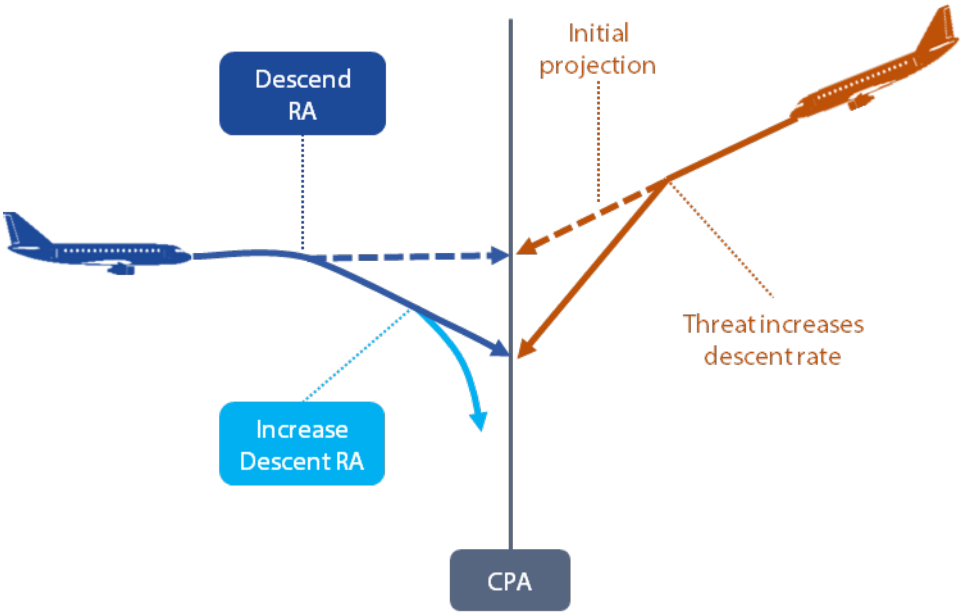

Figure 47: Increase vertical rate RA.

10.4.2.2 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 48 shows an encounter where an initial Climb RA requires a change to a Reversal Descent RA after the threat aircraft manoeuvres.

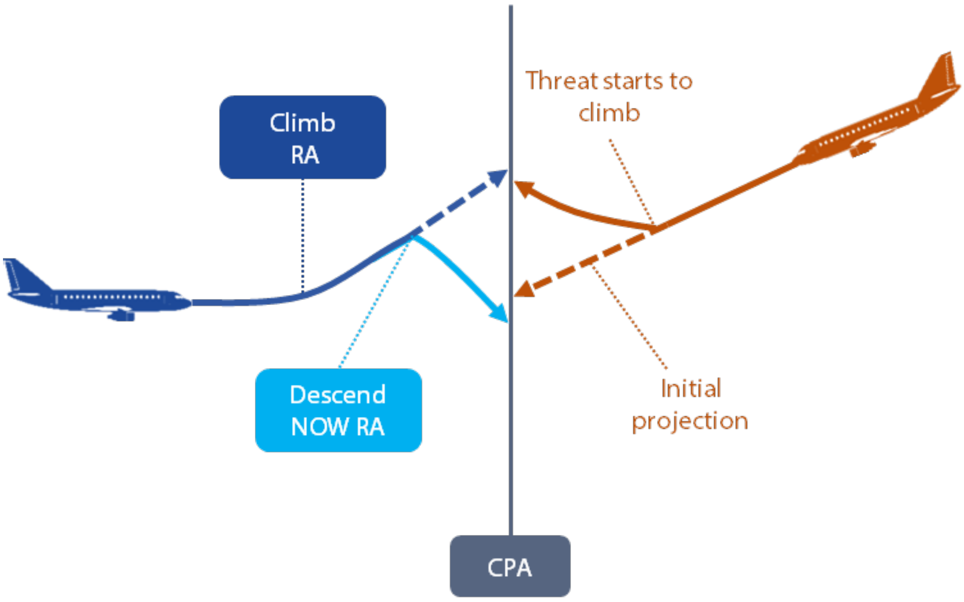

Figure 48: Sense reversal RA.

10.4.2.3 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 49). This is done to minimise unnecessary deviations from the original altitude.

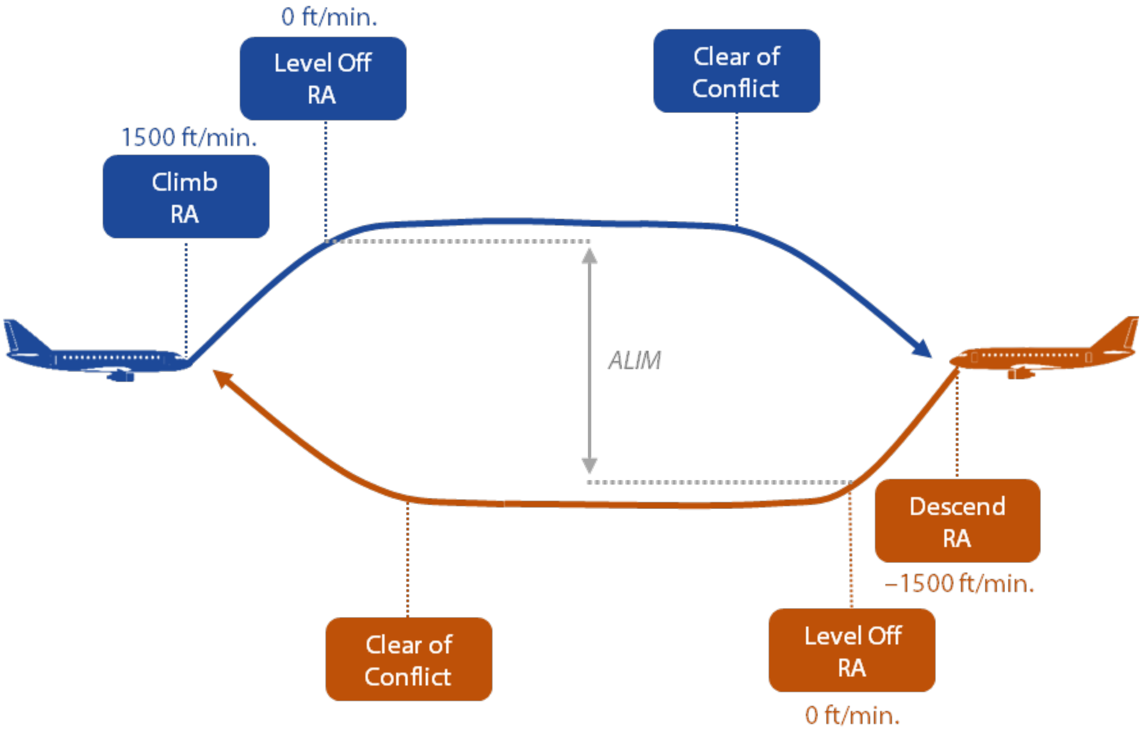

Figure 49: Weakening RAs.

10.4.3 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)[83] or the aircraft descends through the low level inhibition threshold (900 feet AGL)[84], an RA will be removed and terminated but no Clear of Conflict annunciation made.

[83] See Section 7.2.2.

[84] See Section 7.2.1.

10.5 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 2 and Table 3 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.

10.6 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[85];
- Minimum time before weakening RA can be issued – 10 seconds.

A strengthening RA can be issued without any delay.

10.7 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.

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

11 ACAS Xa and ACAS Xo Systems

11.1 ACAS Xa

One of the principle ACAS Xa design objectives was the improvement in safety while reducing the unnecessary alert rate. Operational monitoring of TCAS II revealed numerous cases when RAs were generated in situations when they were not needed (i.e. there was only a remote risk of collision).

11.2 ACAS Xa vs. TCAS II

ACAS Xa is designed as a replacement of existing TCAS II systems[86]. 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[87] 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.

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

11.2.1 Surveillance

- All installations of ACAS Xa systems will include the use of hybrid surveillance (see Section 9.4) 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.
- ACAS Xa provides an annunciation in case of unexpected transponder transition to "stand-by" (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 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 50).

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[86] 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.

[87] See Section 7.2.1.

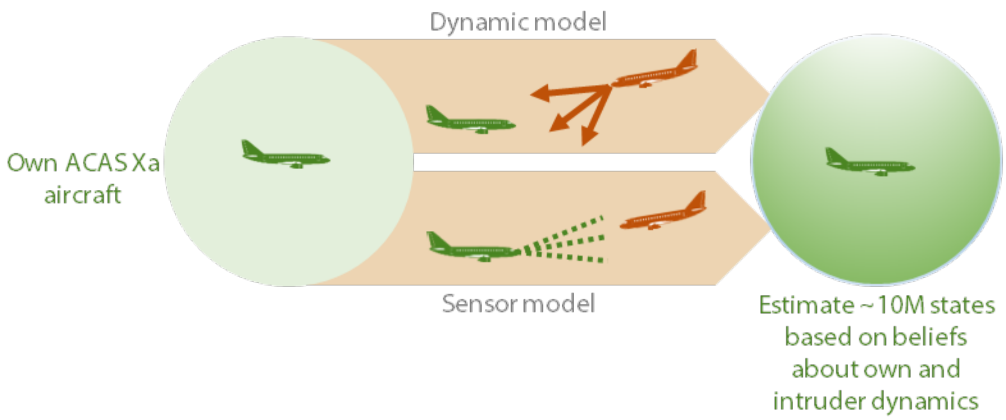

Figure 50: ACAS Xa state estimation.

11.2.2 Logic

- ACAS Xa does not use the Sensitivity Levels (see Section 10.1.3) which are present in the TCAS II design, except as an operating mode indicator (see Section 11.3.6).
- 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 51).
- 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.

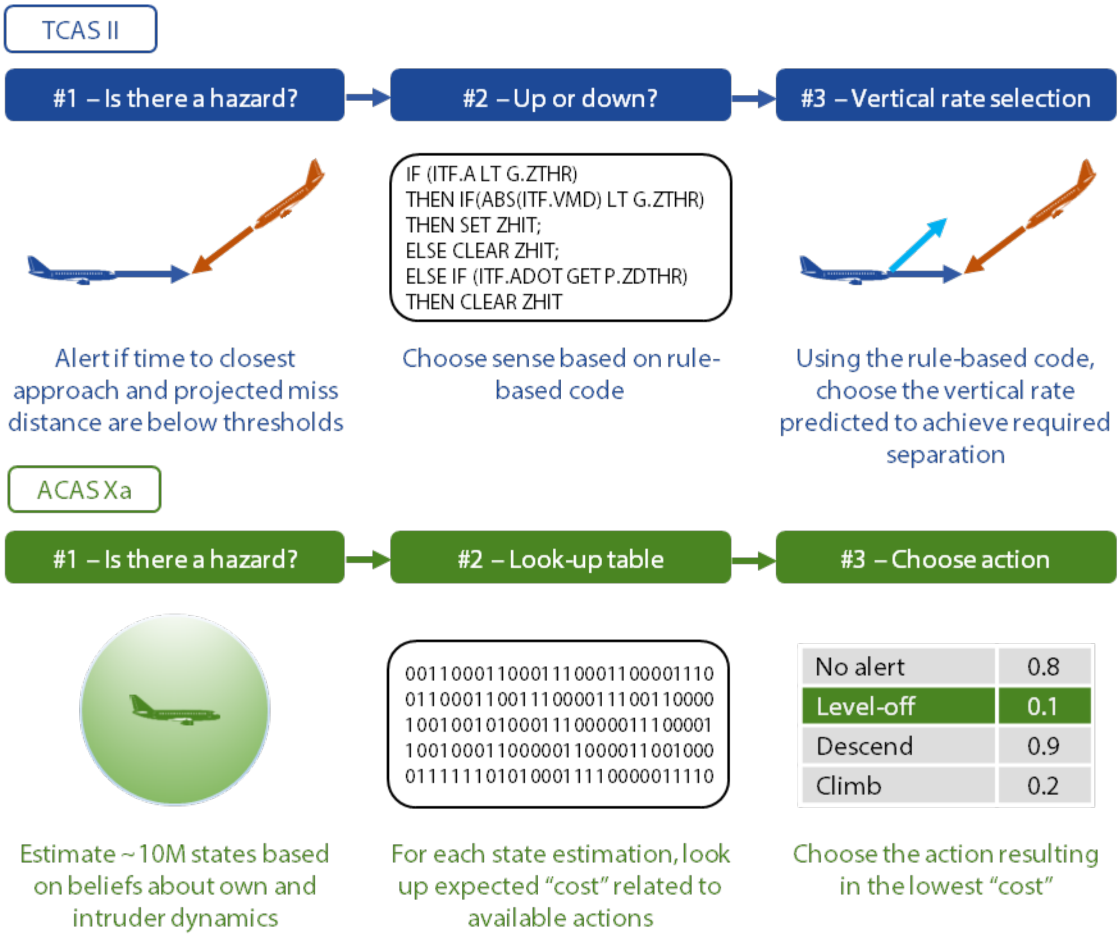

Figure 51: RA selection process: TCAS II vs. ACAS Xa.

11.2.3 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 is different (see Section 11.3.4).
- The minimum time limits on RA duration used in TCAS II (see Section 10.6) 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[88].
- 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.

[88] 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.

11.3 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 52. 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).

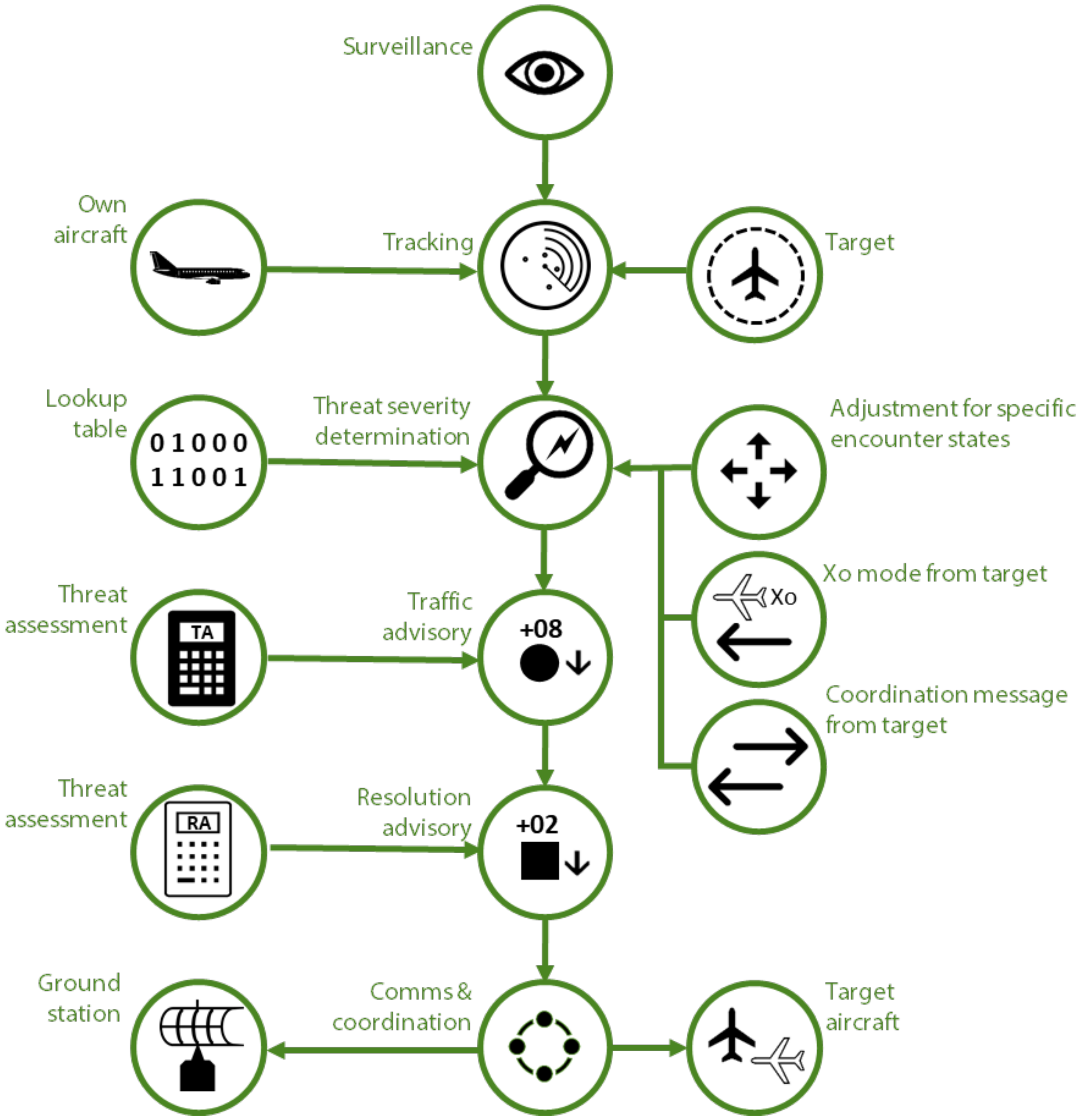

Figure 52: ACAS Xa logic functions.

11.3.1 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.

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 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. 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.

11.3.2 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 establish 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.

"Cost" estimation is performed separately for off-line "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.

11.3.3 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.

11.3.4 ACAS Xa Resolution Advisories

ACAS Xa uses a similar range of RAs as TCAS II. The differences are described below and summarised in Table 9 below. The full range of TCAS II and ACAS Xa RAs and associated cockpit presentation, as well as aural messages, are presented in Table 2 for single threat encounters and in Table 3 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" and "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 cancel 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. 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 9: 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 Descend to 500, 1000 or 2000 ft/min.	Monitor vertical speed	—
Do Not Climb Weakening RA Issued after maintain descend 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	—

11.3.5 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.

11.3.6 Sensitivity levels and modes of operation

In ACAS Xa sensitivity levels are not used to modify the protection volume according to altitude as in TCAS II (see Section 10.1.3). 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 10.1.4) 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*.

11.4 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 options within ACAS Xo: DNA (**D**esignated **N**o **A**lert) and CSPO-3000 (**C**losely **S**paced **P**arallel **O**perations **3000**[89]); additional applications are possible in the future. ACAS Xo use cases are depicted in Figure 53. More modes may be developed in the future. ACAS Xo installations will have to be integrated with an ASAS (Airborne Separation Assurance Systems) interface to allow the designation of traffic.

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

11.4.1 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 in order to suppress any TAs and RAs against this aircraft, while ACAS Xa 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.

11.4.2 Closely Spaced Parallel Operations 3000 (CSPO-3000)

A CSPO-3000 mode, for closely spaced parallel approaches when runways are spaced by 3000 feet (915 meters) or less, 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 traffic. 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 53 is not fixed like the TCAS II protection volume (see Figure 40) 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.

[89] 3000-foot (915-meter) spacing between parallel runways.

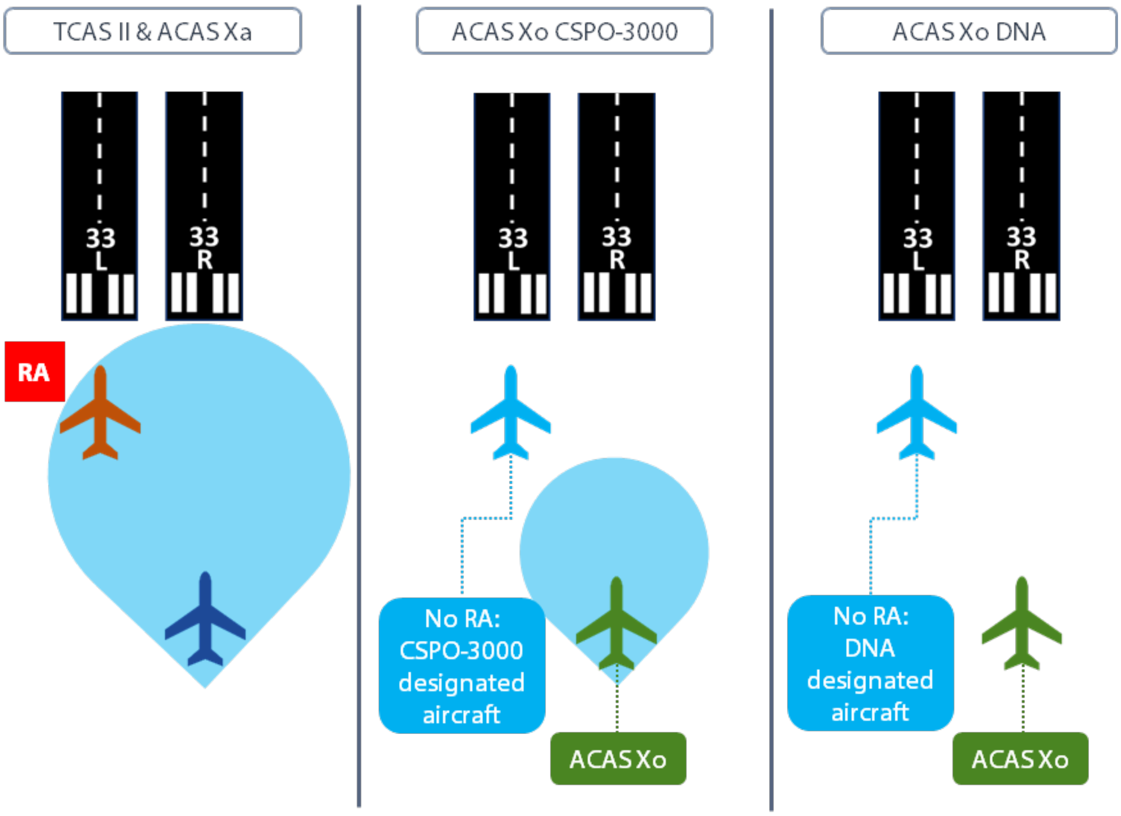

Figure 53: ACAS Xo use cases (runway spacing 3000 – 4500 feet).

11.5 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 TCAS Standby, for instance, upon landing or during higher priority flight deck alerts (e.g. GPWS/TAWS).

12 RA Statistics and Assessment of Pilot Compliance

The statistical data presented in this Section is a summary of the TCAS statistical and performance study, of which full details are available in the report referred to in the footnote[90]. That data was subsequently used in the study assessing pilot compliance with RAs[91], which is summarised in Section 12.9.1.

It should be noted that the data has been collected using Mode S radars in core European airspace[92] in the middle/late 2010s, i.e. it reflects the pre-COVID pandemic traffic levels. The reduction in air traffic due to the COVID-related restrictions will certainly have an impact on the frequency of TCAS II alerts, as due to the lower traffic density and the lower number of flights, aircraft will be less likely to be in conflict. Initial monitoring data indicates that the number of RAs dropped to 25-30% of the pre-COVID situation.

12.1 Frequency of RAs and TAs

It has been estimated through various monitoring activities that in core European airspace an RA occurs approximately every 7250 flight hours (or 3½ time a day). Outside the core airspace, the rate is believed to be lower.

Data obtained from aircraft operators indicates that an RA occurs once per approximately 3000 sectors flown by a short and medium haul aircraft and once per 1050 sectors for a long haul fleet. TAs are much more frequent events – they occur once every 10-15 legs (regardless of the fleet). A TA to RA ratio is approximately 200:1 and 110:1 for short/medium haul and long haul fleets respectively.

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[93] collects and processes reports received from other sources (e.g. pilot or ATC reports) and supports the involved parties with feedback regarding the events.

12.2 Encounter distribution by threat type

In the monitoring activity mentioned above, 1242 RAs were recorded in 1072 encounters (i.e. events in which at least one aircraft received an RA). In the vast majority of encounters, only one aircraft involved received an RA (see Figure 54). 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.

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

[91] 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.

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

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

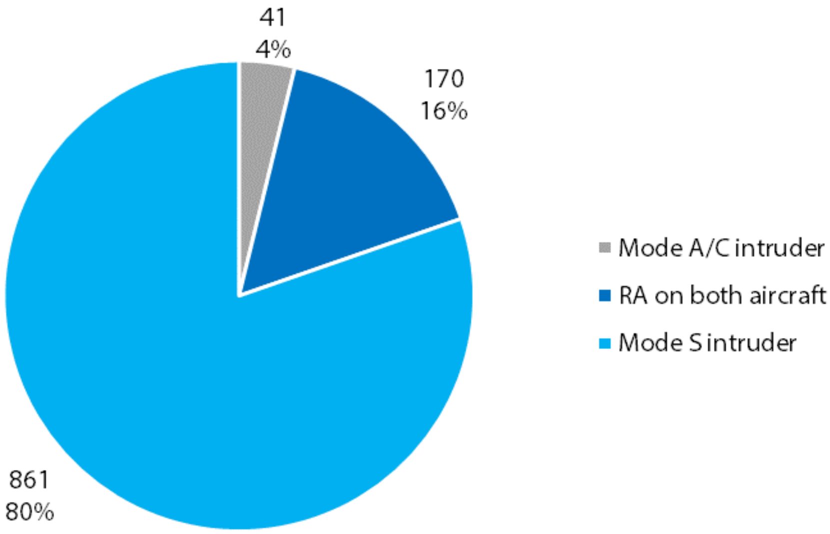

Figure 54: Encounter distribution by threat type.

12.3 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. A distribution of encounters by Flight Level and threat type is shown in Figure 55.

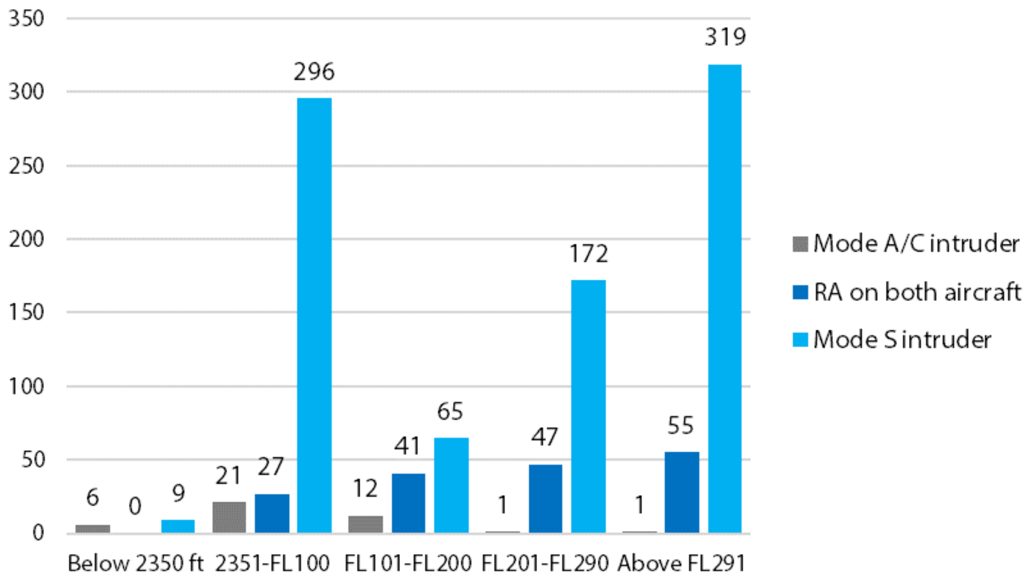

Figure 55: Encounter distribution by threat type and Flight Level.

12.4 RA distribution by RA type

12.4.1 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 56). 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.

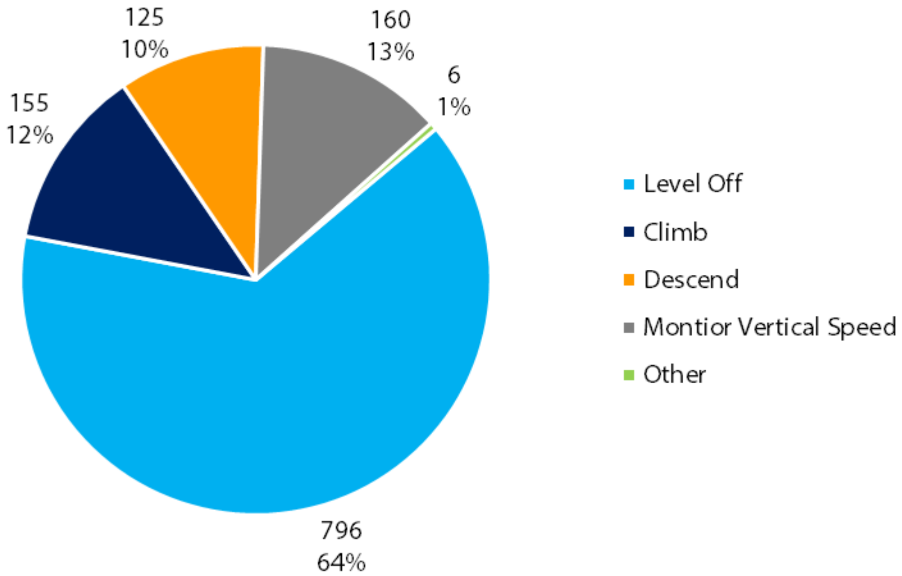

Figure 56: Initial RAs by RA type.

12.4.2 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 57). 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.

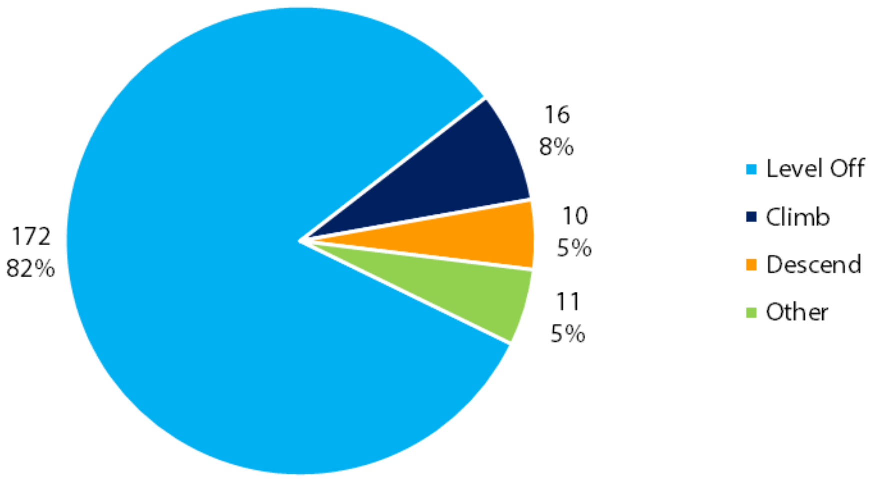

Figure 57: Number of subsequent RAs by RA type.

12.5 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 58).

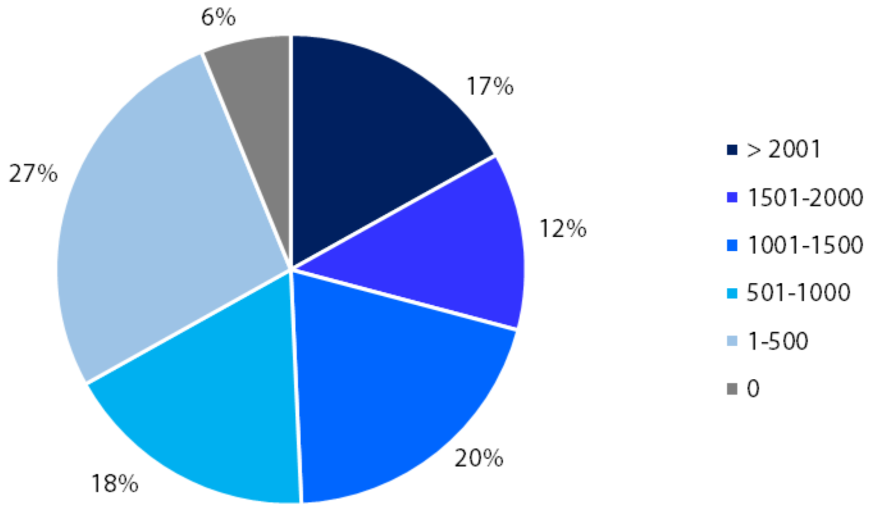

Figure 58: Vertical rate (ft/min.) at the time of RA.

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 21.2), are applied.

12.6 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 59 below.

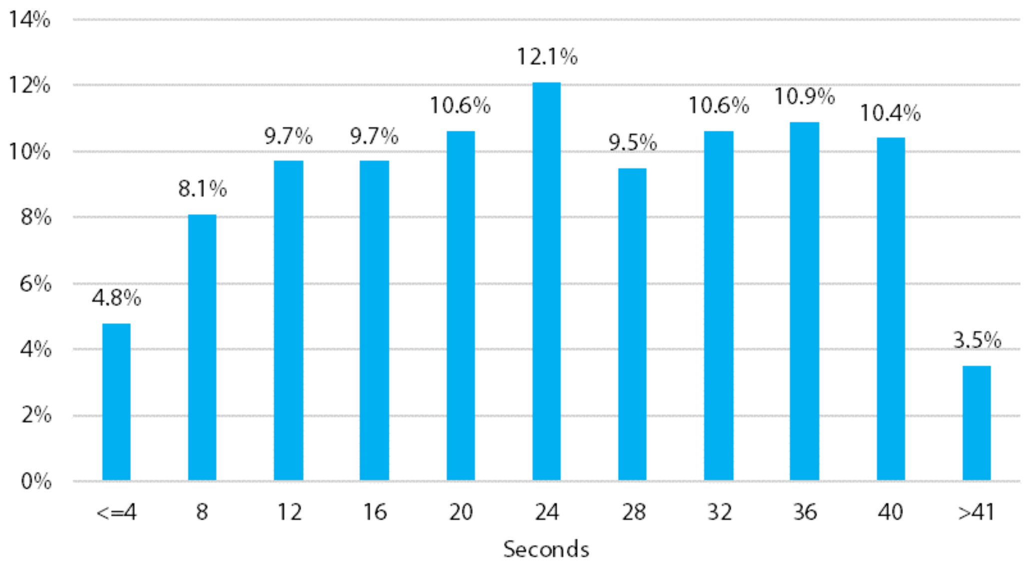

Figure 59: RA duration (in seconds).

12.7 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 60, the majority of RAs were issued when the aircraft were still separated by over 800 feet vertically and 1.6 NM horizontally.

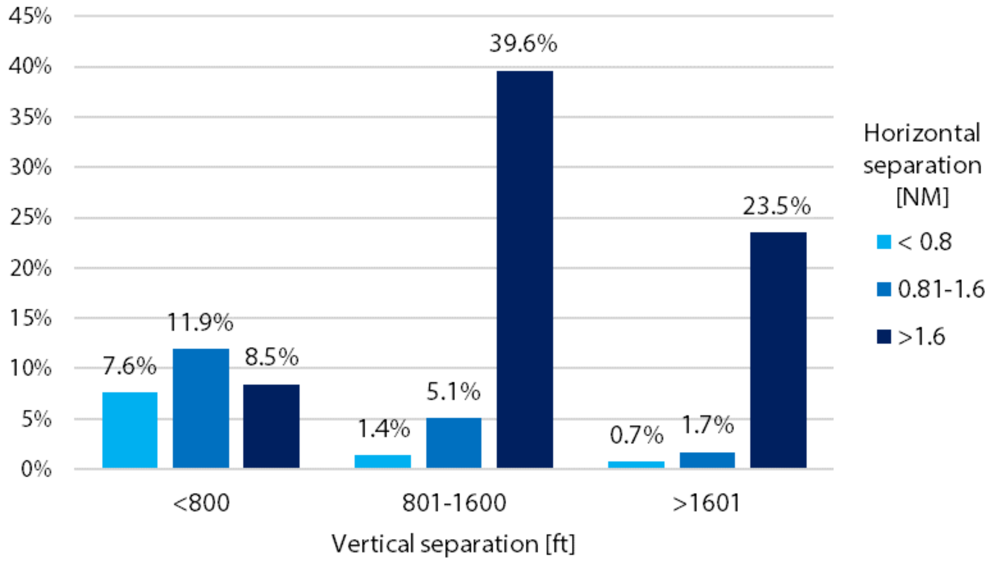

Figure 60: Horizontal and vertical spacing at the time of RA.

12.8 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 61, 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.

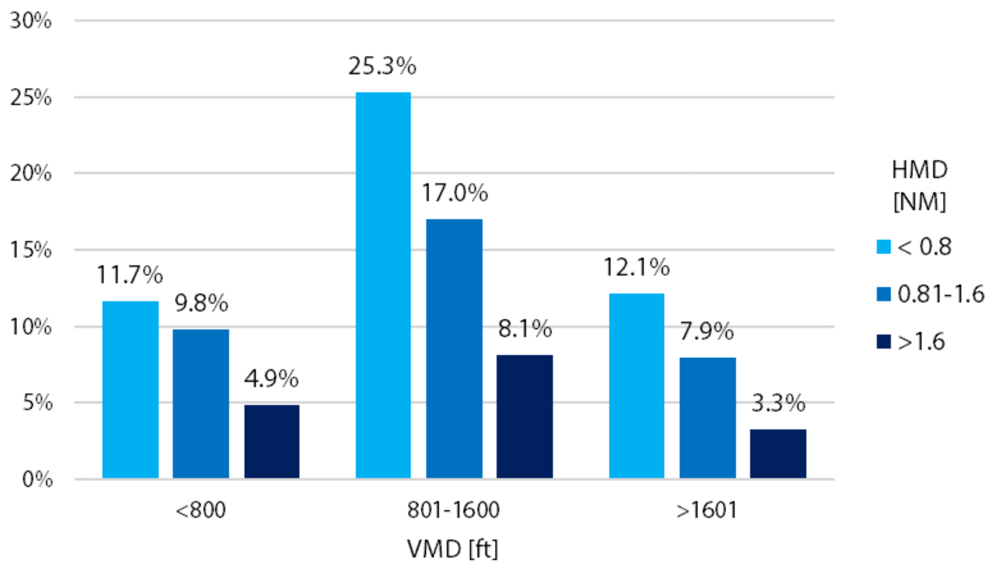

Figure 61: HMD and VMD at CPA.

12.9 Operational compliance

12.9.1 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[94]. Two methods have been used in the study:

- **Method A**: examines the vertical rates of aircraft after the RA and compares these against the predefined thresholds;
- **Method B**: an alternative method which takes into account the ability of a pilot to respond promptly, for example, to a Climb RA whilst in descent.

Method A covered both initial (i.e. the first RA in the encounter) and subsequent RAs, while under Method B only initial RAs were analysed. Each Method took into account RAs that lasted 8 seconds or longer, as shorter RAs may not give the pilot an opportunity to respond and change 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.

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** (Method B only)**:** 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 is in the opposite vertical sense compared to the RA;
- **Excessive:** the response exceeds the required vertical rate.

The results indicated that 38% (Method A) and 55% (Method B) of initial RAs were followed correctly at 8 seconds after the RA and 55% and 54% after 12 seconds. The remaining responses were either too weak, opposite or excessive – see Figure 62. Note: Initial RAs with duration shorter than 8 seconds were disregarded.

Subsequent RAs in the encounter (Method A only) were followed at the desired vertical rate in 48% of cases.

[94] 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.

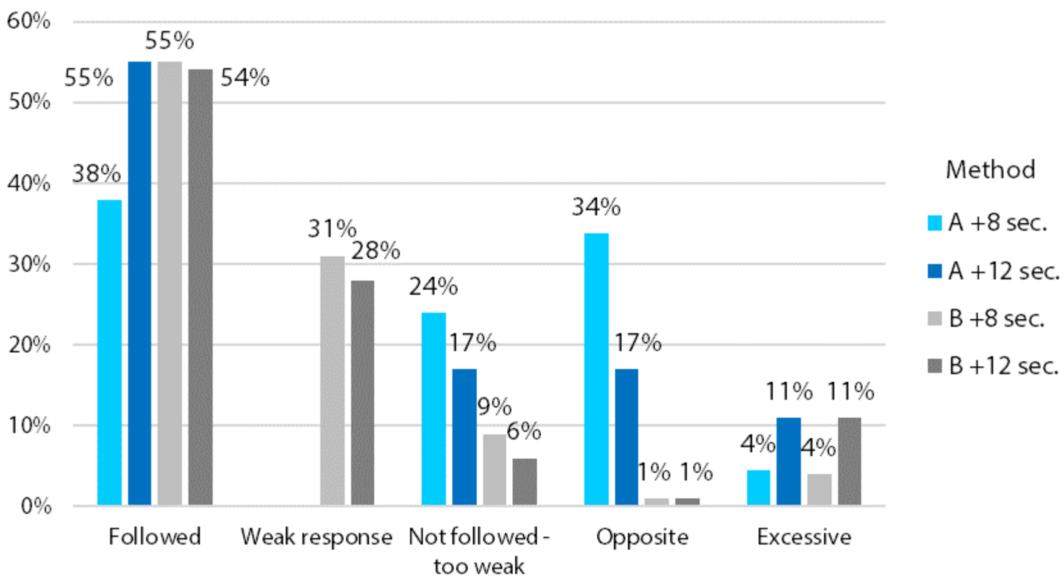

Figure 62: Pilot compliance with RAs after 8 or 12 seconds Methods A & B.

12.9.2 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 8.11). 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.[95]

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.

12.9.3 TCAS II serviceability

Under the provisions of MEL (see Section 8.12) 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.

[95] 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.

13 ACAS II Operational Anomalies

13.1 Self-tracking RAs

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. The pseudo-intruder is then seen at the same altitude and same position as own aircraft. TCAS II will not track Mode S intruders whose Mode S 24-bit address is the same as own aircraft. Although an aircraft's suppression bus should prevent own transponder replying to interrogations, failures may occasionally occur.

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

13.2 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.*"

13.3 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 while 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. 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 classified as a 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.

13.4 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 an 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.

14 SAFETY BENEFITS

14.1 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.

14.2 TCAS II

For Europe, TCAS II was estimated in 2002[96] to reduce the risk of midair collision by a factor of about 5 (i.e. a risk ratio of approximately 22%)[97]. Current, unpublished studies indicate that the risk ratio is in fact lower (i.e. the risk of midair collision is reduced even further, especially with a nominal pilot reaction and both aircraft being equipped).

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 by other aircraft, the risk of collision for a specific aircraft can be reduced by a factor greater than three by fitting TCAS II[98].

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.

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

[97] It should be noted this is a theoretical calculation, based on models rather than on real traffic, and it was conducted before TCAS II was widely implemented in European airspace.

[98] 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.

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.

14.3 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 [99] 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 [100]. 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 studies have also been conducted in Europe and delivered similar overall results with some differences in a few operational areas. The results of the European studies at the time of writing are subject to evaluation by European regulatory authorities.

[99] FAA TCAS Program Office, Post-FRAC Operational Validation Report, DO-385 V1R0, December 2018.

[100] Source: ICAO ACAS Manual, Doc 9863, 3rd edition.

15 ACAS II TRAINING

15.1 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 11.2. While the displays and alerts are similar, certain features like timing and type of alerts generated, ACAS Xo (see Section 11.4), AOTO mode (see Section 11.3.5) 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).

15.2 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.

15.3 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 17.

16 Conclusions

Airborne Collision Avoidance Systems are a last resort system designed to prevent midair collisions between aircraft. Currently, this role is fulfilled by TCAS II and a new generation of Airborne Collision Avoidance Systems (ACAS X) is being developed. First ACAS Xa equipped aircraft are likely to start operations in the next few years.

The technical features of the system provide a significant improvement in flight safety and TCAS II has attained universal recognition in the world of aviation. TAs and RAs are relatively infrequent and are unplanned events, which call for prompt and appropriate reactions from the flight crew. Consequently, flight crew require specific and recurrent training in ACAS procedures.

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

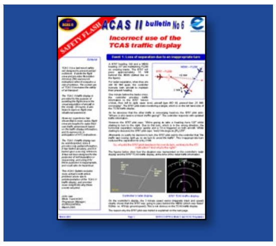
The implementation of TCAS II has increased safety and reduced the possibility of midair collision. However, in order for TCAS II, and in the future ACAS Xa, to continue to deliver its safety benefit, it is essential that pilots and controllers are adequately trained on airborne collision avoidance operations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

17 ADDITIONAL TRAINING AND INFORMATION RESOURCES

17.1 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. The list below provides links to selected issues (click on a link or icon to access a specific Bulletin):



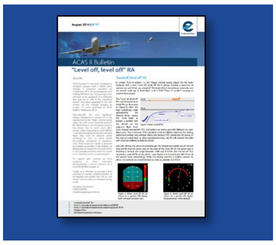
6 - Incorrect use of the TCAS traffic display (March 2005)

13 - Reversing to resolve (September 2011)

14 - Version 7.1 is coming (January 2012)

15 - Not so fast… (May 2012)

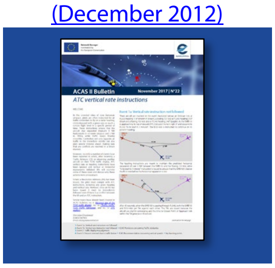
16 - "Traffic, traffic" TCAS Traffic Advisories (December 2012)



17 - "Level off, level off" RA (August 2014)

19 - ATC Matters (February 2016)

20 - Low level events (June 2016)



22 - ATC vertical rate instructions (November 2017)

23 - Equipment matters (June 2018)

24 - Investigating RAs (November 2018)

25 - Near collision over Yaizu (January 2022)

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

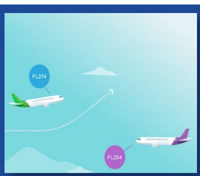
Future issues of ACAS II Bulletin will be available on SKYbrary.

17.2 EUROCONTROL training courses and presentations

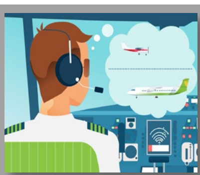
Click on a link or icon to access a specific course or publication:

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.

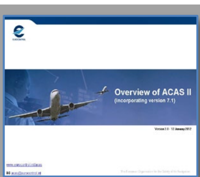


TCAS RA High Vertical Rate
A short animated video about a TCAS RA due to high vertical rates.



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

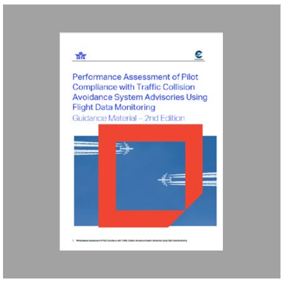
TCAS II version 7.1 for pilots

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

17.3 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.

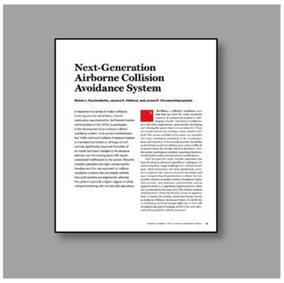
FAA Booklet – Introduction to TCAS II version 7.1 (February 28, 2011)

The Traffic Alert and Collision Avoidance System by James K. Kuchar and Ann C. Drumm – an article from the Lincoln Laboratory Journal (Volume 16, Number 2, 2007)

17.4 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

18 GLOSSARY

***The glossary is provided for reference only** and it has been derived from the definitions published in ICAO Annex 10, ICAO PANS-OPS (Doc 8168), ICAO PANS-ATM (Doc 4444), ICAO ACAS Manual (Doc 9863), TCAS II MOPS (RTCA DO-185B and EUROCAE ED-143) and ACAS Xa/Xo MOPS (RTCA DO-385 and EUROCAE ED-256).*

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 and 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)[101].

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.

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 available for assignment to an aircraft for the purpose of air-ground communications, navigation and surveillance. Also known as ICAO 24-bit Aircraft Address.

Altitude crossing RA – An RA 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. A resolution advisory 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.

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[101] So far, ACAS III has not materialised due to limitations the conventional surveillance systems have with horizontal tracking. A new collision avoidance system for Remotely Piloted Aircraft Systems (RPAS) or drones – ACAS Xu – incorporates 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.

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

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

Collision avoidance logic – The sub-system or part of ACAS 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.

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.

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). 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: Unnecessary RA and Nuisance RA.

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

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 RA 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.

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.

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

Own aircraft – The aircraft fitted with the ACAS 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") when the aircraft is level. See also: Corrective advisory. A Preventive advisory can be Positive or Negative.

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

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.

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

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

Resolution Advisory Complement (RAC) – Information provided by one ACAS 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.

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 14.1).

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 collision between aircraft by generating, in a timely manner, an alert of a potential or actual infringement of separation minima.

Squitter – Spontaneous transmission generated by Mode S transponders.

Slave aircraft – For the purpose of 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 deserving special attention either because of its close proximity to own aircraft or because successive range and altitude measurements indicate that it could be on a collision or near collision course with own aircraft.

Traffic Advisory (TA) – An indication given to the flight crew that a certain intruder is a potential threat. This indication contains no suggested manoeuvre.

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

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

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

Upward sense RA – 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 interrogation to ensure complementary manoeuvres by restricting the choice of manoeuvres available to the ACAS II receiving the VRC.

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

Weakening RA – A resolution advisory with a strength that recommends 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.

19 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
ATM	Air Traffic Management
BCAS	Beacon Collision Avoidance System
CAS	Collision Avoidance System
CPA	Closest Point of Approach
CSPO-3000	Closely Spaced Parallel Operations (3000-foot spacing between parallel runways)
CVSM	Conventional Vertical Separation Minima
DMOD	Distance Modification (TCAS II)
DNA	Designated No Alerts mode (ACAS Xo)
EASA	European Aviation Safety Agency
EFIS	Electronic Flight Instrument System
EICAS	Engine Indication and Crew Alerting System
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration (USA)
FDM	Flight Data Monitoring
FL	Flight Level
FMS	Flight Management System
ft	Feet
ft/min.	Feet per minute
g	Gravitational acceleration of 9.81 m/sec^2
GNSS	Global Navigation Satellite System
GPWS	Ground Proximity Warning System
hPa	Hectopascals (atmospheric pressure unit)
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
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
MDF	Miss Distance Filter (TCAS II)
MEL	Minimum Equipment List
MHz	Megahertz
MOPS	Minimum Operational Performance Standards
MTOM	Maximum Take-off Mass
m/s	Meters per second
m/sec	Meters per second
NAR	Non-altitude reporting [target]
NM	Nautical Mile(s)
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
SARPs	Standards and Recommended Practices
sec	Second(s)
SKYbrary	A repository of safety knowledge related to ATM and aviation safety in general
SL	Sensitivity Level
STCA	Short Term Conflict Alert
STM	Surveillance and Tracking Module (ACAS Xa)
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 Xa)
TVTHR	Time (Vertical) Threshold – Reduced Time to Co-altitude Threshold (TCAS II)
UAS	Unmanned Aircraft Systems
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VS	Vertical Speed
XPNDR	Transponder
ZTHR	Z Threshold – Vertical Threshold for Resolution Advisory (TCAS II)
ZTHRTA	Z Threshold – Vertical Threshold for Traffic Advisory (TCAS II)

20 BIBLIOGRAPHY

Note: A list of publications and links below are provided here for reference only and are current on 5 November 2021 and are subject to change.

20.1 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 (Eleventh edition – 2108, amendment 46, date applicable: 25 March 2021).

ICAO Annex 10 – Aeronautical Telecommunications – Volume IV – Surveillance Radar and Collision Avoidance Systems (Fifth edition – 2014, amendment 90, date applicable: 8 November 2018).

ICAO Doc 4444 – PANS-ATM – Procedures for Air Navigation Services – Rules of the Air and Air Traffic Services (Sixteenth edition – 2016, amendment 9, date applicable: 5 November 2020).

ICAO Doc 8168 – PANS-OPS – Procedures for Air Navigation Services – Aircraft Operations – Volume III – Aircraft Operating Procedures (First edition – 2018, amendment 1, date applicable: 4 November 2021).

ICAO Doc 9863 – Airborne Collision Avoidance System (ACAS) Manual (Third edition – 2021).

20.2 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[102], change 2, March 2013.

RTCA DO-300A (change 1) – Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System (TCAS II) For TCAS II Hybrid Surveillance, December 2015.

RTCA DO-385 – Minimum Operational Performance Standards for Airborne Collision Avoidance System X (ACAS X) (ACAS Xa and ACAS Xo), change 1, September 2019.

RTCA DO-386 – Minimum Operational Performance Standards for Airborne Collision Avoidance System Xu (ACAS Xu), December 2020.

[102] Superseding DO-185A (TCAS II version 7.0 MOPS).

20.3 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)[103], change 2, April 2013.

EUROCAE ED-221A – MOPS for TCAS II Hybrid Surveillance, December 2015.

EUROCAE ED-224 – Minimum Aviation System Performance Specification (MASPS) for Flight Guidance System (FGS) coupled to ACAS, March 2014.

EUROCAE ED-256 – Minimum Operational Performance Standards for Airborne Collision Avoidance System X (ACAS X) (ACAS Xa and ACAS Xo)[104], change 1, September 2019.

EUROCAE ED-275 – Minimum Operational Performance Standards for Airborne Collision Avoidance System Xu (ACAS Xu)[105], December 2020.

20.4 EASA & European Union publications

Easy Access Rules for Standardised European Rules of the Air (SERA) – European Aviation Safety Agency, November 2021.

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 Regulation (EU) No 2016/583 – of 15 April 2016 *laying down common airspace usage requirements and operating procedures for airborne collision avoidance* published in the Official Journal of the European Union on 16 April 2016.

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.

EASA (European Aviation Safety Agency) – ED Decision 2012/018/R – Acceptable Means of Compliance and Guidance Material to Part-CAT. 25 October 2012.

EASA (European Aviation Safety Agency) – ED Decision 2016/023/R – Acceptable Means of Compliance and Guidance Material to the rules of the air. 14 October 2016.

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

[104] Jointly published with RTCA and commensurate with DO-385.

[105] Jointly published with RTCA and commensurate with DO-386.

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

EASA (European Aviation Safety Agency) Easy Access Rules for Generic Master Minimum Equipment List (CS-GEN-MMEL). February 2018.

20.5 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 C219 (Technical Standard Order) – Airborne Collision Avoidance System (ACAS) Xa/Xo, 28 February 2020.

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 120-55C Change 1 (Advisory Circular) – Air Carrier Operational Approval and Use of TCAS II, 18 March 2013

Introduction to TCAS II version 7.1 – 28 February 2011.

20.6 EUROCONTROL publications

ACAS II Bulletins – EUROCONTROL (2002-2022).

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.

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.

21 APPENDIX – RELEVANT ICAO PROVISIONS

Note: Extracts from ICAO documents are provided here for reference only and are current on 1 September 2021 and are subject to change.

21.1 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.

21.2 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.

21.3 Annex 10 – Volume IV

4.3.5.3.1 New ACAS installations after 1 January 2014 shall monitor own aircraft's vertical rate to verify compliance with the RA sense. If non-compliance is detected, ACAS shall stop assuming compliance, and instead shall assume the observed vertical rate.
Note 1.— This overcomes the retention of an RA sense that would work only if followed. The revised vertical rate assumption is more likely to allow the logic to select the opposite sense when it is consistent with the non-complying aircraft's vertical rate.
Note 2.— Equipment complying with RTCA/DO-185 or DO-185A standards (also known as TCAS Version 6.04A or TCAS Version 7.0) do not comply with this requirement.
Note 3.— Compliance with this requirement can be achieved through the implementation of traffic alert and collision avoidance system (TCAS) Version 7.1 as specified in RTCA/DO-185B or EUROCAE/ED-143.

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

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

21.4 PANS-ATM – Doc 4444

21.4.1 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.

21.4.2 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;

21.5 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. […]

21.6 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.

22 RELEVANT EUROPEAN REGULATION AND GUIDANCE MATEIRAL

Note: Extracts from European regulatory documents are provided here for reference only and are current on 5 November 2021 and are subject to change.

22.1 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).

22.2 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, November 2021.

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