ACAS II operations in the European RVSM environment

ACAS training for operations in RVSM environment

Project ACTOR

NOTE

This document is designed specifically for the training of people involved in the implementation and the use of the Airborne Collision Avoidance System (ACAS II). In particular, it addresses ACAS II operation use and performance in European Reduced Vertical Separation Minima (RVSM) airspace. 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 ICAO and RTCA documentation listed in the bibliography section.

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1. Introduction

This brochure is part of a training package that addresses ACAS II (Airborne Collision Avoidance System) performance in the RVSM (Reduced Vertical Separation Minimum) environment, both from a pilot and a controller perspective.

For clarity, the brochure will only deal with TCAS II (Traffic alert and Collision Avoidance System) and more precisely with TCAS II version 7.0 even if it should be ACAS II, except for the description of the European ACAS II mandate.

The objective of the brochure is to enable pilots and controllers to:

- understand the behaviour of TCAS II in the RVSM environment;
- know what to expect from TCAS II in the RVSM environment;
- better manage advisories whether they are perceived necessary or not.

This package also includes:

- a set of slides highlighting the main points described in the brochure;
- a quiz aiming to verify that the basic knowledge of TCAS II operations in the RVSM environment has been acquired.

The brochure first describes some background about the ACAS II mandate in Europe, the RVSM implementation and the experience of TCAS II in the North Atlantic RVSM airspace.

The second part describes the principal and essential technical features of TCAS II, specifically for RVSM airspace, to understand the principle of advisory triggering. This part of the brochure also describes the improvements brought by TCAS II version 7.0 in comparison with version 6.04a for the RVSM environment.

The core of the brochure, which presents the expected TCAS II and RVSM interaction in Europe, is divided into two parts:

- the main results of the study on the TCAS II and RVSM interaction performed within the EUROCONTROL co-ordinated ACASA project. They include some statistics about the expected advisories in the European airspace (e.g. number, duration, induced deviations) and a comparison with TCAS II performance in the current FL250-FL290 altitude band.
- the description of the standard RVSM vertical separation, the main critical configurations expected (i.e. imperfect altitude keeping, which includes vertical offsets, oscillations and turbulences, and 1000 ft level-off) and the specific case of low closure rate encounters. The TCAS II behaviour is explained for each configuration and operational recommendations are provided.

The last part summarises the operational implication of TCAS II in the RVSM environment separately for controllers and pilots.

2. Background

2.1. ACAS II mandate in Europe

In 1995, the ECAC (European Civil Aviation Conference) States agreed a common ACAS policy and implementation schedule for the mandatory carriage of an ACAS II in Europe. This policy was confirmed by the ECAC Transport Ministers in 1997. The approved policy requires that:

- **from 1st January 2000**, all civil fixed-wing turbine-engine aircraft having a maximum take-off mass exceeding 15000 kg or a maximum approved passenger seating configuration of more than 30 will be required to be equipped with ACAS II, and
- **from 1st January 2005**, all civil fixed-wing turbine-engine aircraft having a maximum take-off mass exceeding 5,700 kg or a maximum approved passenger seating configuration of more than 19 will be required to be equipped with ACAS II.

ACAS II can issue two types of advisories:

- **Traffic Advisories** (TAs), which aim at alerting the crew to be ready for a potential Resolution Advisory and at helping the crew in the visual search for the intruder aircraft;
- **Resolution Advisories** (RAs), which are avoidance manoeuvres in the vertical plane recommended to the pilot.

TCAS II version 7.0 is the only equipment, which complies fully with ACAS II Standards And Recommended Practices (SARPs) published by the International Civil Aviation Organisation (ICAO). Therefore TCAS II version 7.0 is required to meet the ACAS II mandate.

TCAS II version 7.0 has not been specifically developed to address the issue of TCAS II version 6.04a and RVSM operational incompatibility, which has been identified with the NAT (North Atlantic) RVSM implementation. The overall objective of this new version is to improve the general TCAS II performance (e.g. better compliance with ATC (Air Traffic Control) procedures, interference limiting, limitation of the altitude deviations in response to RAs, etc.).

Practical implementation issues, involving supply, installation and certification of ACAS II equipment were identified during the implementation phase. To permit resolution of these difficulties ACAS II temporary exemptions were available until 30 September 2001 in order to provide respite to some operators that were unable to equip some of their aircraft with ACAS II in time because of technical or supply problems.

2.2. RVSM implementation

RVSM is an approved ICAO concept to reduce aircraft separation minimum from 2000 ft to 1000 ft from FL290 to FL410 inclusive. The purpose of RVSM is to increase airspace capacity and provide airspace users with more flight levels and thus optimised flight profiles.

The NAT Region was the first one in which RVSM was implemented on 27 March 1997, initially from FL330 to FL370. On 8 October 1998 NAT RVSM operations were expanded to FL310-FL390 inclusive. On 24 January 2002 RVSM in the NAT Region is planned to be further expanded to FL290-FL410 inclusive, so that the RVSM operations will be harmonised with the European (EUR) Region [RVSM].

RVSM has also been implemented in the Pacific Region since 24 February 2000, between FL290 and FL390, within the Oakland Oceanic FIR and Anchorage FIR.

On 12 July 2001 the EUROCONTROL Provisional Council confirmed the implementation of RVSM in the European airspace (shown on figure 1) with effect from the 24 January 2002, between FL290 and FL410 (inclusive). Except where transition tasks are carried out, only aircraft, which are RVSM approved, will be authorised to operate within the EUR RVSM airspace.

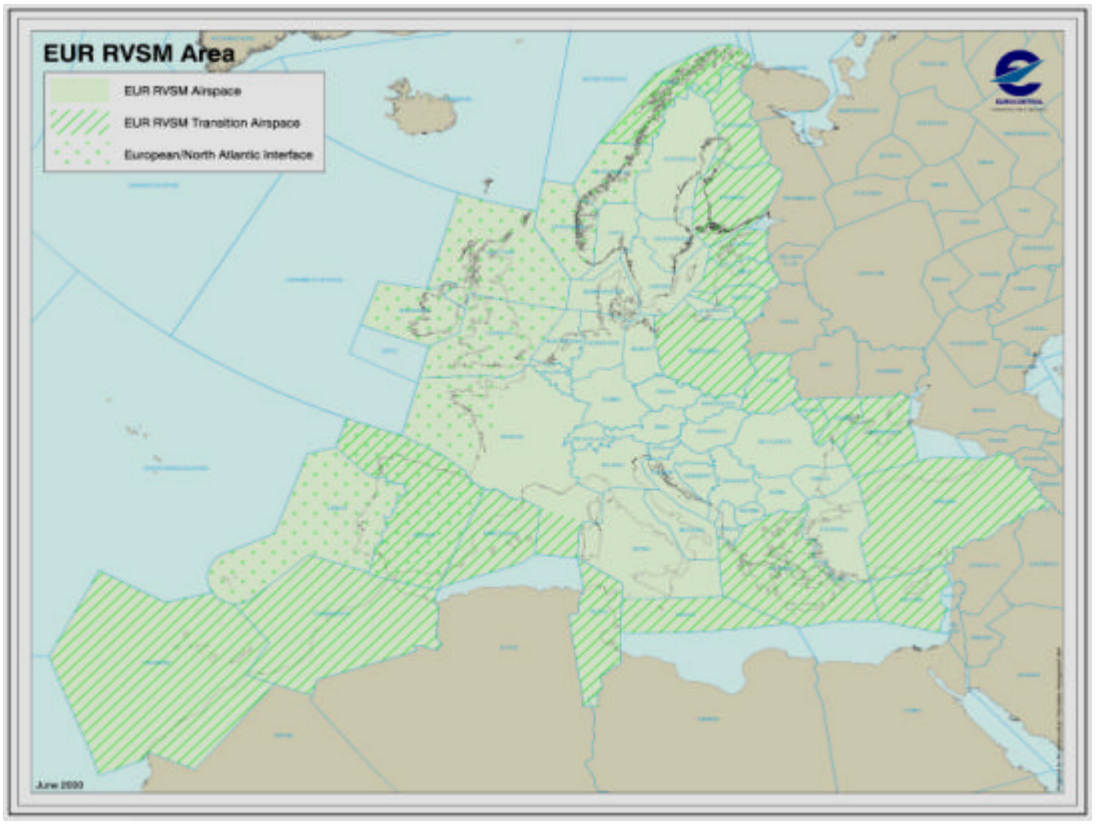


Figure 1: European RVSM and RVSM transition airspace

An early introduction of RVSM has started in Ireland, the United Kingdom, Germany and Austria. This early introduction is not based on the procedures and requirements in place for the full European RVSM implementation. The early introduction of RVSM by Germany and Austria consists of the application by ATC of a 1000 ft vertical separation above FL290 between RVSM approved aircraft on a tactical basis. In the United Kingdom and Ireland RVSM levels can be requested on the flight plan. Until 24 January 2002, non-RVSM approved aircraft are not excluded from the airspace in which this early application is in use.

The mandatory carriage of ACAS II in Europe and the implementation of RVSM are not linked even if there is an interaction between them. ACAS II is not, itself, a prerequisite for RVSM. The ACAS II mandate does not imply that all aircraft in the RVSM airspace will be equipped with TCAS II version 7.0, in particular before 1st January 2005. Some of them (e.g. certain business jets) can either still be equipped with TCAS II version 6.04a or not equipped at all.

2.3. Experience of TCAS II in NAT RVSM

Since 27 March 1997, RVSM has been implemented progressively in the NAT airspace. Aircraft equipped with TCAS II version 6.04a have flown in this airspace since this date. As TCAS II version 6.04a has been developed on the basis of a 2000 ft vertical separation above FL300, it is not adapted to RVSM airspace. Furthermore in the NAT airspace, aircraft follow the same tracks for several hours with close ground speed values, which was a new operational configuration for TCAS II.

Prior to the implementation of RVSM in the NAT airspace, a study [NAT] showed that TCAS II version 6.04a in RVSM airspace would generate some potential issues:

- undesirable TAs would be triggered between level aircraft separated by 1000 ft and they can last several minutes and be repetitive;
- undesirable RAs could be triggered between aircraft separated by 1000 ft;
- large vertical deviations (e.g. several thousands of feet) in response to RAs could occur despite appropriate pilots' reactions.

In the first weeks following the implementation of RVSM in the NAT airspace, a large number of complaints emerging from pilots were identified about undesirable long duration TAs between aircraft at adjacent flight levels. Such TAs were regularly issued by TCAS II version 6.04a. No operational procedure like a navigational offset or a slight speed modification has been approved to eliminate the recurring or long duration TAs, a lateral offset being only allowed to avoid wake vortex.

Since the beginning, a few undesirable RAs have been reported. However none of them has induced any large vertical deviation. The RAs were triggered mainly because of turbulence (wake vortex or meteorological turbulence) or imperfect altitude keeping.

3. TCAS II description

3.1. TCAS II principles

3.1.1. Main functionalities

TCAS II is an on-board system designed to improve air safety by acting as a 'last-resort' method of preventing mid-air collisions or near mid-air collisions by recommending to pilots manoeuvres in the vertical plane when a risk of collision is detected.

TCAS II is designed to work both autonomously and independently of any aircraft navigation equipment and ground systems. TCAS II monitors other aircraft in the vicinity by interrogating their transponder and assesses the risk of collision.

When the intruder aircraft is also fitted with a TCAS II, both TCAS II units co-ordinate their RAs in order to select complementary resolution senses. **This feature makes it very important that pilots should follow their RAs as accurately as possible. Furthermore it is hazardous to manoeuvre in the opposite sense to the RA**, as shown on figure 2.

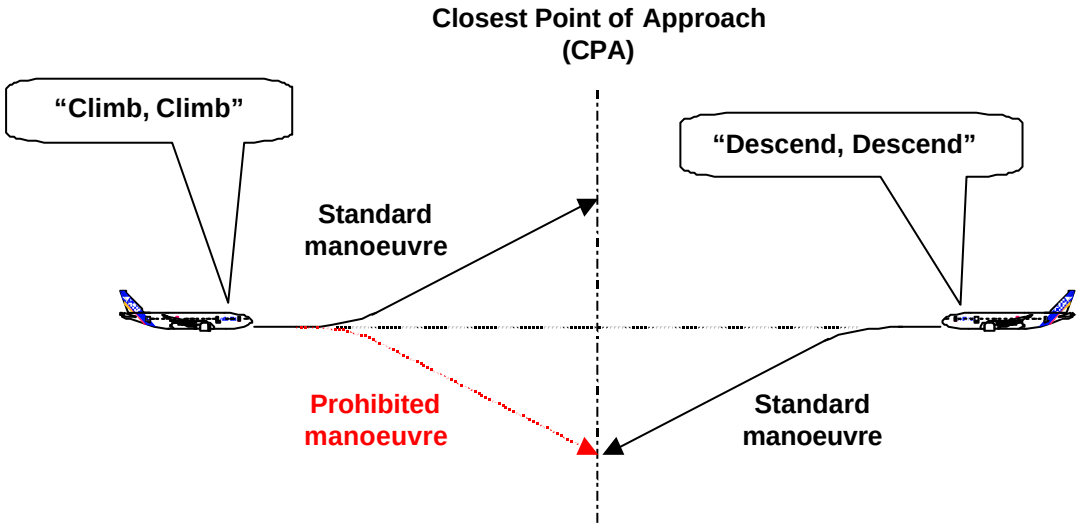


Figure 2: Co-ordinated RAs in TCAS-TCAS encounters

If for any reason, a pilot cannot follow a "Climb" RA triggered by his TCAS II, he should at least remain level and not initiate a descent.

The TCAS II logic is based on two main concepts:

- the warning time, which is based on the time-to-go (and not distance-to-go) to the Closest Point of Approach (CPA);
- the sensitivity level, which is a function of the altitude and which defines the level of protection by assigning larger threshold values for higher altitude bands.

To better understand the main critical configurations between TCAS II and RVSM, the next part describes briefly the basic principles for the triggering of TAs and RAs. However, it addresses specifically the sensitivity level value ranging from FL200 to FL420, which includes the RVSM airspace altitudes.

For a more detailed description of TCAS II, readers should refer to the ACAS brochure developed by the EUROCONTROL ACAS Programme [ACAS].

3.1.2. Triggering of the advisories

TCAS II triggers an advisory when **a range test and an altitude test are both satisfied**. These tests are performed on each altitude-reporting target, every second.

The principle of the **range test** is to compute the time-to-go to the CPA by dividing the distance between aircraft by the closure rate. The range test is satisfied if this time is lower than a threshold value, i.e. 48 s for TAs and 35 s for RAs.

To address the specific case of very low closure rates, a protection distance has been introduced to avoid an intruder coming very close in range without triggering any advisories. For this type of encounter, the range test is satisfied if the distance between aircraft is lower than this protection distance, i.e. 1.3 NM for TAs and 1.1 NM for RAs.

The principle of the **altitude test** is to compute the time to reach co-altitude by dividing the relative altitude between aircraft by the relative vertical speed. The altitude test is satisfied if this time is lower than a threshold value, i.e. 48 s for TAs and 35 s for RAs. If the own aircraft is level, the time threshold value for RAs is reduced to 25 s in order to detect a possible level-off manoeuvre of the intruder and thus to avoid the triggering of the RA.

To address the specific case of level aircraft or aircraft with a very low relative vertical speed, the altitude test is satisfied if the relative altitude between aircraft is lower than a fixed vertical distance threshold, i.e. 850 ft for TAs and 700 ft for RAs.

It should be noted that the altitude of the intruder used by TCAS II is received by interrogating its transponder. Therefore this altitude is encoded with either a 100 ft or a 25 ft quantization. It means that the altitude of the intruder seen by TCAS II can be slightly different than the real one. In contrast, TCAS II sees the altitude of the own aircraft with a 1-ft quantization.

Figures 3 and 4 illustrate the range and the altitude tests, with the associated threshold values for the altitude band including the RVSM airspace.

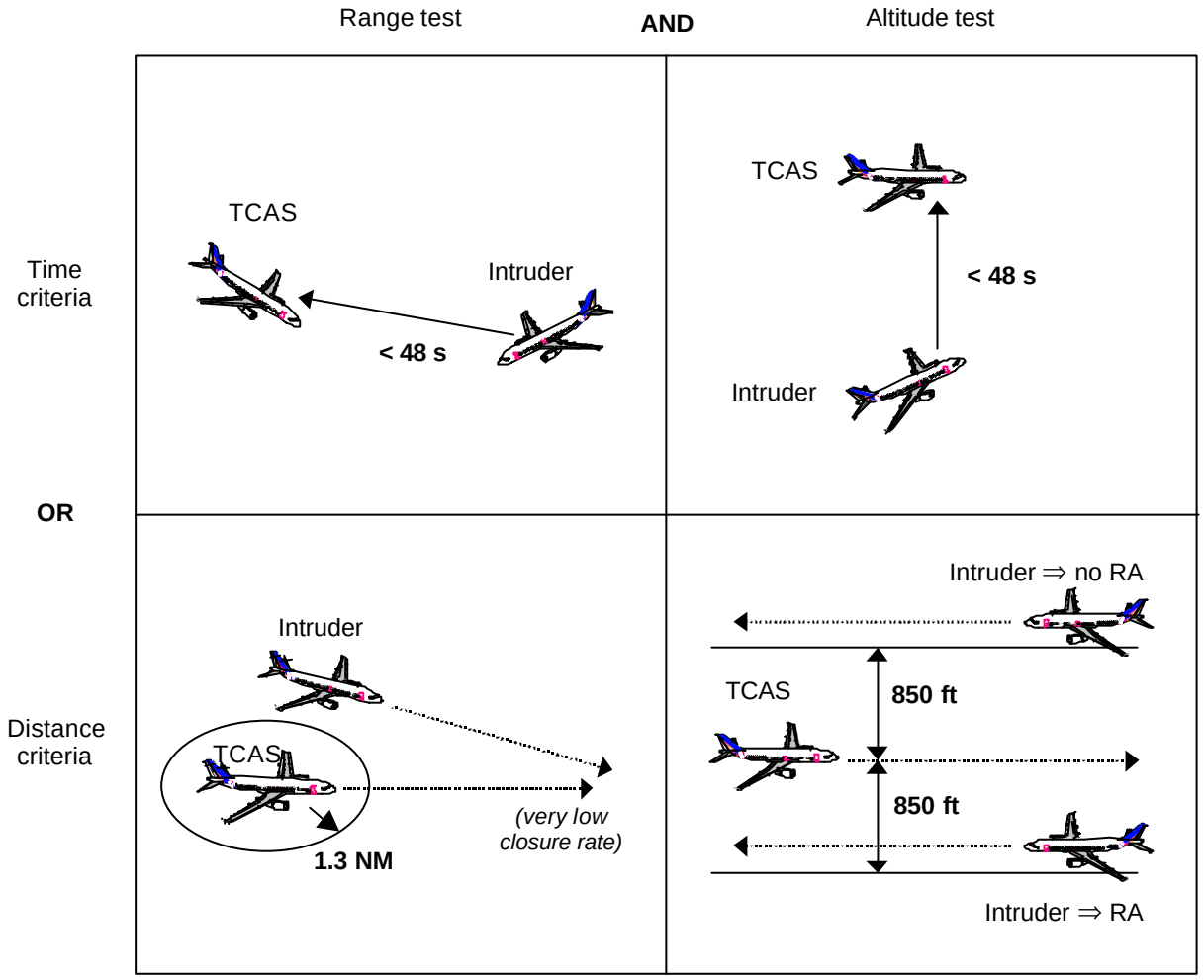


Figure 3: TA triggering by TCAS II version 7.0 in RVSM airspace

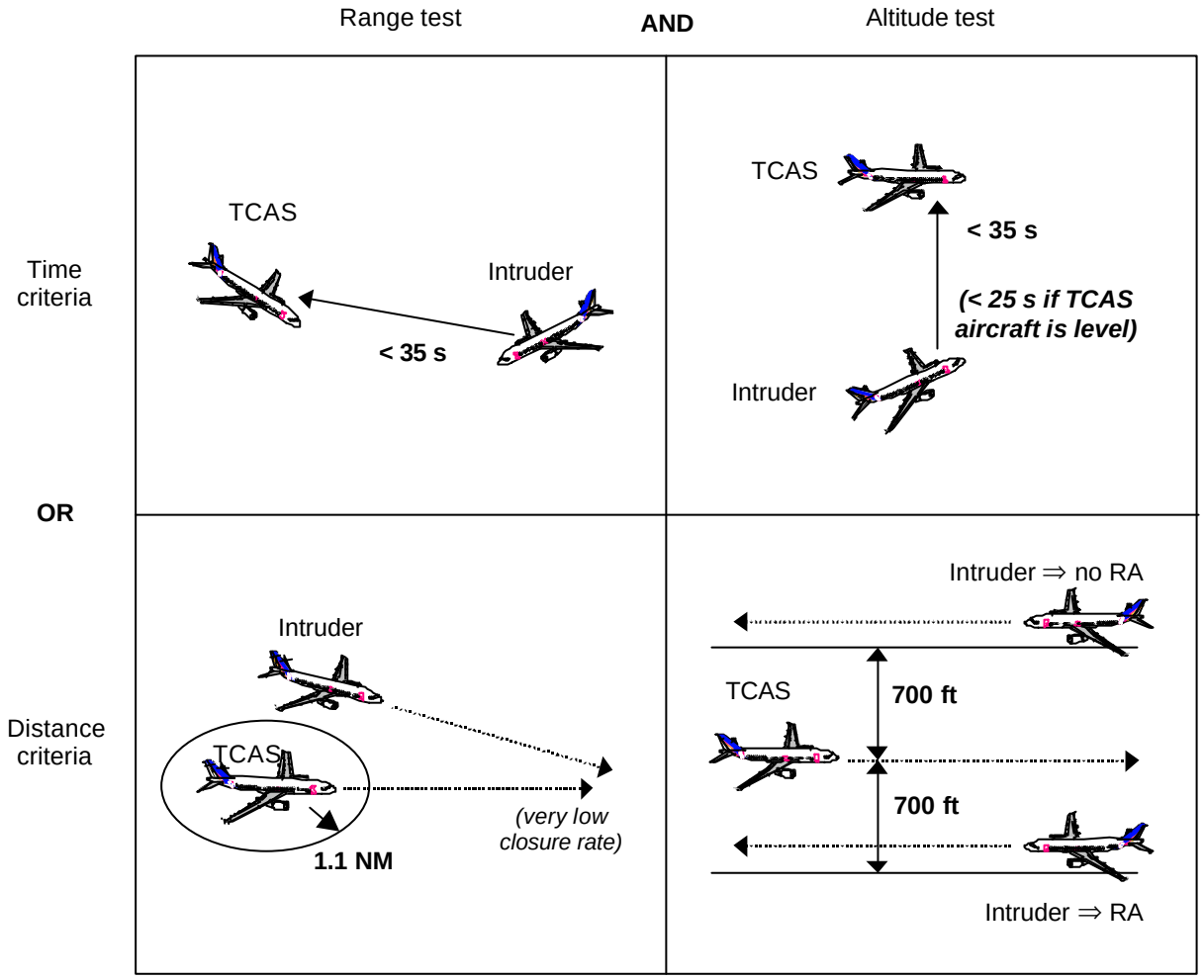


Figure 4: RA triggering by TCAS II version 7.0 in RVSM airspace

When an RA is triggered, TCAS II computes the most appropriate vertical manoeuvre in order to achieve a target vertical miss distance, which is equal to 600 ft.

TCAS II tries to prevent as much as possible the triggering of RAs that induce a vertical crossing of the trajectories. Some very strong biases against crossing RAs have been implemented. This type of RA is rare.

During the course of the encounter, the advisory strength is continuously evaluated and can be modified either by increasing it or reversing it if necessary, or by weakening it if the threat reduces. Weakening the RA should reduce the vertical deviation.

TCAS II is able to handle multiple threat encounters either by attempting to resolve the situation with a single RA, which will provide the target vertical miss distance from each of the threat aircraft, or by selecting an RA that is a composite of non-contradictory climb and descend restrictions.

3.2. Improvements provided by TCAS II version 7.0

The development of TCAS II version 7.0 was based on the results of the various operational monitoring programmes of TCAS II version 6.04a, which have identified several operational and technical issues. The FAA, in collaboration with RTCA SC-147, decided that version 7.0 would address only the items that were considered essential [TCAS7]. Among all the changes that were included in version 7.0, some were made in order to improve the TCAS II operations in RVSM airspace.

The main improvement comes from the modification of the altitude band boundaries of the TCAS II. TCAS II version 6.04a defines a set of parameter values for altitudes greater than FL300, which is compatible with the 2000 ft vertical separation applied in CVSM (Conventional Vertical Separation Minimum) airspace but not with a 1000 ft vertical separation. To take into account the implementation of RVSM, the FL300 boundary has been modified to FL420 within TCAS II version 7.0. Therefore TCAS II version 7.0 uses the same parameter values between FL200 and FL420, which are compatible with RVSM.

Table 1 shows the values of the main TCAS II parameters for the advisory triggering in the altitude band including the RVSM airspace for both TCAS II versions.

	TA		**RA**		
	Time threshold	Altitude threshold	Time threshold	Altitude threshold	Target vertical miss distance
TCAS II v6.04a	48 s	1200 ft	35 s	800 ft	700 ft
TCAS II v7.0	**48 s**	**850 ft**	**35 s**	**700 ft**	**600 ft**

Table 1: TA and RA parameter values in RVSM airspace

The consequences of this boundary modification are:

- a reduction of the altitude threshold for TAs from 1200 ft to 850 ft, which prevents the triggering of TAs between level aircraft separated by 1000 ft;
- a reduction of the altitude threshold for RAs from 800 ft to 700 ft, which decreases the TCAS sensitivity to imperfect altitude keeping;
- a reduction of the target vertical miss distance from 700 ft to 600 ft, which should decrease or even remove the vertical deviations in response to RAs.

In addition, if the own aircraft is level, the reduced time threshold value is further reduced from 30 s to 25 s in order to provide a few more seconds to detect a possible level-off manoeuvre of the intruder and thus to avoid the triggering of the RA. This should decrease the number of RAs for level aircraft triggered by aircraft levelling off 1000 ft above or below.

TCAS II version 7.0 also introduces a mechanism to weaken RAs when aircraft are diverging very slowly but not sufficiently to issue the clear of conflict. This improvement is implemented in order to avoid large deviations resulting from long duration RAs that are not weakened by TCAS II version 6.04a.

Yet another new feature of TCAS II version 7.0 should improve significantly TCAS II overall performance and therefore in RVSM airspace too. A filtering of RAs in the horizontal plane, called Miss Distance Filtering (MDF), has been implemented. It prevents RAs to be triggered if the predicted horizontal distance at CPA is sufficient in terms of collision avoidance. As a consequence, some RAs can be filtered in the RVSM airspace for aircraft with a predicted horizontal distance at CPA greater than 2.2 NM under specific conditions (e.g. aircraft steady in heading). Therefore there is a possibility that some expected RAs may not be triggered in such situations.

Finally, the determination process of the type of RA to be triggered during an encounter with another TCAS II equipped aircraft has been modified in TCAS II version 7.0. The objective is to avoid as far as possible to generate an RA, which would require a manoeuvre opposite to the current own aircraft vertical trajectory. For instance, a climbing aircraft should receive an “Adjust Vertical Speed” RA requiring to reduce the rate of climb instead of a “Descend” RA. The aim is to improve the compatibility of the triggered RA with the clearance and therefore to reduce the disruption caused to controllers and pilots.

4. Expected TCAS II advisories in RVSM airspace

4.1. Introduction

Within the framework of the EUROCONTROL co-ordinated ACASA (Airborne Collision Avoidance System Analysis) project, whose objective was to investigate several areas related to TCAS II operations in Europe, one of the main activity was dedicated to the study of TCAS II and RVSM interaction in continental Europe [ACASA].

The goal of the TCAS II and RVSM interaction study was to perform a comparison of TCAS II performance within the future RVSM environment and the current CVSM environment. The study was to focus not only on technical issues, but also to identify potential operational issues and to provide recommendations. In order to cope with a larger set of issues, the study was based on different sources of data, i.e. modified radar data, real-time and fast-time simulations, automatic and non-automatic artificial encounters.

The main results of this study are presented hereafter. They provide a good indication of the number of advisories that are expected to occur when TCAS II version 7.0 will be in operation in RVSM airspace. To better assess the operational implication for pilots and controllers, a comparison is made with what is currently happening in the altitude band FL250-FL290.

4.2. Traffic Advisories

With the whole TCAS II fleet fitted with TCAS II version 7.0, the number of TAs in RVSM is expected to increase by a factor of about 4 in comparison with CVSM operations. Actually, this increase is mainly due to the low number of TAs triggered in CVSM.

However, the number of TAs triggered by TCAS II version 7.0 in RVSM airspace is expected to be lower than the number in the FL250-290 altitude band. Nevertheless, the increased number of TAs triggered above FL290 may become an operational issue if pilots are not properly informed.

This issue is much more critical for aircraft that will still be fitted with TCAS II version 6.04a: the study has pointed out that the number of TAs triggered in RVSM should be increased by a factor of about 25 in comparison with CVSM. In this case, the rate of TA triggering is disturbing for pilots. It may also have a negative implication on ATC if pilots request for a traffic information following a TA or even initiate a manoeuvre.

On a pilot perspective, it is expected that a maximum of 47 TAs per 1000 flight hours should be triggered by TCAS II version 7.0 in RVSM (e.g. about 1 TA every 20 flight hours). This ratio is three times greater than the one for CVSM (17 TAs per 1000 flight hours) but it is four times smaller than the one for the FL250-290 altitude band (184 TAs per 1000 flight hours). Finally it is expected that TCAS II version 6.04a should generate 840 TAs per 1000 flight hours in RVSM, i.e. about 1 TA per flight hour.

Two specific types of TAs can be expected in greater proportions than in CVSM: repetitive TAs and long duration TAs.

The proportion of repetitive TAs is expected to increase compared with CVSM but it should be close to the one already experienced below FL290 (i.e. about one out of ten TAs). Nevertheless, repetitive TAs may appear to be a TCAS II operational issue if pilots consider the repeated occurrences of the “Traffic, Traffic” aural annunciation as disruptive.

The issue of long duration TAs is not expected to be as significant as it was with TCAS II version 6.04a during the implementation of RVSM in the NAT. First, TCAS II version 7.0 reduces drastically the number of TAs, in particular by suppressing TAs between aircraft separated by 1000 ft. Then, the route structure is totally different in the NAT and EUR Regions: the specific configuration that induces long duration TA (i.e. low closure rate encounters, see part 4.4) is expected to be rare in the European airspace.

4.3. Resolution Advisories

With the whole TCAS II fleet fitted with TCAS II version 7.0, the number of RAs in RVSM is also expected to increase by a factor of about 4 in comparison with CVSM operations. This increase is again due to the very low number of RAs triggered in CVSM.

For aircraft equipped with TCAS II version 6.04a, pilots will receive approximately twice as many RAs as with TCAS II version 7.0. Nevertheless, based on the current experience below FL290, this number is expected to be operationally tolerable to both pilots and controllers.

On a pilot perspective, it is expected that a maximum of 3 RAs per 1000 flight hours should be triggered by TCAS II version 7.0 in RVSM (e.g. about 1 RA every 330 flight hours). This ratio is three times greater than the one for CVSM (1 RA per 1000 flight hours) but it is five times smaller than the one for the FL250-290 altitude band (15 RAs per 1000 flight hours). It is expected that TCAS II version 6.04a should generate 6 RAs per 1000 flight hours in RVSM, i.e. twice as many as TCAS II version 7.0.

A majority of the RAs could be considered as undesirable. Nevertheless, this number is expected to be lower than the one currently experienced in the FL250-290 altitude band, which has no adverse effect on ATC performance.

A large proportion of these undesirable RAs are caused by 1000 ft level-off manoeuvre, which is an already known TCAS II issue below FL290 (cf. paragraph 5.3.4 for the description and paragraph 3.2 for the improvements provided by TCAS II version 7.0).

The characteristics of the RAs triggered by TCAS II version 7.0 in RVSM airspace are close to those triggered between FL250 and FL290 in terms of duration (about 22 s), percentage of positive RAs (i.e., “Climb” or “Descend”) or deviations.

The study has also highlighted that some repetitive RAs may be expected with TCAS II version 7.0.

4.4. Ratio between TAs and RAs

The ratio between TAs and RAs for TCAS II version 7.0 is not greatly modified by the implementation of RVSM. The number of TAs not followed by an RA is still significant.

This result underlines the fact that no action (i.e. request of traffic information or manoeuvre) should be initiated by pilots in the event of a TA.

With TCAS II version 6.04a, the ratio is expected to be about 4 times greater than with TCAS II version 7.0 because of the very high frequency of TA triggering. The consequence is that TAs would not fulfil their role to prepare the crew for a possible RA because of the very large number of TAs without any RA.

4.5. Concluding remarks

TCAS II version 7.0 is compatible with RVSM. However, the number of TCAS II advisories above FL290 is expected to increase with the implementation of RVSM. Nevertheless, the expected advisory rate in the RVSM airspace is lower than the rate currently observed between FL250 and FL290.

TCAS II version 6.04a is not compatible with RVSM for operational reasons, mainly a very high rate of TA triggering.

However, a mixed equipage with a low percentage of TCAS II version 6.04a (i.e. 10%) among a fleet mainly equipped with TCAS II version 7.0 is not expected to have a significant implication for controllers in comparison with a full TCAS II version 7.0 scenario. Nevertheless, the high rate of advisories triggered by TCAS II version 6.04a will be an operational issue for the pilots of these aircraft.

No TCAS II safety issues related to the implementation of RVSM have been identified. The preliminary safety studies have concluded that TCAS II version 7.0 provides safety benefits in an RVSM environment. Despite operational compatibility issues, TCAS II version 6.04a also provides safety benefits.

5. Common encounters in the RVSM environment in Europe

5.1. Introduction

The most common encounter involves two level aircraft separated by 1000 ft. TCAS II version 7.0 is compatible with such configurations whereas TCAS II version 6.04a triggers TAs.

In addition some potential critical configurations between TCAS II and RVSM have been identified. Advisories are expected to be mainly triggered by two of them:

- imperfect altitude keeping, which includes vertical offset, oscillation and turbulence;
- 1000 ft level-off encounters.

In addition, there is the specific case of encounters involving aircraft with a low closure rate. They do not by themselves trigger any advisory but they are likely to make the advisories caused by the critical configurations last much longer (i.e. several minutes).

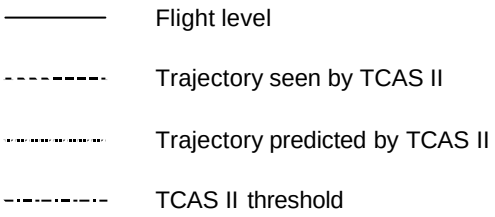
All these configurations are described separately hereafter. However, it should be noted that several of them can occur simultaneously in a specific encounter (e.g. an aircraft levelling off below an oscillating aircraft), thus increasing the probability of an advisory triggering.

In the description of the critical configurations, it is assumed that:

- the aircraft are equipped with TCAS II version 7.0 (a specific paragraph deals with TCAS II version 6.04a in each description);
- the aircraft are RVSM approved[1];

the aircraft are converging or are close in range.

The conventions used in the figures to describe the configurations are as follows:



[1] "automatic altitude control system is required capable of controlling altitude within ±20 m (±65 ft) about the selected altitude, when the aircraft is operated in straight and level flight under non-turbulent non-gust conditions" [TGL6].

5.2. Standard RVSM vertical separation

Description

These encounters involve level aircraft at adjacent flight levels separated by 1000 ft. Figure 6 illustrates this standard type of encounter for TCAS II version 7.0.

Explanation for TCAS II version 7.0

In case of level aircraft, the altitude test is performed by the comparison of the relative altitude between the aircraft with an altitude threshold. If the relative altitude is lower than this threshold, the altitude test is satisfied and an advisory is triggered.

The altitude threshold values for TCAS II version 7.0 are 850 ft for TAs and 700 ft for RAs. It means that when both aircraft are level at adjacent flight levels, the altitude test is not satisfied and therefore neither a TA nor an RA will be triggered.

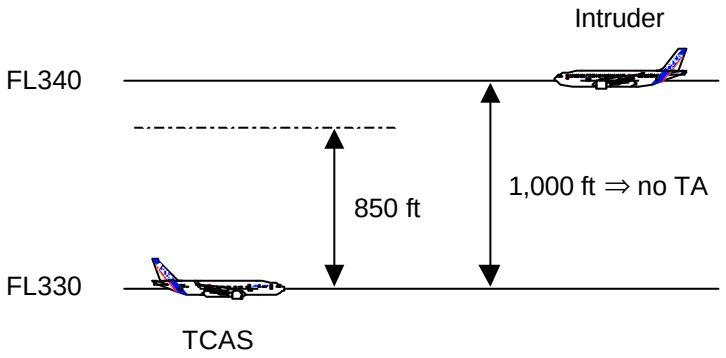


Figure 6: standard RVSM vertical separation

Difference with CVSM airspace

TCAS II version 7.0 behaves identically in CVSM and RVSM (i.e. no advisory between aircraft separated by the standard vertical separation) because its thresholds are compatible with a 1000 ft vertical separation between FL290 and FL410.

Specific case of TCAS II version 6.04a

TCAS II version 6.04a has larger threshold values for altitudes corresponding to RVSM: 1200 ft for TAs and 800 ft for RAs.

As a consequence, in RVSM, a TA will be triggered as soon as the range test is satisfied between two aircraft because the relative altitude is lower than the altitude threshold for TAs.

Nevertheless, when two aircraft are level at adjacent flight levels, TCAS II version 6.04a does not trigger any RA. Indeed the altitude test is not satisfied because the altitude threshold for RAs is lower than the standard vertical separation.

In CVSM, the standard vertical separation between flight levels is 2000 ft, which is much larger than the altitude threshold value, thus preventing the triggering of any advisory.

Pilots' and controllers' behaviour

With a full TCAS II version 7.0 equipage, no advisory will be triggered even with the reduced vertical separation. Therefore there will be no implication for controllers and pilots.

Pilots of aircraft fitted with TCAS II version 6.04a should be aware that they are going to experience a large number of TAs in RVSM triggered by aircraft level and separated by 1000 ft. Nevertheless, those pilots should not request for a traffic information and they shall not manoeuvre in response to TAs only.

5.3. Main critical configurations expected

5.3.1. Vertical offset

Description

These encounters involve level aircraft at adjacent flight levels. Each aircraft has a vertical offset towards the flight level of the other aircraft. As a consequence the relative altitude between the aircraft is lower than 1000 ft and TAs can be triggered in some rare cases. Figure 7 illustrates this type of encounter in which both aircraft have offsets.

Explanation for TCAS II version 7.0

When each aircraft has a vertical offset towards the other aircraft, the relative altitude seen by TCAS II can be lower than the altitude threshold for TAs (i.e. 850 ft). Consequently, the altitude test is satisfied and a TA is triggered.

This type of encounter can occur with RVSM approved aircraft, i.e. with a maximum offset value of 65 ft. Indeed, the altitude of the intruder aircraft seen by TCAS II can be slightly different from the real one due to the altitude report quantization, especially with a 100 ft altitude report quantization.

For instance, two 51-ft offsets induce the triggering of a TA with a 100 ft altitude report quantization. A level aircraft at 33949 ft is seen at 33900 ft by the TCAS II of the other aircraft (i.e. a 100 ft offset is seen).

Then if the other aircraft has also an offset of 51 ft (i.e. the aircraft flies at 33051 ft), the relative altitude seen by TCAS II is 849 ft (i.e. a 151 ft combined offset). As this value is lower than the altitude threshold (850 ft), the altitude test is therefore satisfied and a TA is triggered.

The minimum relative altitude seen by TCAS II will not be lower than 835 ft whereas the altitude threshold for RAs is 700 ft. Therefore no RA can be triggered even with two offsets equal to the maximum value compatible with RVSM approval (i.e. 65 ft) and with a 100 ft altitude report quantization.

If only one aircraft has a vertical offset, no advisory is triggered because even with a 100 ft altitude report quantization, the relative altitude seen by TCAS II will not be lower than 900 ft. Therefore the altitude test will not be satisfied.

With a 25 ft altitude report quantization, which is the most frequent case, no TA can be triggered even with two offsets equal to the maximum value compatible with RVSM approval (i.e. 65 ft). Indeed, for instance an aircraft is at 33065 ft and the other aircraft is at 33935 ft. With the 25 ft altitude report quantization, the altitude seen by the TCAS II of the lower aircraft is 33925 ft. Therefore the minimum relative altitude seen by TCAS II is 860 ft. The altitude test is not satisfied.

As a conclusion, TAs triggered between level aircraft at adjacent flight levels with vertical offsets are rare events. They can occur when the intruder reports its altitude with a 100 ft altitude report quantization (a small proportion of the fleet) and when both aircraft have at least a 51-ft vertical offset.

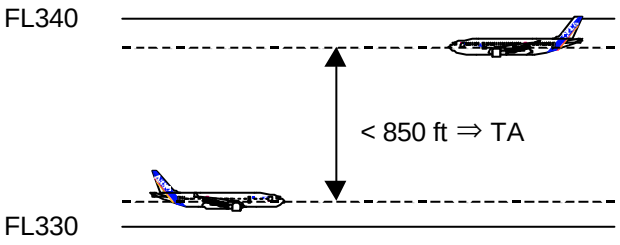


Figure 7: vertical offset

Difference with CVSM airspace

In CVSM airspace, neither TAs nor RAs can be triggered: the difference between the 2000 ft vertical separation applied in this airspace and the altitude threshold (i.e. 850 ft for TAs) is too large to be influenced by vertical offsets of both aircraft, even if they are at the maximum of the approved values.

Specific case of TCAS II version 6.04a

TCAS II version 6.04a triggers TAs between level aircraft at adjacent flight levels separated by 1000 ft. Therefore it also generates TAs for aircraft with vertical offsets.

With a 100 ft altitude report quantization, the minimum relative altitude seen by TCAS II cannot be lower than 835 ft whereas the altitude threshold for RAs is 800 ft. Therefore TCAS II version 6.04a does not trigger any RA between RVSM approved aircraft flying with vertical offsets.

Pilots' and controllers' behaviour

In case of TAs, whether in an RVSM airspace or not, pilots should not request for a traffic information and they shall not manoeuvre in response to TAs only. The main objective of the TA is to prepare the crew to a possible RA.

TAs are not to be notified by pilots to controllers (there is no standardised phraseology to report TAs). Therefore controllers have no specific procedure to apply.

5.3.2. Oscillation

Description

These encounters involve level aircraft at adjacent flight levels. They have oscillations in the altitude keeping. As a consequence the relative altitude between the aircraft can be lower than 1000 ft and TAs can be triggered in some rare cases. Figure 8 illustrates this type of encounter in which both aircraft are oscillating respectively around FL330 and FL340.

Explanation for TCAS II version 7.0

When both aircraft oscillate around their cleared flight level, the relative altitude seen by TCAS II can be lower than the altitude threshold for TAs (i.e. 850 ft). Consequently, the altitude test is satisfied and a TA is triggered.

This type of encounter can occur with RVSM approved aircraft, i.e. with a maximum oscillation amplitude of 65 ft. Indeed, the altitude of the intruder aircraft seen by TCAS II can be slightly different from the real one due to the altitude report quantization, especially with a 100 ft altitude report quantization.

For instance, two aircraft oscillating with a 60-ft amplitude around their cleared flight level can induce the triggering of a TA with a 100 ft altitude report quantization. Indeed, an aircraft oscillating around 34000 ft can be seen at 33900 ft by the TCAS II of the other aircraft when its altitude gets lower than 33950 ft. Then if at the same time the altitude of the other aircraft is greater than 33050 ft, the relative altitude seen by its TCAS II is lower than the altitude threshold (850 ft). Therefore the altitude test is satisfied and a TA is triggered.

The minimum relative altitude seen by TCAS II will not be lower than 835 ft whereas the altitude threshold for RAs is 700 ft. Therefore no RA can be triggered even with two simultaneous opposite oscillations equal to the maximum value compatible with RVSM approval (i.e. 65 ft) and with a 100 ft altitude report quantization.

If only one aircraft is oscillating, no advisory is triggered because even with a 100 ft altitude report quantization, the relative altitude seen by TCAS II will not be lower than 900 ft. Therefore the altitude test will not be satisfied.

With a 25 ft altitude report quantization, which is the most frequent case, no TA can be triggered even for two aircraft oscillating with the maximum value compatible with RVSM approval (i.e. 65 ft). Indeed, an aircraft can reach 33065 ft and the other aircraft 33935 ft. With the 25 ft altitude report quantization, the altitude seen by the TCAS II of the lower aircraft is 33925 ft. Therefore the minimum relative altitude seen by TCAS II is 860 ft. The altitude test is not satisfied.

As a conclusion, TAs triggered between oscillating aircraft on adjacent flight levels are rare events. They can occur when the intruder reports its altitude with a 100 ft altitude report quantization (a small proportion of the fleet) and when both aircraft have at least 51-ft simultaneous opposite oscillations.

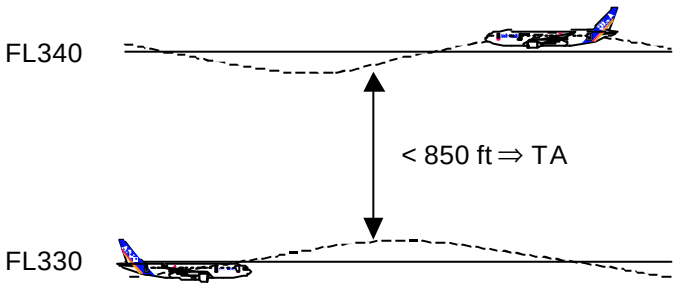


Figure 8: oscillation

Difference with CVSM airspace

In CVSM airspace, neither TAs nor RAs can be triggered: the difference between the 2000 ft vertical separation applied in this airspace and the altitude threshold (i.e. 850 ft for TAs) is too large to be influenced by oscillations of both aircraft, even if the amplitudes are at the maximum of the approved values.

Specific case of TCAS II version 6.04a

TCAS II version 6.04a triggers TAs between level aircraft at adjacent flight levels separated by 1000 ft. Therefore it also generates TAs for oscillating aircraft.

With a 100 ft altitude report quantization, the minimum relative altitude seen by TCAS II cannot be lower than 835 ft whereas the altitude threshold for RAs is 800 ft. Therefore TCAS II version 6.04a does not trigger any RA between RVSM approved aircraft oscillating around their cleared flight level.

Pilots' and controllers' behaviour

In case of TAs, whether in an RVSM airspace or not, pilots should not request for a traffic information and they shall not manoeuvre in response to TAs only. The main objective of the TA is to prepare the crew to a possible RA.

TAs are not to be notified by pilots to controllers (there is no standardised phraseology to report TAs). Therefore controllers have no specific procedure to apply.

5.3.3. Turbulence

Description

These encounters involve an aircraft experiencing an atmospheric or a vortex turbulence that makes it deviate very suddenly with a high instantaneous vertical speed and an important acceleration towards another aircraft on an adjacent flight level. As a consequence there is a high vertical convergence and pop-up RAs can be triggered on-board both aircraft. Figure 9 illustrates this type of encounter in which the lower aircraft experiences a turbulence that makes it suddenly climb towards the other aircraft.

Explanation for TCAS II version 7.0

TCAS II is provided every second with the altitude of the own aircraft, from which it computes a vertical speed. If the aircraft experiences severe turbulence that makes it deviate very suddenly towards another aircraft, the altitude varies with an important acceleration. Therefore, TCAS II computes a high vertical speed. Therefore when it performs the altitude test with this high vertical speed, the time to reach co-altitude is lower than the time threshold. The altitude test is thus satisfied and an advisory is triggered.

Depending on the acceleration during the altitude variation, the time to co-altitude can become suddenly lower than the time thresholds for both TAs and RAs. In this case, a pop-up RA (i.e. no preliminary TA) is triggered. If it is only lower than the time threshold for TAs, then a TA is triggered.

The behaviour of the level aircraft TCAS II is similar. It receives the altitude of the intruder every second. When it detects the sudden altitude variation, it computes a high vertical speed for this intruder. Due to this high vertical convergence, the altitude test can be then satisfied and an advisory is triggered. Depending on the severity of the turbulence, either a TA or a pop-up RA can be triggered.

For instance, a level aircraft at FL330 is experiencing severe turbulence. Suddenly, its altitude varies so as its TCAS II computes a rate of climb of 2,200 fpm. If there is another aircraft at FL340, the time to reach this altitude with the computed vertical speed is 27 s. This value is lower than the time threshold for TAs (i.e. 48 s) and for RAs (i.e. 35 s). Therefore a pop-up RA (either an "Adjust Vertical Speed" or a "Descend") is triggered. Supposing that the other aircraft has a perfectly symmetrical view (this is an approximation because of the altitude report quantization), the time to co-altitude is also lower than the time threshold for TAs (i.e. 48 s). However it is greater than the one for RAs (i.e. 25 s) because of the reduced time threshold for level aircraft(cf. paragraph 3.1.2). Therefore only a TA is triggered for the level aircraft.

As a conclusion, TAs or pop-up RAs can be triggered between aircraft on adjacent flight levels because of turbulence. Nevertheless these are rare events. They are more likely to occur during slow overtakes like in the NAT airspace than during crossings.

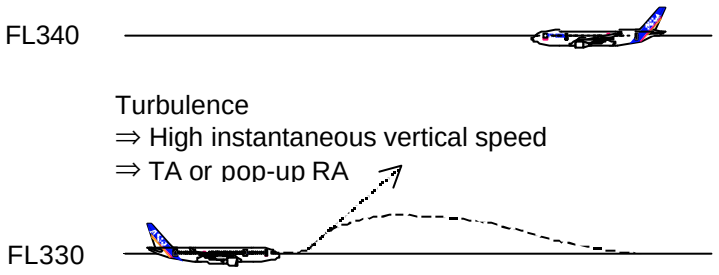


Figure 9: turbulence

Difference with CVSM airspace

In CVSM airspace, the 2000 ft vertical separation prevents most of the advisories to be triggered because of turbulence except in case of very fast and long altitude variation. The computed vertical speed has to be twice greater than in RVSM (i.e. around 4000 fpm) to induce an RA.

Specific case of TCAS II version 6.04a

TCAS II version 6.04a triggers TAs between aircraft level at adjacent flight levels separated by 1000 ft. Therefore it also generates TAs for aircraft experiencing turbulence

The time threshold for level aircraft being greater (i.e. 30 s), TCAS II version 6.04a generates a few more pop-up RAs than version 7.0.

Pilots' and controllers' behaviour

When an RA is triggered, including pop-up RAs, pilots shall comply with their airline operational instructions, which usually recommend to follow all RAs.

To take a lateral offset because of TCAS II advisory (e.g. a pop-up RA) is not an approved procedure.

In case of TAs, whether in an RVSM airspace or not, pilots should not request for a traffic information and they shall not manoeuvre in response to TAs only. The main objective of the TA is to prepare the crew to a possible RA.

When a pilot reports a manoeuvre induced by an RA, the controller shall not attempt to modify the aircraft flight path but shall provide traffic information as appropriate

5.3.4. 1000 ft level-off

Description

These encounters involve at least one aircraft levelling off at 1000 ft from another aircraft. If the vertical rate of the manoeuvring aircraft is high when close to the cleared flight level, TCAS II computes that both aircraft will soon be at co-altitude. Therefore it triggers an advisory, either a TA or an RA. Figure 10 illustrates this type of encounter in which a descending aircraft is levelling off 1000 ft above a level aircraft.

Explanation for TCAS II version 7.0

During level-off encounters, the altitude test is based on the computation of the time to reach co-altitude (i.e. 48 s for TAs, 35 s for RAs for manoeuvring aircraft and 25 s for RAs for level aircraft).

TCAS II is an independent system that does not have knowledge of the positive intent of either the own or the intruder aircraft. It assumes that the current flight profiles will be maintained. As modern aircraft have high vertical rates even when close to the cleared flight level, TCAS II detects a high vertical closure rate configuration and predicts that both aircraft will be at co-altitude in a short term. Therefore it generates either a TA or an RA depending on the predicted time value.

Figure 10 depicts an example where an aircraft with a 2,400 fpm rate of descent is levelling off 1000 ft above a level aircraft.

The time threshold for TAs for both aircraft is 48 s, which represents 1,920 ft with a 2,400 fpm relative vertical speed. Therefore a TA is triggered for both aircraft when the descending aircraft passes through FL349.

The time threshold for RAs is 35 s for the descending aircraft, which represents 1,400 ft with a 2,400 fpm relative vertical speed. Therefore an RA is triggered when the descending aircraft is at 400 ft from the clearance (i.e. FL344).

The time threshold for RAs is 25 s for the level aircraft, which represents 1000 ft with a 2,400 fpm-relative vertical speed. Therefore no RA is triggered for the level aircraft if the descending aircraft levels off correctly.

TCAS II version 7.0 has been designed to avoid as far as possible to trigger RAs that requires a vertical trajectory change (e.g. "Climb RA" for a descending aircraft). It triggers RAs compatible with the clearance, which require a vertical rate reduction (i.e. "Adjust Vertical Speed").

As a conclusion, RAs can be triggered during 1000 ft level-off encounters in case of high vertical rate. These RAs could be considered undesirable by controllers and pilots. Nevertheless, if the manoeuvring aircraft does not level off as required, the triggered RAs would become necessary.

Furthermore, a reduction in the vertical rate of the manoeuvring aircraft (e.g. 1000 fpm by 1000 ft from the clearance) should prevent RAs and minimise the number of TAs because the altitude test is not satisfied.

Note: If both aircraft are manoeuvring to level off 1000 ft apart, the relative vertical speed is greater. Therefore it is more likely that RAs are triggered.

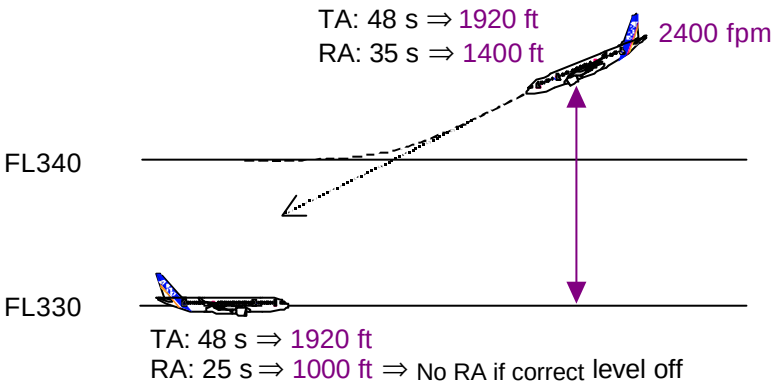


Figure 10: 1000 ft level-off

Difference with CVSM airspace

In CVSM airspace, the 2000 ft vertical separation prevents most of the RAs to be triggered because of a level-off manoeuvre to an adjacent flight level. RAs could be triggered for aircraft with a very high vertical rate (about 4,000 fpm), which is usually achievable only in descent at these altitudes.

For the same reason, the number of TAs triggered in this configuration is also lower in CVSM airspace.

Specific case of TCAS II version 6.04a

TCAS II version 6.04a is expected to trigger a larger number of RAs than TCAS II version 7.0 as many improvements have been implemented in the latest version: the reduced time threshold for the level aircraft, a 25 ft vertical tracker, the MDF.

In the example depicted in the figure 10, the level aircraft should also receive an RA if it is equipped with TCAS II version 6.04a: 30 s represents 1,200 ft with a 2,400 fpm relative vertical speed.

In addition, the triggered RAs might more often request the aircraft to change its vertical trajectory (e.g. “Climb” instead of “Adjust Vertical Speed”).

Pilots’ and controllers’ behaviour

To minimise the number of TAs and RAs triggered during 1000 ft level-off encounters,it is recommended that:

- when an aircraft is climbing or descending,
- when reaching an altitude 1000 ft below or above the cleared flight level,
- when the crew is aware of a traffic in the close vicinity at an altitude adjacent to the cleared flight level,
- where possible and appropriate,

pilots should climb or descend at a rate less than 1000 fpm until reaching the cleared flight level.

With this reduction in vertical rate before level-off, no advisory would be triggered by 1000 ft level-off encounters with one manoeuvring aircraft and only TAs could be triggered if both aircraft are manoeuvring.

As an example, the reduction in vertical rate could result from a traffic information provided by the controller.

When an RA is triggered, pilots shall comply with their airline operational instructions, which usually recommend to follow all RAs, whether a traffic information has been provided or not and whether the intruder is visually acquired or not.

When a pilot reports a manoeuvre induced by an RA, the controller shall not attempt to modify the aircraft flight path but shall provide traffic information as appropriate.

5.3.5. Specific case of low closure rates

Description

These encounters involve level aircraft at adjacent flight levels and following the same route with close ground speeds. The trailing aircraft is overtaking the leading aircraft with a low closure rate. This type of encounter by itself does not trigger any advisory, but it will likely get the advisories caused by the critical configurations (i.e. vertical offsets, oscillations, turbulence and 1000 ft level-off) to last much longer. Figure 11 illustrates this type of encounter in which both aircraft have offsets and one aircraft is overtaking the other aircraft with a 30 kts closure rate.

Explanation for TCAS II version 7.0

The low closure rate does not induce any advisory triggering. Therefore the advisory needs to be triggered by one of the critical configurations (i.e. vertical offsets, oscillations, turbulence and 1000 ft level-off). Figure 11 depicts an example where the TA is triggered because of two vertical offsets (cf. paragraph 5.3.1).

Generally, when the range test is satisfied based on the time-to-go to the CPA, the advisory lasts about the time threshold value (i.e. 48 s for TAs)

In the case of low closure rate encounters, the range test is satisfied based on the protection distance (i.e. 1.3 NM for TAs) because the time-to-go is very high even with a low range. The advisory will last about the time that the aircraft remains within the protection distance. As both aircraft have close ground speeds, the aircraft can remain several minutes within the protection distance. Therefore the advisory can last several minutes.

In order to reduce the advisory duration, a specific algorithm is implemented to terminate the advisory when the aircraft are diverging and even if the aircraft are still slightly within the protection distance. Consequently, the range at the termination is lower than the protection distance (i.e. about 1 NM for TAs). However, this algorithm may in rare cases induce the triggering of secondary short-duration advisories.

In the example depicted in figure 11, both aircraft have close ground speeds (i.e. 450 and 480 kts). A TA is triggered when the fastest aircraft is 1.3 NM behind the slowest one. It ends when the aircraft are diverging and the range is slightly lower than 1.3 NM. With a 30 kts relative ground speed, the TA should last about 5 minutes.

RAs triggered during a low closure rate can also last several minutes. If the pilots react properly to the "Climb" or "Descend" RAs, TCAS II version 7.0 will quickly weaken these RAs into "Adjust vertical speed" RAs (i.e. the pilots have to level off) so as to limit the vertical deviation.

As a conclusion, long duration TAs or RAs can be triggered during low closure rate encounters if they correspond to one of the critical configurations (i.e. vertical offsets, oscillations, turbulence and 1000 ft level-off). Nevertheless, these are expected to be rare events because they are a small subset of the advisories triggered in RVSM. Indeed, compared with the NAT airspace the route structure in Europe seldom provides such encounters.

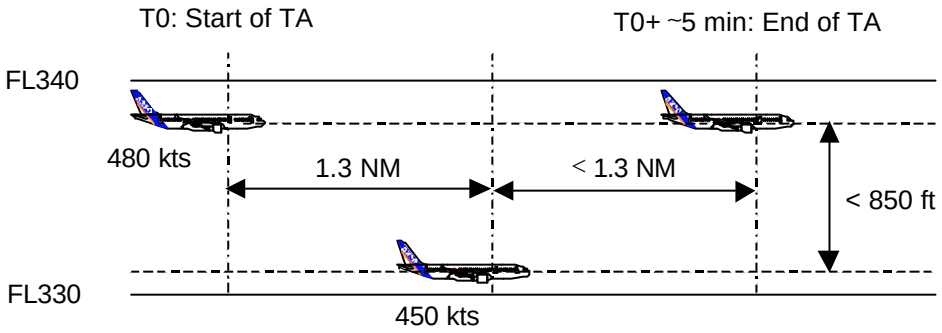


Figure 11: low closure rate and vertical offsets

Difference with CVSM airspace

In CVSM airspace, TAs and RAs are much less frequent because of the 2000 ft vertical separation applied in this airspace. Therefore the implication of low closure rate encounters is even less noticeable than in RVSM.

Specific case of TCAS II version 6.04a

The implication of low closure rate encounters is greater with TCAS II version 6.04a because it triggers much more TAs, in particular between aircraft level at adjacent flight levels separated by 1000 ft.

In addition, if TCAS II version 6.04a triggers a “Descend” or a “Climb” RA during a low closure rate encounter, it cannot weaken this RA, thus leading to larger vertical deviations than with TCAS II version 7.0.

Pilots’ and controllers’ behaviour

When an RA is triggered, pilots shall comply with their airlne operational instructions, which usually recommend to follow all RAs.

In case of TAs, whether in an RVSM airspace or not, pilots should not request for a traffic information and they shall not manoeuvre in response to TAs only. The main objective of the TA is to prepare the crew to a possible RA.

To take a lateral offset to stop a long duration TCAS II advisory (TA or RA) is not an approved procedure.

When a pilot reports a manoeuvre induced by an RA, the controller shall not attempt to modify the aircraft flight path but shall provide traffic information as appropriate.

6. Operational implication

6.1. Controllers

6.1.1. Number of TCAS II advisories

With a full TCAS II version 7.0 equipage, no advisory will be triggered between level aircraft at adjacent flight levels separated by 1000 ft as it is the case in an RVSM airspace.

Nevertheless, the number of TAs and RAs above FL290 is expected to increase with the implementation of RVSM. For RVSM approved aircraft, some TAs could result from imperfect altitude keeping. In addition, some TAs and RAs could be triggered during 1000 ft level-off encounters and because of turbulence.

However, this increase of the number of TAs and RAs above FL290 should not adversely affect the RVSM operations as the expected advisory rate in the RVSM airspace should be lower than the rate currently observed between FL250 and FL290. This statement is particularly true if the operational procedures related to TAs and RAs are properly applied by the crews.

Actually with the implementation of RVSM, the airspace becomes homogeneous up to FL420 because the same vertical separation is applied. Therefore TCAS II is also behaving homogeneously below FL420 whereas it had particular performance in CVSM because of the 2000 ft vertical separation.

6.1.2. Triggering of TAs

The expected increased number of TAs in RVSM should not have any implication for controllers because TAs are not to be notified by pilots to controllers. For this reason, there is no standardised phraseology to report TAs and controllers have no specific procedure to apply.

Nevertheless, some pilots tend to request for traffic information when a TA is triggered. As the number of TAs above FL290 is expected to increase with the implementation of RVSM, the number of traffic information requested by pilots is also expected to increase. This issue is especially relevant for aircraft equipped with TCAS II version 6.04a because this version triggers a much larger number of TAs than TCAS II version 7.0.

6.1.3. Triggering of RAs

As the number of RAs above FL290 is expected to increase slightly with the implementation of RVSM, the number of pilots' responses to RAs is also expected to increase. However, these responses do not mean that the aircraft will deviate from their clearances. Indeed, TCAS II version 7.0 triggers RAs that avoid as far as possible a vertical trajectory change and thus that are compatible with the clearance. In addition, it should be noted that the number of RAs triggered above FL290 is expected to be lower than in the FL250-FL290 altitude band.

As almost all aircraft should be equipped with TCAS II in the RVSM airspace, the triggered RAs are co-ordinated. Therefore for the RAs requiring to deviate from the clearance, the eventual deviation of each aircraft will be limited when both pilots follow properly the RAs. The interoperability between TCAS II version 7.0 and TCAS II version 6.04a in a mixed equipage environment is fully effective. The co-ordination for the triggering of RAs between TCAS II units, whatever the version, is defined in the ICAO ACAS II SARPs.

If a pilot overreacts to an RA, any excessive deviation resulting from the response could be more disruptive than in CVSM because of the reduced vertical separation between flight levels. Nevertheless, induced encounters with a third aircraft are expected to be unlikely, like currently in lower altitudes. If an encounter involving three aircraft happens to occur, TCAS II includes a multiple threat encounter logic, which provides RAs for several simultaneous threats.

"When a pilot reports a manoeuvre induced by an ACAS resolution advisory, the controller shall not attempt to modify the aircraft flight path until the pilot reports returning to the terms of the current air traffic control instruction or clearance but shall provide traffic information as appropriate." [PANS-RAC] Nevertheless, when providing traffic information, controllers shall keep in mind that because of the update rate of their radar display, their perception of the vertical situation of the encounter is less accurate than the TCAS II perception.

While an aircraft is deviating from the clearance in response to an RA, the controller is not responsible for the provision of separation to this aircraft.

During configurations that can result in the triggering of an RA (e.g. 1000 ft level-off encounters), controllers can provide traffic information if practical. It shall not prevent pilots to follow an RA if it is triggered. Nevertheless, in the case of 1000 ft level-off, pilots could reduce the vertical rate when approaching the cleared flight level (i.e. 1000 fpm by 1000 ft from the clearance) in order to prevent the possible triggering of an RA.

6.2. Pilots

6.2.1. Number of TCAS II advisories

In an RVSM airspace, TCAS II version 7.0 equipage does not trigger any advisory between level aircraft at adjacent flight levels separated by 1000 ft.

Nevertheless, the number of TAs and RAs above FL290 is expected to increase slightly with the implementation of RVSM. For RVSM approved aircraft, some RAs could be triggered during 1000 ft level-off encounters and because of turbulence. In addition, some TAs could result from imperfect altitude keeping. A preliminary study has identified that 47 TAs and 3 RAs per 1000 flight hours can be expected with TCAS II version 7.0. These ratios are lower than those for the FL250-FL290 altitude band.

However, pilots of aircraft fitted with TCAS II version 6.04a should be aware that they are going to experience a high number of TAs mainly triggered by aircraft level and separated by 1000 ft (about 1 TA per flight hour). In addition, the expected number of RAs is twice greater than with TCAS II version 7.0. Nevertheless, it is important that pilots follow all the RAs triggered by TCAS II version 6.04a even if the number is greater than with TCAS II version 7.0.

Pilots should be aware of the TCAS II version they use and they should be trained according to this version. Thus pilots will know what to expect from their TCAS II in an RVSM airspace.

6.2.2. Expected behaviour

The implementation of RVSM shall not modify the pilots' behaviour that is expected currently in non-RVSM airspace when a TA or an RA is triggered. This behaviour is the same whatever the TCAS II version and the airspace.

When a TA is triggered, pilots should not request for a traffic information. In addition they shall not manoeuvre their aircraft in response to TAs only [PANS-OPS]. This statement is valid in any airspace, i.e. in an RVSM environment too.

The main objective of the TA is to prepare the crew to a possible RA. The responsibilities are divided between the pilot flying and pilot not flying as follows [TGL11]:

- pilot flying should continue to fly the aeroplane and be prepared to respond to any RA that might follow;
- pilot not flying should provide updates on the traffic location shown on the TCAS II display, using this information to help visually acquire the intruder.

When an RA is triggered, pilots shall comply with their airline operational instructions, which usually recommend to follow all RAs, whether a traffic information has been provided or not and whether the intruder is visually acquired or not. In the case of pop-up RAs, pilots have to deal with the lack of preliminary TAs before RAs.

During the RA, the responsibilities are divided between the pilot flying and pilot not flying as follows [TGL11]:

- pilot flying should be responding to the RA with positive control inputs, when required;
- the pilot not flying is providing updates on the traffic location, checking the traffic display and monitoring the response to the RA.

Pilots shall never manoeuvre in the opposite sense to the RA. If the intruder is also equipped with TCAS II (i.e. the standard case in the European RVSM airspace), a manoeuvre in the opposite sense is hazardous because both RAs are co-ordinated in order to select complementary resolution senses.

Pilots shall inform controllers about manoeuvres in response to RAs as soon as time and workload permit using the standard phraseology.

The alteration of the flight path shall be limited to the minimum extent necessary to comply with the RAs [PANS-OPS].

Pilots who deviate from an air traffic control clearance in response to an RA shall promptly return to the terms of the previous air traffic control instruction or clearance when the conflict is resolved and they shall notify the appropriate ATC unit as soon as possible [PANS-OPS]. As the controller is not responsible for the provision of separation to an aircraft, which is deviating from the clearance in response to an RA, it is important that pilots return to the previous clearance when the RA is terminated.

To take a lateral offset to stop a long duration TCAS II advisory (TA or RA) is not an approved procedure.

6.2.3. Recommendation for 1000 ft level-off encounters

To minimise the number of TAs and RAs triggered during 1000 ft level-off encounters, it is recommended that:

- when an aircraft is climbing or descending,
- when reaching an altitude 1000 ft below or above the cleared flight level,
- when the crew is aware of a traffic in the close vicinity at an altitude adjacent to the cleared flight level,
- where possible and appropriate,

pilots should climb or descend at a rate less than 1000 fpm until reaching the cleared flight level.

With this reduction in vertical rate before level-off, no advisory would be triggered by 1000 ft level-off encounters with one manoeuvring aircraft and only TAs could be triggered if both aircraft are manoeuvring.

As an example, the reduction in vertical rate could result from a traffic information provided by the controller.

7. Conclusion

TCAS II is a last resort safety net designed to prevent mid-air collisions between aircraft. The technical features of the system provide a significant improvement in flight safety, which is valid in an RVSM airspace as in any other airspace. However, pilots and controllers must be aware that TCAS II is not a perfect system. TCAS II cannot exclude all collision risks and the system may, marginally, induce an additional risk. Consequently, it is essential that ATC procedures are designed to provide flight safety without any reliance upon the use of TCAS II.

TCAS II version 7.0 is compatible with the RVSM environment, even if it is expected that the implementation of RVSM will lead to a slight increase of the number of advisories above FL290 in comparison with CVSM operations. Nevertheless, the expected advisory rate in the RVSM airspace is lower than the rate currently observed between FL250 and FL290.

TCAS II version 6.04a is not compatible with RVSM for operational reasons, mainly a very high rate of TA triggering. Nevertheless, a mixed equipage with a low percentage of TCAS II version 6.04a is not expected to have a significant implication for controllers.

The implementation of RVSM shall not modify the behaviour pilots and controllers that is expected in non-RVSM airspace when, a TA or an RA is triggered. To get the full safety benefit brought by TCAS II, pilots shall comply with their airline operational instructions, which usually recommend to follow all RAs. In addition, they shall never manoeuvre in the opposite sense to the RA because of the co-ordination with the TCAS II unit of the other aircraft.

The increased precision of the horizontal navigation combined with the increased precision of the vertical navigation may lead, in case of mistakes and whatever the airspace, to a higher risk of collision. **Therefore TCAS II is all the more efficient as the last resort safety net**.

8. References

[ACAS]: "ACAS brochure" – ACASA/WP6.1/015 – Version 2.0 – May 2000

[ACASA]: "Final report on ACAS/RVSM interaction" – ACASA/WP-3.6/185D – version 1.0, released issue – Christian Aveneau and Béatrice Bonnemaison

[NAT]: "RVSM and Use of TCAS" – SICASP/WG2/IP2/522 – Frankfurt, October 1995 – Francis Casaux and Eric Vallauri

[PANS-OPS]: Procedure for Air Navigation Services – Aircraft Operations – PANS-OPS Doc. 8168

[PANS-RAC]: Procedure for Air Navigation Services – Rules of the Air and Air Traffic Services – PANS-RAC Doc. 4444

[RVSM]: "Guidance Material for Adaptation of the Airspace for EUR RVSM Implementation" – Document ref.: RVSM/A730 – 12/10/2000 – European Reduced Vertical Separation Minimum Programme – Eurocontrol

[TCAS7]: " Preview of TCAS II version 7.0" – Air Traffic Control Quarterly, vol. 6(4) 231-247 (1998) – 1998 – W. Dwight Love

[TGL6]: "Guidance material on the approval of aircraft and operators for flight in airspace above flight level 290 where a 300 m (1000 ft) vertical separation minimum is applied" – JAA – 01/07/98

[TGL11]: "Guidance for operators on training programmes for the use of Airborne Collision Avoidance Systems (ACAS)" – JAA – 01/06/98

9. Acronyms

ACAS	Airborne Collision Avoidance System
ACASA	Airborne Collision Avoidance System Analysis
ATC	Air Traffic Control
CPA	Closest Point of Approach
CVSM	Conventional Vertical Separation Minimum
ECAC	European Civil Aviation Conference
EUR	Europe
FAA	Federal Aviation Administration
FL	Flight Level
fpm	feet per minute
ft	feet
ICAO	International Civil Aviation Organisation
kts	knots
MDF	Miss Distance Filtering
NAT	North Atlantic
NM	Nautical Mile
RA	Resolution Advisory
RTCA	Radio Technical Commission for Aeronautics
RVSM	Reduced Vertical Separation Minimum
SARPs	Standard And Recommended Practices
TA	Traffic Advisory
TCAS	Traffic alert and Collision Avoidance System

10. Bibliography

Annex 2 of ICAO - Rules of the Air

Annex 6 of ICAO - Parts I, II and III

Annex 10 of ICAO - Aeronautical Telecommunications - Volume IV - "Surveillance Radar and Collision Avoidance Systems"

Doc. 4444 of ICAO - PANS-RAC - "Procedures for Air Navigation Services - Rules of the Air and Air Traffic Services"

Doc. 8168 of ICAO - PANS-OPS - "Procedures for Air Navigation Services - Aircraft Operations"

Doc. 7030/4, Section 16 of ICAO - Use of Airborne Collision Avoidance Systems (ACAS) - "Approval of a proposal for amendment of the ICAO Regional Supplementary Procedures Doc. 7030 (serial N°. EUR/NAT-S 96/48 - EUR RAC/2) - ACAS Amendment Proposal" - 29 October 1997

RTCA SC-147/DO-185A - Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment.