EUROPEAN ORGANISATION
FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

# Review Of ACAS RA Downlink

## An assessment of the technical feasibility and operational usefulness of providing ACAS RA awareness on CWP


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| **Contact Person(s)** | **Tel** | **Unit** | |
| Stanislaw Drozdowski | +32 2 729 3760 | DIS/ATD | |
| Søren Dissing | +32 2 729 3446 | DIS/ATD | |

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**EATMP Infocentre**
EUROCONTROL Headquarters
96 Rue de la Fusée
B-1130 BRUSSELS

Tel: +32 (0)2 729 51 51
Fax: +32 (0)2 729 99 84
E-mail: eatmp.infocentre@eurocontrol.int

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# CONTENTS

# EXECUTIVE SUMMARY

The aim of this study is to assess the technical feasibility and operational usefulness of providing ACAS RA awareness on CWP.

Firstly, technical means that may provide information from the airborne systems to CWP have been discussed. Several potential technical solutions are presented and evaluated.

Secondly, the current legal and operational situation was analysed and discussed. It showed inadequacies in the existing rules. That is followed by analysis of potential operational benefits and identification of follow-up actions.

In appendixes at the end of the document details of previous significant midair occurrences, brief summary of previous research in field, summary of Airline Operating Manual review and potential CWP Human Machine Interface are presented.

The study has concluded that there is operational merit to deliver ACAS RA information to the controller through RA downlink, removing randomness and ambiguity of verbal reports. Full operational impact and technical feasibility need to be evaluated in simulations and by further detailed research.

# 1. INTRODUCTION

## 1.1 Purpose

Air Traffic Control providers and aircraft operators have joint responsibility to the general public for providing safe flow of air traffic. This principal task is only achieved through close cooperation of all parties involved. This cooperation becomes particularly crucial if, for whatever reason, the separation between two aircraft is about to be lost and urgent steps need to be taken to restore it. Both the crews and controllers are provided with a set of automated tools (safety-nets) to support them in maintaining the separation. Principally, these are Short Term Conflict Alert in ground ATC system and airborne Aircraft Collision Avoidance System. However, no connection exists between these systems.

The lack of this connection and a possible inconsistency of information available to the parties involved are a cause for concern. The issue has been highlighted by the recent midair collision over Überlingen. While the investigation into this accident is still ongoing, the details known so far have revealed the fact the controller involved did not possess the information concerning the ACAS resolution advisories.

Following this, as well as other accident and incidents, the High-Level European Action Group for ATM Safety (AGAS) was created to improve safety management and regulation within Europe. The following high priority specific issues were identified in the area of ACAS:

- possible difference between Resolution Advisory (RA) and ATC instructions;
- downlink of ACAS RA data to the controller.

## 1.2 Objectives

The objectives of the present review are:

- To assess the technical feasibility of downlinking ACAS RA data for display on the Controller Working Position (CWP), i.e.:
  - Identify candidate technologies;
  - Determine the relative merits and drawbacks of each option;
  - Identify one or more roadmaps for implementation.
- Review the operational usefulness of ACAS RA data for the controller, i.e.:

- Identify advantages and disadvantages of presenting ACAS RA data in the context of existing procedures;
- Determine possible changes to the existing procedures to maximise the safety benefits of ACAS.

## 1.3 Methodology

The review is based on:

- Study of existing standards, manuals and other relevant documentation;
- Evaluation of relevant previous research;
- Review of recent mid-air incidents and accidents;
- Technical and operational expertise within EUROCONTROL in the areas of ACAS, Surveillance, Communication and Data Processing;
- Operational expertise within EUROCONTROL in the areas of ATM Procedures, ATC and HMI.

## 1.4 Structure Of This Report

**Chapter 2 – Background** provides an overview of the existing situation regarding the use of ACAS in relation to ATC.

**Chapter 3 – Technical Aspects** provides an overview of the technical feasibility of downlink of ACAS RA data for display on the Controller Working Position (CWP).

**Chapter 4 – Operational Aspects** provides an overview of the operational usefulness of ACAS RA data for the controller.

**Chapter 5 – Conclusions and Recommendation** lists the findings of the review and contains recommendations for follow-up actions.

Several Appendixes are provided which contain additional relevant material.

# 2. BACKGROUND

## 2.1 Role of ATC

The Air Traffic Control service has been established for the purpose of preventing collisions between aircraft and on the manoeuvring area between aircraft and obstructions and expediting and maintaining an orderly flow of air traffic.

Although Air Traffic Control utilises highly automated systems and computerised safety-nets, the human involvement and technology flaws may not always provide the intended safety goal. Therefore, additional steps are constantly sought to improve the existing system.

## 2.2 Role of the Flight Crew

The Pilot In Command, supported by other crew members, has final responsibility for the safety of the aircraft and its passengers and has therefore full authority to *inter alia* initiate manoeuvres to avoid collision with other aircraft.

In case of immediate danger of collision, the flight crew is expected to first initiate avoiding manoeuvres and then, as soon as possible, inform ATC that the aircraft is deviating from its clearance. As soon as the risk of collision is mitigated, the flight crew is expected to resume adherence to the last clearance and report this to ATC.

## 2.3 Role of Safety Nets

AGAS WG4 has adopted the following definition: *a **Safety Net** is an airborne and/or ground-based function, the sole purpose of which is to alert the pilot or controller of the imminence of collision of aircraft, aircraft and terrain/obstacles, as well as airspace penetration*.

Short Term Conflict Alert (STCA) is a ground-based safety net that provides the controller with a warning of the imminence of a separation violation that might lead to a near mid-air collision or mid-air collision. The STCA warning is nominally generated in 90 to 120 seconds in advance. No conflict resolution advice is given.

ACAS (also commonly referred to as TCAS – Traffic Alert and Collision Avoidance System) is an airborne safety net that provides the flight crew with a warning of the imminence of a (near) mid-air collision by producing a Resolution Advisory (RA) in 15 – 35 seconds in advance. The RA is usually, but not always, preceded by a Traffic Advisory (TA) generated up to 50 seconds in advance. The generation of a TA will not necessarily be followed by an RA.

These two safety nets are independent from each other. In effect, the only common denominator is the transponder on board of the aircraft and the altitude data source.

## 2.4 Scenarios

Under certain conditions, the following sequence of events and failures might lead to a (near) mid-air collision:

1. Controller fails to detect that separation infringement is about to occur (>120 seconds).

2. STCA fails to trigger or the controller does not notice or responds incorrectly to the STCA alert (120-35 seconds).

3. ACAS fails to trigger or a flight crew responds inaccurately to RAs (<35 seconds).

A late and/or unexpected manoeuvre of an aircraft may create a risk of collision within seconds. As a consequence, the controller and the safety nets may detect the risk simultaneously or the events may happen in a sequence different from the one described above.

The controller will seek to resolve a conflict by issuing instructions to one or more flight crews until positively advised by a flight crew that they are responding to ACAS RAs. The time between the first RA and the report of the flight crew is undetermined. The ACAS specifications assume a nominal time for pilot response of 5 seconds to the first RA. Factors such as frequency congestion may further influence the reporting delay.

# 3. TECHNICAL ASPECTS

## 3.1 Candidate Technologies

This chapter provides an overview of the candidate technical solutions for downlinking ACAS RA data for display on the CWP. The overview is based on input from technical and operational expertise within EUROCONTROL in the areas of ACAS, Surveillance, Communication, Data Processing, ATM Procedures, ATC and HMI.

For each technical solution a brief description of known developments and plans, followed by merits and drawbacks, is given. The overview takes an operational point-of-view, i.e. the focus is on the time delay from the moment when an RA is generated to the presentation of RA information on the CWP. Although the table in 3.1.5 provides delay figures, these should be considered indicative on a general basis only, as there will be differences depending on local implementation.

### 3.1.1 Mode S Radar

Mode S ground stations installed or under installation in Europe are capable of extracting the ACAS capability of aircraft from the Mode S transponder register. When an RA is generated ACAS passes the information to the Mode S transponder where it is stored in one of the transponder registers, and a bit is set indicating that an RA is present. Further, when the Mode S transponders announce that an RA has been generated, that data can be extracted and forwarded through the appropriate surveillance data chain. This solution is available wherever Mode S radar is implemented.

It should be noted that the above mentioned functionality has been designed for monitoring purposes only, and any operational use should consequently be preceded by in-depth testing to assess its feasability for operational implementation. There will be some variation in the delay times due to antenna rotation, but this is assumed to be less critical in a multi-radar environment.

For the purpose of the review of this technology it is assumed that the aircraft are covered by at least 2 Mode S stations since that would be typical coverage in the European region.

### 3.1.2 ADS-B

For any of the candidate ADS-B implementations (Mode S, VDL4, UAT) it can be assumed that an event-driven message transmission can take place very shortly after the RA data could be made available to the ADS-B system. Although the number of planned ADS-B implementations is limited it is assumed that the on-going activities on ADS-B Package 1 will accelerate implementation and widespread coverage.

A drawback of this solution is the need to develop a dedicated interface between the two systems in order to make the RA data available to the ADS-B system.

### 3.1.3 VHF Data Link (VDL)

Currently, VHF Data Link (VDL) for ATC purposes is being planned through the LINK2000+ Program from 2005 onwards. It would be possible to design a solution for the transmission of RA information via VDL. The large differences between maximum and minimum values for this solution are due to the possible delays incurred by transmission via the ATN. Also, the calculation takes into account the fact that the messages are transmitted through the communications provider network (Arinc, SITA) and consequential delay.

As it is the case for ADS-B, this solution will need an airborne interface to make the RA data available to the VDL system. Another factor is the amount of delay for the transmission of VDL data through the networks of a communications provider. As a result, the summary table below also list figures for an alternative solution that would need the establishment of a dedicated VDL channel for the transmission of RA data.

### 3.1.4 RA Broadcast on 1030 MHz

In order to enable monitoring of ACAS in areas where no Mode S ground infrastructure is planned, the ACAS system provides a broadcast of RAs on 1030 MHz (which is actually the Mode S uplink frequency). Properly equipped facilities on the ground would be able to receive these broadcast messages.

RA broadcast interrogations are transmitted at full power from the ACAS bottom antenna at jittered, nominally 8-second intervals for the period that the RA is active.

Once again, it must be emphasised that the above mentioned functionality was designed for monitoring purposes only, and any operational use should consequently be preceded by in-depth testing. The implementation of this solution will need the establishment of a network of receivers on the ground to ensure sufficient coverage.

### 3.1.5 Comparison

The following table compares the expected delay (in seconds) for each of the technologies under consideration. It should be noted that the following delay values that are common to all solutions have been assumed:

- Ground station processing time 0.3 sec

- Surveillance data chain processing time 1.0 sec (where applicable)
- Display processing time 0.5 sec

For the surveillance data chain update a refresh cycle of 5 seconds has been assumed, this may however vary slightly upwards or downwards depending on the technology chosen for the particular implementation.

These delay values have been estimated using the normal data path in a common surveillance data chain implementation. A possibility may be developed to implement a more direct route, bypassing various processors and sending the RA data directly to the CWP. This would obviously reduce delay figures.

| Technology | When | Equipment requirement | Min | Max | Average |
|---|---|---|---|---|---|
| Mode S | Mode S implementation | Mode S ground infrastructure, Mode S transponder | **2.8** | **10.8** | **6.8** |
| ADS-B | 3 to 5 years | ADS-B ground infrastructure, ADS-B equipment on board, interface between ACAS and ADS-B | **1.8** | **6.8** | **4.3** |
| VDL on dedicated channel | 2 to 4 years | VDL capability, interface between ACAS and on-board VDL | **1.8** | **6.8** | **4.3** |
| VDL via communications provider | 2 to 4 years | VDL infrastructure, interface between ACAS and on-board VDL | **7.8** | **14.8** | **11.8** |
| RA Broadcast | 1 to 3 years | Ground system capable of receiving the broadcasts | **1.8** | **8.8** | **4.8** |

Note: All minimum, maximum and average times are in seconds. Times are indicative based on best technical estimate as no actual full implementation exists.

## 3.2 Possible Roadmap

From an operational perspective, it is obvious that any time delay from the moment when an RA is generated till it is displayed should be minimised. It can be concluded that some of the candidate technical solutions offer levels of delay that are operationally acceptable.

As a proposed roadmap it is suggested that the use of the monitoring facilities of Mode S and RA Broadcast are considered for operational use. This would provide a reasonably quick solution with the particular advantage that no modifications are necessary to ACAS-equipped aircraft. These methods also seem to be relatively low cost approaches.

The main drawback of the Mode S solution is the dependency (at least in part) on the rotation speed of the Mode S antennas, with the resulting variations in the elapsed time of eventual ACAS information delivery.

For a longer-term solution, it would seem that the use of ADS-B (in whatever shape it may take) is the best way forward. This would offer consistent elapsed time of ACAS information delivery and that would increase the level of controller's confidence. The major problem will be the interface between the ACAS and ADS-B systems on-board the aircraft that will require, as mentioned before, possibly extensive modifications and re-certification as well as the cost associated with these procedures. The level of equipage might prove to be a problem as well.

# 4. OPERATIONAL ASPECTS

## 4.1 Present Situation

### 4.1.1 Rules in Effect

The following ICAO rules apply to ACAS:

- Doc. 4444 – “Air Traffic Management (PANS-ATM)”
  - Para. 12.3.1.2 (phraseology)
  - Para. 15.6.3
- Doc. 7030 – “Regional Supplementary Procedures”
  - EUR. Part 1, chapter 20
- Doc. 8168 – “Procedures – Aircraft Operations”
  - Para. 3.1
  - Para. 3.2
- ICAO Annex 2 – “Rules of Air”
  - Para. 3.2.2
- ICAO Annex 6 – “Operation of Aircraft”
  - Para. 6.18
  - Para 6.19
- ICAO Annex 10 – “Aeronautical Telecommunications”
  - Vol. IV – definitions (Resolution Advisory)
  - Para. 3.5.8.10.3
  - Para. 4.3.3.3.1
- ICAO Annex 11 – “Air Traffic Services”
  - Para. 2.25

No European or CIS (Commonwealth of Independent States) states are known to have filed any differences to ICAO ACAS related regulations. This implies that rules are uniform in the European Region.

In Europe the Joint Aviation Authorities (JAA) allow aeroplanes operated for the purpose of commercial air transportation only in accordance with the current contents of their Minimum Equipment List (MEL). Under this provision, air carriers are allowed to operate up to 10 consecutive days without serviceable ACAS II equipment.

Airline Operating Manuals (AOM) provide detailed instructions for pilots how they should act when ACAS advisories are issued and how ACAS should be operated. In principle, the AOM shall be harmonious with ICAO rules. Each carrier is responsible for publishing its AOM.

### 4.1.2 Review of Rules in Effect

The review of ICAO documentation revealed some inconsistencies and areas of concern.

Must prominently, it has been noted that a discrepancy exists between doc. 4444 and doc. 7030. Doc. 4444 states: *"...the controller shall not attempt to modify the aircraft flight path until the pilot reports returning to the current [clearance]…"* (para. 15.6.3.2). However, doc. 7030 states: *"On being notified [about RA manoeuvre] … a controller shall not issue instructions to the aircraft which are contrary to the RA as communicated by the pilot"* (para. 20.2.2).

Doc. 4444 implies that no horizontal changes are allowed. Doc 7030 implies that only changes that are contrary to the RA are not allowed; therefore horizontal changes are allowed.

Document 4444, para. 15.6.3.2 states that the controller shall not attempt to modify the aircraft flight path when a pilot reports a manoeuvre induced by the ACAS. However, the air traffic controller will not be aware of such manoeuvre until the pilot reports it verbally.

It must be recognised that such verbal report will certainly be significantly delayed by:

- Increased cockpit workload during RA
- Busy frequency
- Aircraft on different frequency
- Use of HF in oceanic airspace (non-direct means of controller – pilot communication).

Because of the limited time span such verbal report might arrive at the time when it will be of no or limited operational use for the controller.

The comprehension of such verbal report might also be reduced by the "surprise factor".

Also, it should be noted that annex 10 defines Resolution Advisory as *"an indication given to the flight crew recommending...".* This definition clearly lacks a wording that implies that the following an RA is obligatory.

In today's radar detection systems, delay in updating the altitude information will, most likely, prevent the controller from deriving the RA manoeuvre information from the altitude updates presented on the CWP display. Also, it is obvious that any change in the reported altitude observed on CWP, cannot imply that the pilot is performing the manoeuvre prescribed by the ACAS.

Therefore, it must be assumed that the controller will not be aware that the aircraft has received the RA and the crew is following the RA until the pilot actually reports that event. If two aircraft are performing the Resolution Advisory manoeuvres at the same time, it is possible that both crews would report the event on the same radio frequency more or less simultaneously, consequently jamming the frequency and, most likely, preventing the controller from understanding the transmissions.

The phraseology section of Doc. 4444 gives the provision for the controller to issue an alternative clearance once the pilot reports that ACAS manoeuvre has been completed. The controller will not be able to prepare and plan such alternative clearance unless he/she possesses the advance knowledge of the ACAS manoeuvre.

The phraseology provision to notify the controller when the pilot is unable to comply with a clearance because of a TCAS RA (point z), would seem to be somewhat inadequate. The pilot should be required to advise the controller in the same transmission about the direction of the TCAS manoeuvres. To facilitate radio exchanges, in the addition to the existing phrase "*Unable, TCAS Resolution Advisory",* a message containing the direction of the manoeuvre, if applicable, for example: "*Unable, TCAS Climb (Descent)",* such be added to the phraseology list.

It cannot be assumed that the pilot will always follow the RA based on doc. 8168 para. 3.1.2.: "*Nothing in the procedures … shall prevent pilots-in-command from exercising their best judgement and full authority in the choice of the best course of action to resolve a traffic conflict."* This should be carefully considered while assessing the feasibility of downlinking RA to the CWP as the information provided to the controller may not be consistent with the type of avoiding action chosen by the pilot, unless the rules are modified.

When an RA is issued, the pilot's actions will be instrumental for the successful traffic avoidance. However, experience from previous incidents shows that pilot responses to RAs are inconsistent. Therefore, a number of Aircraft Operating Manuals (AOM) from various carriers has been informally examined. This very concise review revealed that a number of variations exist between the operators and these differences might explain why pilot response to RA varies.

It should be noted that controllers do not know whether the aircraft is ACAS equipped, ACAS is operational or it is operational in a "TA only" mode. The aircraft might be flying under the JAA rule which currently allows air carriers to operate up to 10 consecutive days without serviceable ACAS II equipment in accordance with their MEL (Minimum Equipment List).

## 4.2 Way Forward

### 4.2.1 Case for System Improvement

Without any doubt, air traffic will be increasing in the years to come. The skies will be more congested and the likelihood of near misses will naturally increase. Therefore, the efforts of pilots and controllers to prevent the tragic consequences of a near miss must be harmonised and improved.

When other safety nets, for whatever reason, fail and an ACAS RA is issued, the pilot will have the ultimate responsibility for performing the avoidance manoeuvre and ensuring safety of the aircraft. The rules require that controllers do not alter the flight path of the aircraft subject to an RA. However, when the controller knows that an RA has been issued because RA information is displayed on CWP in a timely manner, he/she may provide assistance to the aircraft involved and other traffic in the area by:

- providing traffic information
- providing information about significant terrain and/or obstacles
- providing horizontal spacing
- planning traffic situation when the conflict is resolved.

Currently, the controllers are kept out of the information loop unless a verbal report about RA is received from the pilot. Therefore, controllers' assistance in a conflict situation is quite limited. One of the basic principles of Air Traffic Control is to keep controllers fully aware about traffic situation in the sector. The lack of information about ACAS RAs is a departure from that operational principle and considerably limits controllers' situational awareness.

However, it should be recognised that the time constraint in displaying RA information on CWP is one of the most critical factors. An RA is generated at the aircraft at only 15-35 seconds before the CPA (Closest Point of Approach) and any delay in transmission and displaying the information on CWP will mean that the controller will informed some crucial seconds later.

According to the rules in force today, pilots must inform the controller about an RA by radiotelephony. Not only does the pilot have the responsibility to perform the avoidance manoeuvre but also he has the responsibility to keep the controller informed. Obviously, the first task takes the highest priority and, therefore, notification of ATC is usually delayed. Also, typically such notification is transmitted under stress and, consequently, its comprehension by the controller might be limited due to the nervous tone of the voice, stuttering, stronger accent, and other various speech deficiencies typically associated with stress.

It must be assumed that the crew will be first responding to the RA by manoeuvring the aircraft, watching out for the conflicting aircraft, and then reporting the TCAS manoeuvre to the controller. This will typically happen not earlier than 8-10 sec. after the RA has been issued. Depending on the technology used, RA information can be delivered to CWP in most of the cases before a verbal report from the pilot is made.

RA information delivered in a structured way will remove any randomness and ambiguity associated with verbal reports. If it is displayed on the CWP screen in a harmonised and consistent manner with the HMI principles used for other safety nets, it will assist the controller in the proper conduct in a critical situation. It should help to limit confusion and excessive stress that might prevent the controller from performing these duties.

If must be noted that even when the RA is downlinked the controller will not know if the pilot adheres to RA.

### 4.2.2 Frequency of ACAS Occurrences

The exact number of TAs and RAs generated daily in the European airspace is unknown. There is no uniform Europe-wide reporting procedure in place to capture this number. Currently, ACAS event data is collected from a limited number of Mode S radars and through voluntary but inconsistent airline and ATC reporting. These reports do not provide the full picture and are not complete but are considered to constitute a sufficient basis to estimate the number of TAs and RAs.

Based on collected data it is assumed that an RA event will occur every 300 – 500 flight hours, depending on airspace and traffic density. Assuming 25,000 flight hours a day in the European airspace (based on CFMU data), it is estimated that a RA event occurs somewhere in European airspace 50 – 83 times a day (or every 17 – 29 minutes).

It should be noted that an RA event does not necessarily mean that the aircraft is commanded to perform a manoeuvre that is a departure from its current flight path. Many RAs just advise the pilot to continue the current manoeuvre (e.g. “monitor vertical speed”).

TA events are several times more frequent.

### 4.2.3 Recommended Follow-up

The following issues have been identified during the study as requiring a follow-up:

1. Conduct tests at Eurocontrol Human Factor Lab to determine controllers’ reaction to ACAS RA display, time delay effect and development of the proper course of action shall be conducted. Various aspect of Human Machine Interface (HMI) shall be examined and evaluated. That should include synchronisation of other safety-net display and incorporation of voice prompts. Preliminary HMI design is shown Appendix C.

2. The Eurocontrol Human Factor Lab test shall identify to the extent possible all additional operational advantages and disadvantages. Based on these results advantages shall be used to further facilitate controller’s situational awareness. The means to deal with disadvantages shall be identified and introduced.

3. The said test must be conducted in conditions as close as possible to real-life, utilising real traffic and conflict samples, various scenarios (multiple RAs, reverse sense RAs, only one aircraft equipped, only one following RA – other ignoring, one aircraft

receiving RA – other TA, etc.) and typical operational room distractions (noisy coordination, interrupted communication, sector not fully-staffed, etc.). A close attention must be paid to the fact that ACAS RA information will be delayed due to time required for transmission and processing of the information.

4. The above mentioned tests should be used to develop ATC procedures and working methods in case an RA is displayed on CWP.

5. In parallel with this test new and better training methods should be established. The controllers and pilots should have better and full understanding of ACAS procedures, required course of action and each party should have their role clearly identified to avoid any misunderstandings. ACAS exercises should be included in periodical simulator refreshment courses.

6. It must be remembered that the controller community perceives to most of ACAS RA alarms as nuisances or false. The Eurocontrol Human Factor Lab test shall also address this issue by determining why the confidence level is low and how to improve the confidence level.

7. A follow-up research shall be conducted to carefully examine the proposed technical solutions in detail and if they are indeed feasible.

8. The Regulators shall continue working towards clarifying the rules and removing any grey areas. It is known that the work is in progress to address the regulatory issues. If the RA downlink is implemented, the Regulators must address the liability issue. The ATC community is concerned about a possibility that controller's liability in case of an incident will increase when RA is displayed.

9. There is a need to perform a comprehensive review and unification of AOM.

10. A need to flag to the controllers which aircraft are not ACAS equipped (or not operational) should be examined. Under the existing rules and operational practices an aircraft may be operating without ACAS being operational without ATC knowledge

11. A procedure should be put in place for mandatory reporting of all RAs by airlines and ATC by a designated body. Without any doubt, important lessons can be learnt from previous incidents. Without a mandatory reporting scheme in place, the number of RAs events can only be estimated and the full real impact of RAs on safety of air traffic is unknown.

# 5. CONCLUSIONS

## 5.1 Conclusions

The study concluded that:

1. Technology available today may provide the means of delivering ACAS RA information to CWP.

2. There are potential operational safety benefits in providing the ACAS Resolution Advisory to the controller.

3. Eurocontrol should pursue the recommended follow-up actions as described in section 4.2.3.

4. Areas of concern in the rules, regulations and AOMs have been identified.

# 6. APPENDIX A – PREVIOUS RESEARCH IN THE FIELD

## 6.1 MITRE Study – Baltimore, USA 1995

The 1995 MITRE study was conducted at the BWI (Baltimore Washington International Airport) approach facility. The evaluation consisted of interactive simulation with presentation of a variety of conflict geometries and resulting RAs. Contiguous Conflict Alert – Resolution Advisory event and varying pilot responses to RAs were modelled. The study assumed that the RA information is received via mode S.

The study showed that the majority of participants perceive the display of RA information to enhance the controller's situation awareness comfort level during an RA event. There was a consensus among participants that only a set of information (RA indication and sense) should be displayed.

The study concluded that approach (terminal) controllers see RA downlink to be an aid to their situational awareness.

## 6.2 MITRE Study – Boston, USA 1996-97

The MITRE study was conducted at the Boston Terminal Facility (TRACON) from July 1996 through January 1997. Boston had been selected for this study at it had an optimal number of RAs.

The study concluded that the RA downlink had positive operational benefits for controllers. However, the capability does not constitute an ATC operational requirement. The operational concept for the downlink presentation and use by controllers was acceptable. The downlink did not have significant negative effect on TRACON operations. The participants believed that the training for the study was adequate but enhancements were needed if the capability was deployed to other facilities.

Controllers reported many predictable VSL (Vertical Speed Limit) RAs generated where departure and arrival routes cross and during parallel approaches.

By the end of evaluation period, there was strong controller consensus that the RA message heightens controllers' awareness of traffic situations that trigger TCAS RA generation, informs controllers that the cockpit is receiving an RA and that the crew might take an action, and could reduce controller surprise when an aircraft manoeuvres off course unexpectedly in response to an RA.

The other benefits listed in the study summary include the enhancement in overall cockpit-ATC integration by making traffic alerting information common to air and ground. Despite its benefits, controllers do not consider an RA downlink a requirement for the performance of their job duties. Controllers did not report observing RA events where an evasive manoeuvre was taken without their anticipation. This, however, implies that the acceptance might have been different if unanticipated RA-related deviations had occurred.

Among disadvantages reported by the participants were slight demand on attention and minor display clutter. Several controllers raised the concern about possible liability if an RA occurs, the controller takes no action based on the RA information received, and an accident occurs.

The study did not find that the RA downlink had any effect on controller's plans for separation, spacing and manoeuvring.

There was a strong consensus among participants that message notifies controller of RAs before flight crew does. The message increases controller's "comfort level" by compensating for lack of crew communication of RAs. VSLs are not usually reported to ATC.

Most of controllers reported observing simultaneous CA/RA events during the evaluation. Controller consensus was that the display of these two events together did not result in confusion or uncertainty about separation responsibility.

In the Boston trial RAs were displayed on the CWP 1.3 – 6.1 seconds after being displayed in the cockpit and removed 18.3 – 19 seconds after removal in the cockpit.

## 6.3 CENA Study (VICTOR project) – France 1994

CENA study (a.k.a VICTOR Project – Visual Interface for Controllers for the Transfer of Resolution Advisories) was conducted in France in 1994.

During this study a sample of traffic was generated with a number of conflicts that lead to RA to be generated. It was assumed during the experiment that all aircraft are ACAS equipped and visible on the radar screen (including military traffic).

The study concluded that the RA information cannot imply a controller's action, as the RA is under the pilot's responsibility. It is information for the controller about the event that taking place. The study also pointed out that the RA events, due to transmission delays, might be presented to the controller when they are obsolete.

There was no clear conclusion in the study whether any RA should be presented to the controller. In any case, the authors of the study believe that only minimal information should be presented, i.e. no detail on manoeuvre prescribed by the ACAS.

## 6.4 Japan Civil Aviation Bureau Study – Japan 2001

A near mid-air collision occurred in Japan on January 31, 2001. ACAS RAs were issued on both aircraft. One of the pilots did not follow the RA based on instructions received from the controller just seconds prior to RA. After the incident, a special committee was established in the JCAB to consider how to avoid such incidents in the future. This committee concluded in June 2001 that ACAS RA information should be displayed on CWP, so the air traffic controller knows the situation in the cockpit.

JCAB advised that once the radar near to Tokyo's Nartia airport is in the process of being equipped with mode S. The work is scheduled to be complete in March 2003 and from April 2003 data from this radar will be sent to the JCAB experimental facility in Osaka for technical and operational evaluation. If the results of trial are positive, it is planned that RA will be displayed on CWP in Tokyo ACC from October 2003.

## 6.5 UK CAA – Simultaneous Operation of STCA and TCAS II in En-route Airspace – United Kingdom 1994

This extensive study aimed on investigating the potential effects upon UK airspace of the simultaneous operation of the NATS ground based en-route STCA system and the airborne TCAS.

The study showed that with TCAS ver. 6.0 approximately 15% and with TCAS ver. 6.04 approximately 20% of the alerts examined which were common to TCAS and STCA might have resulted in pilot or controller disruption because of a controller instruction and an RA being issued at or near same time.

The results for TCAS ver. 6.0 were as follows (for TCAS 6.04 results are given in the brackets): for in 99% (99.8%) of encounters the ground system had generated an STCA alert and in 3% (1.3%) of cases had generated a TCAS RA. Roughly 2% of the encounters generated both an STCA and a TCAS RA. Additional RAs, about 6 (2) per 1000 STCA alerts, will also be generated for which the controller does not receive an STCA warning.

For roughly 15% (TCAS ver. 6.0) and 20% (TCAS ver. 6.04) of the encounters which generated both an STCA alert and a TCAS RA it is possible that some confusion concerning the resolution of the conflict may occur because of the controller's instructions and the RA could have been received by the pilot at or near the same time. On average, 150 STCA alerts are generated per day. With 100% of TCAS equipage it can be expected that one alert may be received within UK's en-route airspace every other day which may result in confusion.

If no avoiding action is given by a controller upon receiving an STCA alert, approximately 55% of RAs, generated by either TCAS version, would result in an aircraft deviating from its cleared flight path.

# 7. APPENDIX B – PREVIOUS SIGNIFICANT MIDAIR OCCURRENCES

## 7.1 Mid-air occurrences

First mid-air collision between airliners occurred in 1922 involving French Farman Goliath and a British de Havilland DH18 about 60 miles north of Paris killing seven people.

Since 1960, there have been 82 mid-air collisions involving a commercial flight. The majority of these accidents (66 or 80%) occurred prior to 1990 and 26 out of 82 (32%) involved a passenger jet. The world's worst mid-air occurred in India in 1996 where 349 died. Europe's worst happened over Zagreb in 1976 with 176 fatalities. Not all mid-air collisions were fatal.

The significant drop in the number of mid-air collisions since 1990 most likely can be contributed to the increased radar coverage all over the world, improved quality of ATC services and navigation and ACAS/TCAS equipage.

The most recent mid-air collisions were on 1 July 2002 over Überlingen between B757 and Tu-154 (71 fatalities) and on 26 December 2002 over Windhoek between a Cessna and B737 (non-fatal).

### 7.1.1 Charki Dadri – 12 November 1996

Air Kazakhstan Ilyushin 76 freighter was descending to FL150 on approach to New Delhi. Saudia Boeing 747 had taken off from New Delhi and was climbing to FL140. The Kazakh aircraft descended below its assigned altitude and collided over Charki Dadri with the Boeing. All 312 occupants were killed.

### 7.1.2 Zagreb – 11 September 1976

The British Airways Trident was maintaining FL330 approaching the Zagreb VOR from west when the northbound Inex Adria Dc9 was erroneously cleared to climb from FL260 to FL350. The aircraft collided over Zagreb killing all 176 occupants.

### 7.1.3 Überlingen – 1 July 2002

Note: investigation of this accident is ongoing.

The northbound DHL Boeing 757 freighter and the westbound Bashkirian Tupolev 154 were on a collision course at FL360. Shortly before the accident, the controller gave the Tupolev to FL350 to avoid the conflict. At the same time, the DHL pilot in the response to ACAS RA commenced descent as well. The Tupolev pilot received a “climb” RA but he elected to adhere to the ATC clearance to descend. The aircraft collided over Überlingen at FL353 killing all 71 occupants.

### 7.1.4 Yaizu, Japan – 31 January 2001

On January 31, 2001 an near mid-air collision occurred near Yaizu in Japan and involved a Japan Airlines B747-400 and Japan Airlines DC-10.

The DC-10 was maintaining FL370 while the B747 was cleared, due to controller error, to climb to FL390. When the controller noticed the conflict, the B747 was climbing trough FL369. The controller tried to resolve it by instructing the B747 to descent to FL350. The B747 pilot confirmed descent clearance and when he commenced his descent a TCAS RA “climb” was issued. The pilot elected to continue descent as he had the DC-10 in sight. The DC-10 responding to their TCAS RA was descending as well.

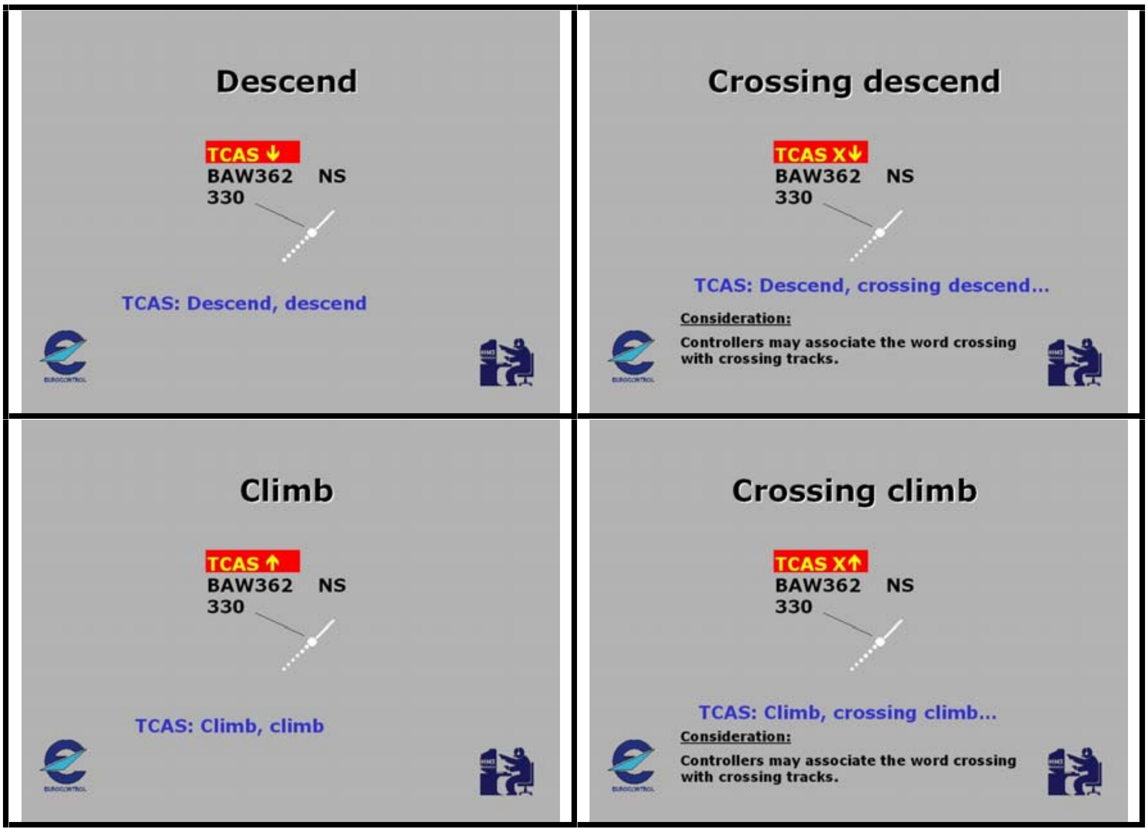
The B747 missed the DC-10 by 105 to 165 meters in lateral distance and 20 to 60 meters in altitude difference. About 100 crew and passengers on board of the B747 sustained injuries due to the emergency manoeuvre.

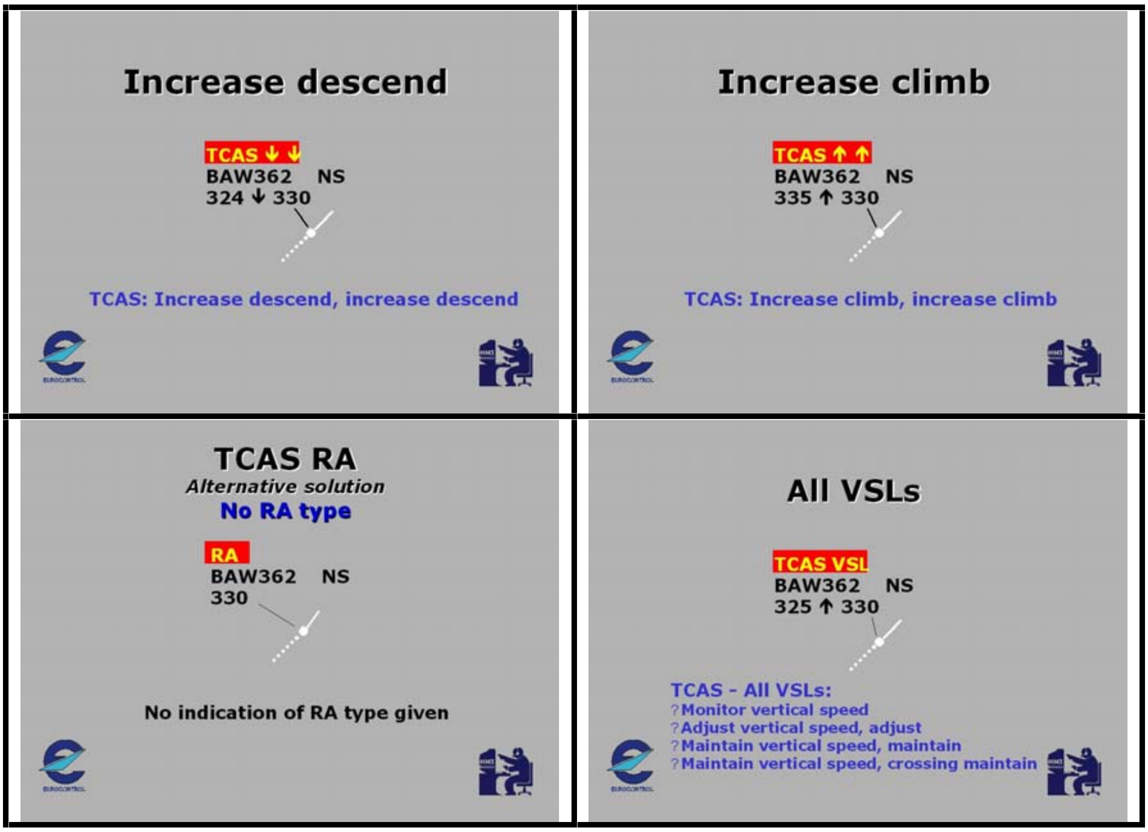
## 8. APPENDIX C – EXAMPLES OF PROPOSED HMI SOLUTIONS

The following principles have been applied in the following proposed HMI:

- HMI consistent with current EATMP HMI
- Due to similar nature of event, the following RAs are combined:
- all VSLs (VSLs include: Monitor vertical speed; Adjust vertical speed, adjust; Maintain vertical speed, maintain; Maintain vertical speed, crossing maintain).
- Climb and crossing climb
- Descend and crossing descend
- Introduction of voice prompts to increase alertness.

The HMI will be subject to further evaluation. Examples of TCAS RA HMI are shown below.




Increase descend
TCAS ↓ ↓
BAW362 NS
324 ↓ 330
TCAS: Increase descend, increase descend
Increase climb
TCAS ↑ ↑
BAW362 NS
335 ↑ 330
TCAS: Increase climb, increase climb
TCAS RA
Alternative solution
No RA type
RA
BAW362 NS
330
No indication of RA type given
All VSLs
TCAS VSL
BAW362 NS
325 ↑ 330
TCAS - All VSLs:
?Monitor vertical speed
?Adjust vertical speed, adjust
?Maintain vertical speed, maintain
?Maintain vertical speed, crossing maintain

# 9. APPENDIX D – EXAMPLES OF AIRLINE OPERATING MANUALS

## 9.1 Carrier A

Following an RA is mandatory, unless the Pilot Flying (PF) determines that this jeopardised safe aircraft operation. The Pilot Not Flying (PNF) is supposed to advice ATC about the manoeuvres. No procedure is given when clear of traffic.

Carrier A is a major European carrier.

## 9.2 Carrier B

Follow the RA in the direction given, unless the Pilot-in-command (PIC) determines it is unsafe or the intruder is in sight. Once clear of traffic, return to the previous clearance. The manual does not mention that ATC should be advised about these manoeuvres.

Carrier B is a major Eastern European carrier.

## 9.3 Carrier C

Follow the RA immediately. Evasive manoeuvre shall not be based on upon the horizontal target information. While following the RA try to establish visual contact with the intruder. Never manoeuver in the direction opposite to the RA. ATC shall be notified only whenever a manoeuvre induced by an RA has led the pilot to deviate from the assigned clearance.

The manual gives procedure to follow once ”clear of conflict” and instructs the pilot to report any RA event.

Carrier C is a major European carrier, no longer in business.

## 9.4 Carrier D

Follow the RA immediately. Advise the controller as soon as possible. Do not manoeuver in the direction opposite to RA. Remember that traffic acquired visually may not be the intruder.

Carrier D is a small Eastern European charter operator.