



The European Organisation for Civil Aviation Equipment
L'Organisation Européenne pour l'Équipement de l'Aviation Civile

GUIDANCE FOR THE DEVELOPMENT OF AIRBORNE COLLISION AVOIDANCE SYSTEMS

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102 rue Etienne Dolet
92240 Malakoff, France
Web Site: www.eurocae.net

Tel: 33 1 46 55 62 65
Fax: 33 1 46 55 62 65
Email: eurocae@eurocae.net

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FOREWORD

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EUROCAE
102, rue Etienne Dolet
92240 MALAKOFF
France

Telephone: 33 1 40 92 79 30

Fax: 33 1 46 55 62 65

Email: eurocae@eurocae.net

Website: www.eurocae.net

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE

This document discusses the role of airborne collision avoidance from other traffic. The purpose is to provide guidance on the design of airborne collision avoidance systems. While the paper contains many statements that probably imply the need for requirements, it is not a requirements document, and the words “shall” and “should” have been avoided where possible.

1.2 SCOPE

The first collision avoidance system, TCAS II (simply referred to as TCAS here) has been in service for nearly 20 years in the USA and Europe, and has been mandated globally for certain categories of aircraft since 2003. There have been technological advances in that time, providing the potential opportunity to improve TCAS or develop new systems. Reasons to consider future airborne collision avoidance systems¹ include:

- the changes in ATM outlined by SESAR, which include some changes that are already in hand;
- the possibility of the collision avoidance function using ADS-B in some way;
- pressures to provide collision avoidance functions for unmanned aircraft; and
- the need for improvements in the present system, viz. TCAS.

The SESAR ATM Master Plan envisages several changes in airborne collision avoidance systems. TCAS needs to be evaluated to ensure that it still performs the required collision avoidance function with new separation modes. Improved compatibility between ground-based and airborne safety nets is foreseen. New semi-automated methods of displaying and following TCAS advisories (AP/FD TCAS) have already been developed. Several ANSPs are using the TCAS RA downlink to provide information about TCAS alerts at controller work-stations. Finally, collision avoidance has to be adapted to the constraints imposed by the new separation modes.

These objectives could be met in either of two radically different ways: the incremental improvement of TCAS; or the development of new airborne collision avoidance systems (one or many). It is not obvious which of these two options would be superior, nor which might be chosen following SESAR work. This document is intended to provide a framework for either approach.

Although ADS-B is not the only new opportunity for obtaining data relevant to collision avoidance, the possibility of using ADS-B data to improve the collision avoidance logic has been recognised since almost before the acronym ADS-B was coined. RTCA has described the use of ADS-B in airborne conflict management and their concept includes a collision avoidance mode, based on ADS-B. This paper starts to outline the issues that need to be brought to these discussions.

¹ The acronym ACAS could be understood by some to be synonymous with TCAS, and by others to refer to the general function of airborne collision avoidance. Because of this ambiguity, this paper avoids using the acronym except when quoting. The phrase “airborne collision avoidance systems” refers to the general function and does not imply particular systems. The term TCAS refers to existing systems.

Unmanned aircraft are expected to demand access to managed (or controlled) airspace in increasing numbers. They will need to cooperate in separation provision and they will need a collision avoidance function. TCAS was designed as an aid to a pilot on board the aircraft and care and extensive studies will be required when considering its use for unmanned aircraft. There is also discussion of a “sense-and-avoid” function, but there is lack of clarity concerning whether sense-and-avoid is part of separation provision or collision avoidance. In a world where separation will be provided through trajectory management, it would seem natural to require unmanned aircraft to support trajectory management for separation provision, and to use sense-and-avoid for collision avoidance. This means sense-and-avoid must be able to coordinate with TCAS, but not that it must be TCAS.

Although this document is dealing with the future of collision avoidance systems, it provides extensive discussion of TCAS, its use and the current environment. Notwithstanding technological advance, the operational role of collision avoidance and the human factors surrounding it are likely to remain largely unchanged. Future collision avoidance systems are likely to be affected by the same dilemmas as TCAS.

1.3 RELATIONSHIPS TO OTHER DOCUMENTS

ICAO recommends that all aeroplanes be equipped with a collision avoidance system in Annex 2 to the Chicago Convention. Annex 10 specifies the Standards and Recommended Practices for Airborne Collision Avoidance Systems, and is, in practice, firmly based on TCAS II. ICAO’s “ATM Operational Concept” (ICAO Doc 9854) describes the role of collision avoidance in the ATM system, and parts of the present document derive directly from that operational concept.

EUROCAE and RTCA technical standards for TCAS II are contained in EUROCAE ED143, RTCA DO-185B. These MOPS documents define TCAS II. The present document foresees the need for TCAS II to evolve, which might require future changes to, or versions of, the existing MOPS. It also foresees the possibility of developing new collision avoidance systems, either specifically for General Aviation or for all aeroplanes; again, this might necessitate new MOPS.

The SESAR ATM Master Plan envisages several changes in airborne collision avoidance systems. The present document is intended as a source of guidance to that work, largely based on experience with TCAS II and the development of the ideas in the ICAO operational concept.

1.4 DESCRIPTION OF THIS DOCUMENT

This document could be considered to be a series of fifteen short essays (i.e., the chapters) on aspects of collision avoidance that are likely to be relevant to the future development of collision avoidance systems. The chapters have been placed in the order that appeared most natural, but there is often little development from one chapter to subsequent chapters.

The discussion that follows in Chapters 2 and 3 on the role of collision avoidance and its relation with separation provision is based on “The Role of Collision Avoidance in Future ATM Systems”, 22 May 2003, AN-Conf/11-WP/34. WP/34 amplified definitive text from the ATM operational concept (ICAO Doc 9854) concerning collision avoidance; the definitive text itself is quoted in chapter 2. Chapters 2 and 3 make no reference to who is the separator (ground-based controllers or the flight crew; humans or computer based systems), nor to where the collision avoidance system resides. WP/34 clearly applies to airborne collision avoidance systems, providing protection from other traffic, regardless of the means of providing separation.

1.5 ACRONYMS AND GLOSSARY OF TERMS

ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance – Broadcast
AMC	Acceptable Means of Compliance
ANSP	Air Navigation Service Provider
AP/FD	Autopilot / Flight Director
ASAS	Airborne Separation Assistance System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
Autoflight CAS	Autoflight Collision Avoidance System
CAT	Commercial Air Traffic
CDTI	Cockpit Display of Traffic Information
COC	Clear of conflict
CS	Certification Specification
CWP	Controller Work Position
E/GPWS	Enhanced Ground Proximity Warning System
EASA	European Aviation Safety Agency
FRUIT	asynchronous overlapping of replies – False Replies Uncorrelated In Time
GA	General Aviation
GNSS	Global Navigation Satellite System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
Mode A (3/A)	identity, squawk code
Mode C	altitude reply
Mode S	Mode Select
MOPS	Minimum Operational Performance Standards
PANS-ATM	Procedures for Air Navigation - Air Traffic Management
RA	Resolution Advisory
RAC	Resolution Advisory Complement
RTCA	originally Radio Technical Commission for Navigation, now just RTCA, Inc
RVSM	Reduced Vertical Separation Minimum
SARPs	Standards and Recommended Practices
SESAR	Single European Sky ATM Research
SSR	Secondary Surveillance Radar
STCA	Short Term Conflict Alert
TAS	Traffic Advisory System
TA	Traffic Advisory
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Alert and Collision Avoidance System

TLS	Target Level of Safety
TMA	Terminal Control Area (<i>sic</i>)
UAS	Unmanned Aircraft Systems
UCAF	UAS Collision Avoidance Function
VFR	Visual Flight Rules

1.6 REFERENCES

“The Role of Collision Avoidance in Future ATM Systems”, 22 May 2003, AN-Conf/11-WP34.

EASA CS 25.1309

EASA CS 25.1302

EASA AMC 25.1302

ICAO Annex 10, Vol. IV (referred to as the ACAS SARPs)

ICAO Annex 2

ICAO Annex 6

ICAO Doc 4444, PANS-ATM

ICAO Doc 8168, PANS-OPS

ICAO Doc 9854, ATM Operational Concept

ICAO Doc 9863, ACAS Manual

EUROCAE ED143, RTCA DO-185B, TCAS II MOPS

RTCA DO-197A, MOPS for active TCAS I

RTCA DO-300, TCAS II Hybrid Surveillance MOPS

SESAR D5, ATM Master Plan

“Safety benefits of ACAS in the future European ATM environment with Very Light Jets - AVAL final report”, EUROCONTROL, CND/CoE/CNS/09-142, Edition 1.3, 16th November 2009.

Available online at:

http://www.eurocontrol.int/msa/gallery/content/public/documents/AVAL_final_report_v13_1.pdf

“Unmanned Aircraft Systems – ATM Collision Avoidance Requirements”, EUROCONTROL, CND/CoE/CNS/09-156, Edition 1.3, 26 March 2010 – CAUSE

Available online at:

http://www.eurocontrol.int/msa/gallery/content/public/documents/CAUSE_report_v13.pdf

CHAPTER 2

THE ROLE OF COLLISION AVOIDANCE IN THE ATM SYSTEM

The ATM operational concept (ICAO Doc 9854) defines three layers of conflict management. In order, these are: strategic conflict management, separation provision, and collision avoidance. Since “conflict management” is the subject of ongoing work, it is important to have a clear understanding of the roles of each of the layers of conflict management and how they interrelate. Section 2.7.6 of the operational concept contains the following paragraph:

“Collision avoidance is the third layer of conflict management, and must activate when the separation mode has been compromised. Collision avoidance is not part of separation provision, and collision avoidance systems are not included in determining the calculated level of safety required for separation provision. Collision avoidance systems will, however, be considered part of the ATM safety management. The collision avoidance functions and the applicable separation mode, although independent, must be compatible.”

The first sentence of this quotation is a statement of principle, in line with its presence in a concept document. In practice, there is considerable interaction between separation provision and collision avoidance, and this interaction is affected by the details of operational procedures and airspace management. For example, for current operations, it is common for TCAS to generate RAs in encounters where there is no serious loss of separation. This interaction is examined further in the next chapter. The intention of the ICAO ATM operational concept is amplified in the next two paragraphs.

The operational concept ensures an integrated and holistic approach to conflict management against all hazards. Each layer has a defined role and place in conflict management. Collision avoidance is the last layer, and is meant to avoid disaster when the first two layers fail.

Collision avoidance is not an optional extra but “must activate when the separation mode has been compromised”. Ensuring that this occurs in all environments is a challenge; however, collision avoidance equipment is compulsory in respect of some hazards in some environments today. The operational concept uses a layered approach which recognizes that any system of separation provision can fail and that a layer is required to avoid collision when the separation provision layer has been compromised.

Collision avoidance is part of the ATM safety management. While current arguments sometimes suggest that the cost of collision avoidance equipment can be justified by reducing separation standards, the operational concept clearly proposes an alternative to this approach. The previous sentence of the operational concept (*viz.*, “Collision avoidance is not part of separation provision, and collision avoidance systems are not included in determining the calculated level of safety required for separation provision.”) indicates that collision avoidance systems are not to be mixed with separation provision. However, the concept does recognize the importance of collision avoidance systems and their value to overall ATM safety management, which can justify their expense.

The discussion above assumed that separation is being provided, either by controllers or using ASAS. Collision avoidance must also operate when there is no separation provision, i.e., in uncontrolled airspace. It is not expected to compensate for the absence of separation provision, since collision avoidance is a last minute action for which success cannot be guaranteed. This is consistent with the arguments above, which suggest separation provision is required to provide a measured and quantifiable level of safety and that collision avoidance only provides emergency protection when, inevitably but rarely, things go wrong.

In summary, in the context of the ATM operational concept:

- a) collision avoidance is an important, but separate, layer of conflict management;
- b) the level of safety required for separation provision does not include allowances for collision avoidance systems;
- c) collision avoidance systems are of value to the ATM system and are an important part of the ATM system design and ATM safety management;
- d) as collision avoidance systems must activate to overcome failure of separation provision, the collision avoidance system must be independent of ATM system components;
- e) collision avoidance must activate to avoid collision when a threat arises in the absence of separation provision, i.e., in uncontrolled airspace.

CHAPTER 3

THE RELATIONSHIP BETWEEN SEPARATION PROVISION AND COLLISION AVOIDANCE

“Collision avoidance is not part of separation provision” is an emphatic statement that separation provision and collision avoidance are not the same, that there is a functional difference, and that the operational concept definition of a third layer is deliberate. The distinctness of separation provision and collision avoidance is taken further by the statement “collision avoidance systems are not included in determining the calculated level of safety required for separation provision”. This is intended to make clear that, at least in relation to separation provision, there will be a different level of safety in separation provision to the overall ATM system level of safety, as the latter will include collision avoidance. This is made more explicit in chapter 4.

“The collision avoidance functions and the applicable separation mode, although independent, must be compatible.” A particular difficulty with TCAS II is the high frequency with which it alerts when separation has not been compromised, or where there is no heightened risk of collision. The ICAO ATM operational concept, having established that the particulars of separation provision (the separation mode) and collision avoidance are separate layers of conflict management, also states that these layers must be compatible; i.e., the activities of one layer must not compromise the activities of the other layer. A correctly implemented separation mode should not invoke the collision avoidance layer. However, the requirement of independence (chapter 5) does not prevent one layer being aware of the activities of the other layer. Separation modes need to act consistently with collision avoidance; and collision avoidance needs to act consistently with separation provision. ATM system designers also need to ensure that there is a capable collision avoidance mode for each separation mode.

As new separation modes are developed, the key priorities (from the perspective of collision avoidance) are to ensure that the new modes interoperate with the existing collision avoidance system, i.e., TCAS II, and to ensure that there is a satisfactory collision avoidance mode capable of operating when the new separation mode is compromised. When new separation modes are proposed, their design must ensure that collision avoidance (whether on own aircraft or on other aircraft) does not alert without operational cause; this might be achieved by careful design of the separation mode, or it might be achieved by modifying TCAS II, or by the introduction of a new collision avoidance system.

The collision avoidance mode can vary between separation modes. For example, where an operation requires identified aircraft to fly in close proximity, the collision avoidance mode might be simply to break away from the other aircraft (e.g., to go-around in the case of parallel approaches) when its trajectory is not as expected, and the collision avoidance system could be a simple monitor of the behaviour of the known proximate aircraft. In this case, TCAS II would require modification so that it does not alert when the nominal separation mode causes the TCAS II logic thresholds to be breached; this could be achieved, for example, by exchanging the 24 bit aircraft addresses of the aircraft involved and disabling RAs against those aircraft, but only provided a replacement collision avoidance mode, designed for the separation mode, is implemented. This possibility is an example of the potential for including information concerning context in future TCAS modifications, or other future collision avoidance systems. Such information could include the “procedure flags” discussed in chapter 6.

CHAPTER 4

REQUIRED LEVELS OF SAFETY

The ICAO ATM operational concept deliberately avoids use of target level of safety (TLS) because the term TLS has particular meanings today. The “calculated level of safety required”, used in the operational concept, is not necessarily expressed in numerical terms, nor does it imply that any numerically expressed level is achieved in practice. In fact, the “level of safety” may be something that is dynamically determined and proved in routine ATM operations in the future based on the operational concept. The current understanding of the meaning and use of TLS is expected to evolve, and the operational concept makes provision for this. In addition, there may be levels of safety for each layer of ATM system design, including conflict management.

The term “required level of safety” will be used here, hoping to maintain the deliberate ambiguity of the previous paragraph. This document is not the place to discuss how the requirement for separation provision to be safe should be expressed, nor how to demonstrate that it is met. If the language used here suggests that the required level of safety is a number, this is merely a device for clarity. There is no intention to imply that the safety requirement must be expressed numerically, nor that it must be proved analytically. Its purpose is to assist decision making on safety issues.

The required level of safety encompasses all hazards, but we are concerned here solely with airborne collision with other aircraft.

The required level of safety could be expressed as a maximum collision rate per flight-hour. In this case, the required level of safety for the ATM system (i.e., the maximum tolerated collision rate) will be lower (i.e., safer) than that for separation provision because collision avoidance provides an additional layer of protection. In both cases (the ATM system as a whole, or separation provision), it is reasonable to express the requirement as a rate. It is not reasonable to express the required level of safety for collision avoidance as a rate unless the ATM context and the separation mode has been defined in advance, because the performance of collision avoidance depends upon the ATM context and separation mode and it will always be possible to select a separation mode that renders the requirement on collision avoidance impractical.

Throughout the development of the current generation of collision avoidance systems, TCAS II, the effect of required performance level for collision avoidance has been expressed through the risk ratio, R .

$$R = \frac{\text{collision rate with TCAS}}{\text{collision rate without TCAS}}$$

The ICAO technical standards for collision avoidance, the ACAS II SARPs, specify the performance required of the collision avoidance logic including the value of R . The value specified is that achieved by TCAS II, and the method of calculation is also specified in some detail. R is sensitive to many assumptions and the characteristics of the airspace in which it is used; it is critical that any comparison of two collision avoidance systems calculates R for the two systems in exactly the same way, using identical assumptions.

Many factors can intervene and prevent collision when separation is lost. However, if we set that point to one side and assume, for the sake of clarifying the role of collision avoidance, that the only processes in play are separation provision and collision avoidance, the risk ratio R can be recast in the following terms:

$$R = \frac{\text{collision rate for the ATM system}}{\text{collision rate for separation provision}}$$

The subject of failure modes that are common to collision avoidance and separation provision is covered in the next chapter, “Independence of collision avoidance”. Here it can be observed that there will be such common failure modes, the shared use of pressure altitude reported by transponders being an example for TCAS. Common failure modes must be included in the calculation of risk ratio and they contribute equally to the numerator and the denominator of the risk ratio.

Many caveats have been entered, in particular that the “required level of safety” might not be a number, and that there are other processes preventing collision. However, when it comes to demonstrating that a collision avoidance system meets an appropriate required level of safety, the rarity of relevant events is likely to compel an approach based on analysis and simulation, and this has been the experience with TCAS. In this context (in which the proof has to be theoretical), it seems compelling to treat the requirement in numerical terms, and natural to disregard the other processes (except as potential complications interfering with the correct operation of collision avoidance).