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# AIRBORNE COLLISION AVOIDANCE SYSTEM (ACAS)

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**Abstract:** An airborne collision avoidance system (ACAS, usually pronounced as ay-kas) operates independently of ground-based equipment and air traffic control in warning pilots of the presence of other aircraft that may present a threat of collision. If the risk of collision is imminent, the system recommends a maneuver that will reduce the risk of collision.

**Key words**: ACAS, Collision avoidance, air traffic controller

ACAS standards and recommended practices are mainly defined in annex 10, volume IV, of the Convention on International Civil Aviation. Much of the technology being applied to both military and general aviation today has been undergoing development by NASA and other partners since the 1980s.

A distinction is increasingly being made between ACAS and ASAS (airborne separation assurance system). ACAS is being used to describe short-range systems intended to prevent actual metal-on-metal collisions. In contrast, ASAS is being used to describe longer-range systems used to maintain standard en route separation between aircraft (5 nautical miles (9.3 km) horizontal and 1,000 feet (300 m) vertical).

## 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 proposed1 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.

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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.

**Information Provided by ACAS**

Two types of alert can be issued by ACAS II - TA (Traffic Advisory) and RA (Resolution Advisory). The former is intended to assist the pilot in the visual acquisition of the conflicting aircraft and prepare the pilot for a potential RA.

If a risk of collision is established by ACAS II, an RA will be generated. Broadly speaking, RAs tell the pilot the range of vertical speed at which the aircraft should be flown to avoid the threat aircraft. The visual indication of these rates is shown on the flight instruments. It is accompanied by an audible message indicating the intention of the RA. A "Clear of Conflict" message will be generated when the aircraft diverge horizontally.


**Picture 1:** *Example of ACAS II traffic display, indicating a Climb" RA with a target vertical speed of 1500 ft/min.*

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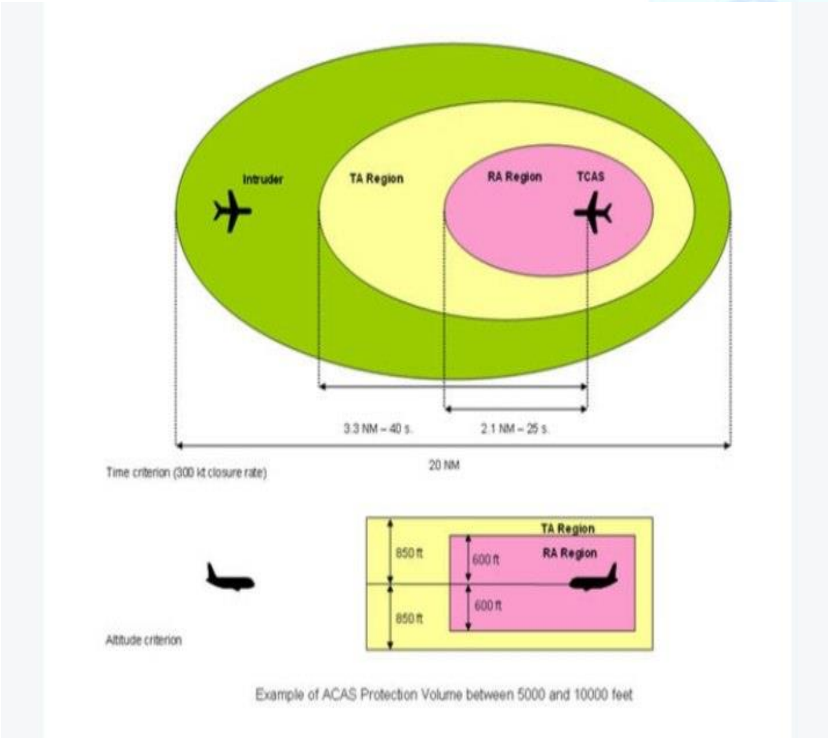
Once an RA has been issued, the vertical sense (direction) of the RA is coordinated with other ACAS II equipped aircraft via a mode S link, so that two aircraft choose complementary manoeuvres. RAs aim for collision avoidance by establishing a safe vertical separation (300 - 700 feet), rather than restoring a prescribed ATC separation.

ACAS II operates on relatively short time scales. The maximum generation time for a TA is 48 seconds before the Closest Point of Approach (CPA). For an RA the time is 35 seconds. The time scales are shorter at lower altitudes (where aircraft typically fly slower). Unexpected or rapid aircraft manoeuvre may cause an RA to be generated with much less lead time. It is possible that an RA will not be preceded by a TA if a threat is imminent. The effectiveness of an RA is evaluated by the ACAS equipment every second and, if necessary, the RA may be strengthened, weakened, reversed, or terminated.

A protected volume of airspace surrounds each ACAS II equipped aircraft. The size of the protected volume depends on the altitude, speed, and heading of the aircraft involved in the encounter. See illustration below.




**Picture 2 :** *A protected volume of airspace surrounds each ACAS II equipped aircraft*

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

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## 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

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 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) Manual10. 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.

## International Standard

The International Civil Aviation Organization (ICAO) is responsible for the global standardisation of ACAS based on the Minimum Operational Performance Standards (MOPS) prepared by RTCA and EUROCAE.

ACAS equipment is available from four vendors (ACSS, Garmin, Honeywell, Rockwell Collins). While each vendor’s implementation is slightly different, they provide the same core functions and the collision avoidance and coordination logic contained in each implementation is the same. In order to be certified, ACAS equipment must meet the Minimum Operational Performance Standards (MOPS) laid down in RTCA and EUROCAE documents.

TCAS II version 7.1 Minimum Operational Performance Standards (MOPS) have been published by RTCA as DO-185B and by EUROCAE as ED-143.

**Types of ACAS**

Currently, ICAO Annex 10 vol. IV defines the following types of ACAS:

--- ACAS I Gives Traffic Advisories (TAs) but does not recommend any manoeuvres. The only implementation of the ACAS I concept is TCAS I. ICAO Standards and Recommended Practices (SARPs) for ACAS I are published in ICAO Annex 10, volume IV but are limited to interoperability and interference issues with ACAS II. ACAS I is mandated in the United States for certain smaller aircraft.

--- ACAS II Gives Traffic Advisories (TAs) and Resolution Advisories (RAs) in the vertical sense (direction). ACAS II SARPs are published in ICAO Annex 10 vol. IV. The only implementations of the ACAS II concept are TCAS II versions 7.0 and 7.1. Annex 10 further states that all aircraft shall carry version 7.1 as of 1 January 2017.

--- ACAS III Gives TAs and RAs in vertical and/or horizontal directions. Also referred to as TCAS III and TCAS IV. So far, ACAS III has not materialised due to limitations the 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 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. Consequently, ICAO is now undertaking the development of ACAS III SARPs.

**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 tau16 or proximity to an intruder aircraft, using two sensitivity levels17. 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

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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 II is an aircraft system based on Secondary Surveillance Radar (SSR) transponder signals. ACAS II interrogates the Mode C and Mode S transponders of nearby aircraft ('intruders') and from the replies tracks their altitude and range and issues alerts to the pilots, as appropriate.

**Equipage Requirements**

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

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

--- all ACAS units shall be compliant with version 7.1 after 1 January 2017.

On 20 December 2011, the European Commission published an Implementing Rule, subsequently amended on 16 April 2016, mandating the carriage of ACAS II version 7.1 within European Union airspace earlier than the dates stipulated in ICAO Annex 10:

--- by all aircraft with a maximum certified take-off mass exceeding 5,700 kg or authorised to carry more 19 passengers from 1 March 2012;

--- with the exception of aircraft with an individual certificate of airworthiness issued before 1 March 2012, that must be equipped from 1 December 2015;

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--- aircraft not referred above but which will be equipped on a voluntary basis with ACAS II, must be equipped with version 7.1.

--- In some parts of the world, notably in the United States, the ACAS equipage mandate is different.

**Safety Benefits**

The safety benefits delivered by ACAS are usually expressed in terms of the risk ratio (does ACAS make safety better or worse?). For Europe, the EUROCONTROL ACASA Project computed, for both the CVSM and the RVSM environments the full system ratio of 21.7% and 21.5% respectively. (ACAS Safety Study: Safety Benefit of ACAS II Phase 1 and Phase 2 in the New European Airspace Environment, ACAS/02-022, May 2002)

The most important single factor affecting the performance of TCAS II is the response of pilots to RAs. At any time, regardless of the level of ACAS equipage by other aircraft, the risk of collision for a specific aircraft can be reduced by a factor greater than three by fitting TCAS II. (EUROCONTROL ACASA Project, Final Report on Studies on the Safety of ACAS II in Europe, WP-1.8/210D, March 2002)

**Implementations**

As of 2022, the only implementations that meets the ACAS II standards set by ICAO are Versions 7.0 and 7.1 of TCAS II (Traffic Collision Avoidance System) produced by Garmin, Rockwell Collins, Honeywell and ACSS (Aviation Communication & Surveillance Systems; an L-3 Communications and Thales Avionics company).

As of 1973, the United States Federal Aviation Administration (FAA) standard for transponder minimal operational performance, Technical Standard Order (TSO) C74c, contained errors which caused compatibility problems with air traffic control radar beacon system (ATCRBS) radar and Traffic Collision Avoidance System (TCAS) abilities to detect aircraft transponders. First called "The Terra Problem", there have since been individual FAA Airworthiness Directives issued against various transponder manufacturers in an attempt to repair the operational deficiencies, to enable newer radars and TCAS systems to operate. Unfortunately, the defect is in the TSO, and the individual corrective actions to transponders have led to significant differences in the logical behavior of transponders by make and mark, as proven by an FAA study of in-situ transponders. In 2009, a new version, TSO C74d was defined with tighter technical requirements.

**Other collision avoidance systems**

Modern aircraft can use several types of collision avoidance systems to prevent unintentional contact with other aircraft, obstacles, or the ground.

## Aircraft collision avoidance

Some of the systems are designed to avoid collisions with other aircraft and UAVs. They are referred to as "electronic conspicuity" by the UK CAA.

--- Airborne radar can detect the relative location of other aircraft, and has been in military use since World War II, when it was introduced to help night fighters (such as the de Havilland Mosquito and Messerschmitt Bf 110) locate bombers. While larger civil aircraft carry weather radar, sensitive anti-collision radar is rare in non-military aircraft.

--- Traffic collision avoidance system (TCAS), the implementation of ACAS,:14 actively interrogates the transponders of other aircraft and negotiates collision-avoidance tactics with them in case of a threat. TCAS systems are relatively expensive, and tend to appear only on larger aircraft. They are effective in avoiding collisions only with other aircraft that are equipped with functioning transponders with altitude reporting.a Portable Collision Avoidance System (PCAS) is a less expensive, passive version of TCAS designed for general aviation use. PCAS systems do not actively interrogate the transponders of other aircraft, but listen passively to responses from other interrogations. PCAS is subject to the same limitations as TCAS, although the cost for PCAS is significantly less.

--- FLARM is a small-size, low-power device (commonly used in gliders or other light aircraft) which broadcasts its own position and speed vector (as obtained with an integrated GPS) over a license-free ISM band radio transmission. At the same time it listens to other devices based on the same standard. Intelligent motion prediction algorithms predict short-term conflicts and warn the pilot accordingly by acoustical and visual means. FLARM incorporates a high-precision WAAS 16-channel GPS receiver and an integrated low-power radio transceiver. Static obstacles are included in FLARM's database. No warning is given if an aircraft does not contain an additional FLARM device.

## Terrain collision avoidance

--- a Ground proximity warning system (GPWS), or Ground collision warning system (GCWS), which uses a radar altimeter to detect proximity to the ground or unusual descent rates. GPWS is common on civil airliners and larger general aviation aircraft.

--- a Terrain awareness and warning system (TAWS) uses a digital terrain map, together with position information from a navigation system such as GPS, to predict whether the aircraft's current flight path could put it in conflict with obstacles such as mountains or high towers, that would not be detected by GPWS (which uses the ground elevation directly beneath the aircraft). One of the best examples of this type of technology is the Auto-GCAS (Automatic Ground Collision Avoidance System) and

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PARS (Pilot Activated Recovery System) that was installed on the entire USAF fleet of F-16's in 2014.

--- Synthetic vision provides pilots with a computer-generated simulation of their outside environment for use in low or zero-visibility situations. Information used to present warnings is often taken from GPS, INS, or gyroscopic sensors.

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