" FOLLOW THE RA ! "

MANAGING TCAS "RA" ORDERS AND ATC INSTRUCTIONS

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1. INTRODUCTION

1.1. Background

The midair collision over Germany on Jul.01/02 raised several issues regarding the interaction between the crew response to TCAS Resolution Advisory (RA) orders and ATC instructions.

Airbus procedures for response to a corrective TCAS RA (i.e., all CLIMB and DESCEND types of messages) clearly prioritize the response to the TCAS orders over any other action, including notifying the ATC.

However the above collision raised issues regarding the provision, interpretation and implementation of :

- International recommendations,
- Regional supplements,
- National requirements.

1.2. Scope of the Article

The purpose of this article is to provide an overview and discussion of the following references :

- ICAO recommendations,
- JAR-OPS regulations,
- Eurocontrol recommendations.

The second part of the article also provides an update on the implementation of the TCAS II Change 7 / ACAS II and ATC Mode S Level 2.

1.3. Statistical Data

The following statistical data, based on the analysis of TCAS events reported to the French DGAC, provide a sizing assessment of the issues discussed in this article :

- 76 % of reported TCAS events involved a RA,
- 8 % of reported RA's involved coordinated RA orders between affected aircraft,
- 92 % of RA orders were correctly followed, even if visual contact had been established,
- 6 % of RA orders were not followed due to visual contact and avoidance maneuver,
- 2 % of RA orders were not followed, although visual contact had not been established,
- 2/3 of events involved a deviation from the assigned altitude lower than 600 ft,
- 85 % of events were considered by pilots as justified and with appropriate RA orders,
- 30 % of events were considered by controllers as having hindered their management of traffic.

2. REGULATORY REFERENCES

2.1. ICAO

The ICAO defines the following elements involved in the response to an ACAS RA :

- Responsibility and authority of the pilot-in-command,
- Avoidance of collisions – ATC services,
- Response to ACAS RA's – Responsibility for separation.

2.1.1. Responsibility and Authority of Pilot-in-Command

Complying with a RA order results in deviating from the current clearance, ICAO clearly defines the responsibility and authority of the pilot-in-command in Annex 2 - Rules of the Air - Chapter 2 - Applicability of the Rules of the Air :

- 2.3 - Responsibility for compliance with the rule of the air :

  " ... except that the pilot-in-command may depart from these rules in circumstances that render such departure absolutely necessary in the interests of safety. "

- 2.4 - Authority of pilot-in-command of an aircraft :

  " The pilot-in-command of an aircraft shall have final authority as to the disposition of the aircraft while in command. "

2.1.2. Avoidance of Collisions – ATC Service

Although ICAO defines the concepts of "right of way" and "clearance", ICAO - Annex 2 – Chapter 3 recognizes that situations may exist that warrant deviation from these concepts.

The ICAO - Annex 2 - Rules of the Air - Chapter 3 - General Rules addresses the avoidance of collisions and related ATC service as follows :

- 3.2 - Avoidance of collisions :

  " The aircraft that has the right-of-way shall maintain its heading and speed, but nothing in these rules shall relieve the pilot-in-command of the aircraft from the responsibility of taking such action, including collision avoidance maneuvers based upon resolution advisories provided by ACAS equipment, as will best avert collision. "

- 3.6 - ATC service :

  "... an aircraft shall adhere to the current flight plan [...], or unless an emergency arises which necessitates immediate action by the aircraft, in which event as soon as circumstances permit, after such emergency authority is exercised, the appropriate air traffic unit shall be notified of the action taken and that this action has been taken under emergency authority. "

2.1.3. Response to ACAS RA's – Responsibility for Separation

The ICAO PANS-ATM (Doc. 4444) - Rules of the Air and Air Traffic Services defines the respective responsibilities of the pilot and controller as follows :

- " When a pilot reports a maneuver induced by an ACAS RA, the controller shall not attempt to modify the aircraft flight path until the pilots report returning to the terms of the current air traffic control instruction or clearance, but shall provide traffic information as appropriate ."

  Note 1 : The ACAS capability of an aircraft will not normally be known to air traffic controllers.

  Note 2 : Operating procedures for use of ACAS are contained in PANS-OPS (Doc. 8168), Volume 1, Part VIII, Chapter 3.

  Note 3 : The phraseology to be used by controllers and pilots is defined in PANS-ATM (Doc.4444), Part X, 3.1.2.

- " … Once an aircraft departs from an assigned ATC clearance in compliance with a RA, the controller ceases to be responsible for providing separation between the aircraft and other aircraft affected as a direct consequence of the maneuver induced by the RA. "

- " The controller's responsibility for providing separation for all affected aircraft resumes when :

  - the controller acknowledges a report from the pilot that the aircraft has resumed its assigned clearance; or
  - the controller acknowledges a report from the pilot that the aircraft is resuming its assigned clearance or issues an alternative clearance which is acknowledged by the flight crew ."

Indeed, in case of coordinated RA orders, any attempt by the controller to modify the flight path of an aircraft might result in further reducing the vertical separation.

However, when circumstances permit, the controller should endeavor to provide traffic information to aircraft affected by the maneuver.

ICAO recommendations are amplified in the following European supplements :

- Proposed amendment, agreed by the EANPG, of the EUR Regional Supplementary Procedures, Doc. 7030,
- DOC 7910 - (EUR) - Part 1, Chapter 16.2, Responsibility for separation of aircraft during maneuvers in compliance with a resolution advisory (RA),
- Amendment No. 191 incorporates additions to EUR SUPPS concerning procedures and the use of airborne collision avoidance system (ACAS).

" Responsibility for separation of aircraft during maneuvers in compliance with a resolution advisory (RA) includes the following requirements :

- The use of ACAS II does not alter the respective responsibilities of pilots and controllers for the safe operation of aircraft.
- On being notified that an aircraft, under air traffic control, is maneuvering in accordance with a resolution advisory (RA), a controller should not issue instructions to that aircraft which are contrary to the RA as communicated by the pilot.
- Once an aircraft departs from the current ATC clearance in compliance with a RA, the controller ceases to be responsible for providing separation between that aircraft and other aircraft affected as a direct consequence of the maneuver induced by the RA.
- However, when circumstances permit, the controller should endeavor to provide traffic information to aircraft affected by the maneuver.
- The controller's responsibility for providing separation for all the affected aircraft resumes when :
  - the controller acknowledges a report from the pilot that the aircraft has resumed the current clearance; or
  - the controller acknowledges a report from the pilot that the aircraft is resuming the current clearance and issues an alternative clearance which is acknowledged by the flight crew. "

2.1.4. ACAS Performance Monitoring and Event Reporting

ACAS may have a significant effect on ATC. Thus, there is a continuing need to monitor the performance of ACAS in the developing ATM environment.

Following a RA event, or other significant ACAS event, pilots and controllers should complete an ACAS RA report; aircraft operators and ATS authorities should forward the completed reports through established channels.

ICAO is developing guidance material in order to prevent unnecessary RA's associated with high vertical rates of climb or descent.

The guidance will advise pilots that when traffic information is provided by ATC the rate of climb or descent should be less than 1500 ft/mn when approaching 1000 ft above or below the cleared FL.

2.2. NATIONAL REQUIREMENTS

ICAO recommendations are reflected in national requirements (AIP's) and regulations (FAR's and JAR's).

The interpretation and implementation of ICAO recommendations by member states may differ as illustrated by the two examples below :

- Requirement to obtain prior approval from ATC to comply with an ACAS RA order,
- Precedence of ATC instructions over ACAS RA orders.

Conversely, the French Air Information Circular (AIC) 16/96 clearly states :

- " The pilot may deviate from or refuse an ATC instruction in order to comply with a RA."

The ICAO State Letter AN11/1/1/23/AN 11/19.1-02/99 (Oct.02) proposes amendments to the ACAS provisions in Annex 6, Part 1, Chapter 4 and PANS-OPS (Doc.8168), Volume 1, Part VIII, Chapter 3 in order to enhance the existing recommendations and ensure a consistent interpretation and implementation by member states.

Eurocontrol emphasizes that pilots who deviate from an air traffic control instruction or clearance in response to a resolution advisory shall :

- After initiating the maneuver, as soon as possible consistent with flying the aircraft, notify the appropriate ATC unit of the deviation, including its direction;
- When they are unable to comply with a clearance or instruction that conflicts with an RA, notify ATC as soon as possible consistent with flying the aircraft;
- Promptly return to the terms of the ATC instruction or clearance when the conflict is resolved; and,
- After initiating a return to, or resuming the current clearance, notify ATC as soon as possible consistent with flying the aircraft.

2.3. EUROCONTROL SAFETY-AWARENESS INFORMATION

2.3.1. Eurocontrol ACAS II Bulletin

Before the Jul.01/02 midair collision, the Eurocontrol ACAS Programme group had prepared a safety-awareness bulletin :

ACAS II Bulletin – Issue July 2002 - " Follow the RA ! ".

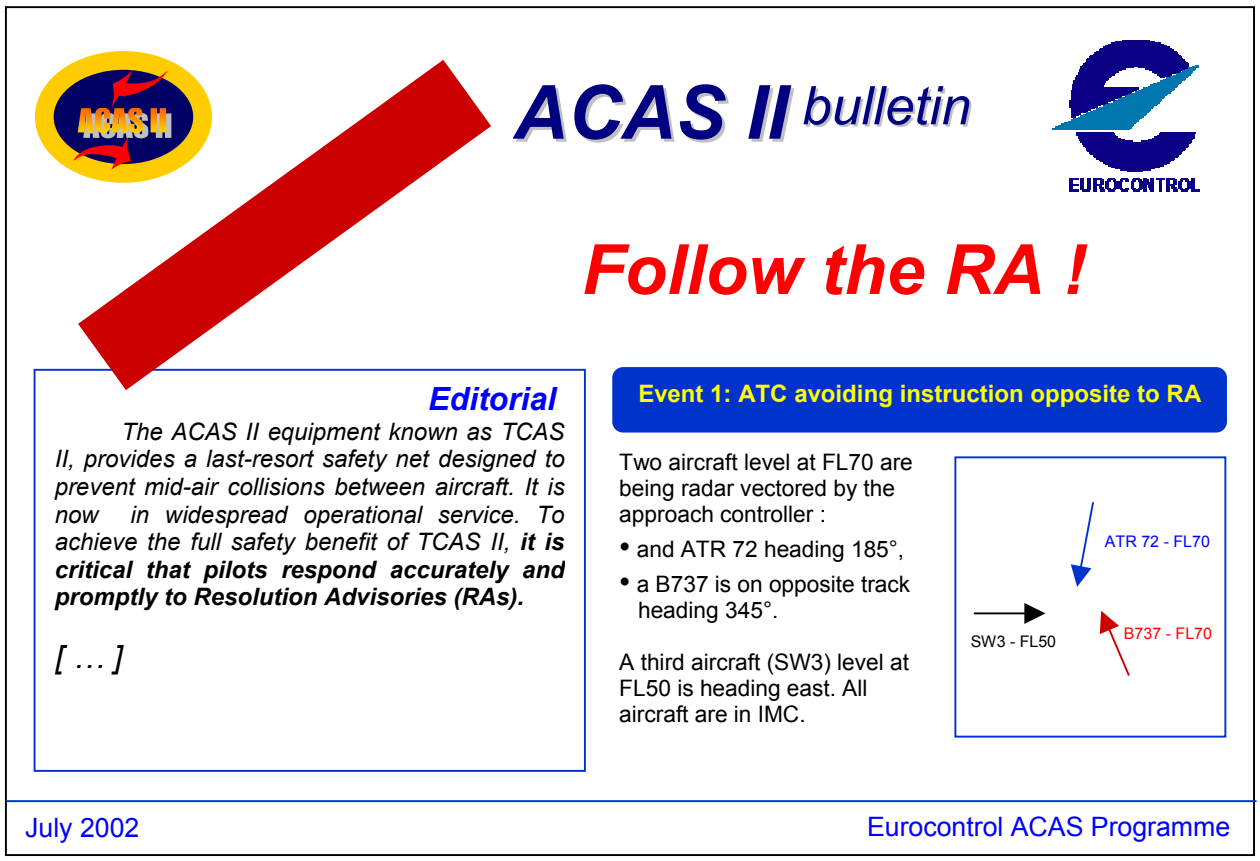

Figure 1

Eurocontrol ACAS II Bulletin

This Bulletin, released in the aftermath of the collision, highlights the following key points :

- The ACAS II provides a last resort safety net,
- To achieve the full safety benefit of ACAS II, it is critical that pilots respond accurately and promptly to Resolution Advisories (RA's),
- Safety studies reinforce the need to follow the RA's.

The Eurocontrol ACAS II Bulletin reviews 7 events, covering the following scenarios :

- ATC avoidance instruction opposite to RA orders (with or without crew compliance - or with late crew compliance - with ATC instructions),
- Erroneous traffic information (FL versus altitude in high QNH conditions) and incorrect visual perception leading to disregard RA,
- Inefficient visual avoiding maneuver,
- Climb RA at the maximum certified flight level :
  - If there is some doubt of the ability to respond to a "Climb" RA, the Bulletin recommends at least to remain in level flight but to not descend.

Based on the analysis of documented ACAS events, the Bulletin stresses that :

- A correct RA response by both pilots usually provides more vertical separation than the ACAS II separation objective.
- An inadequate response or the absence of response to a RA order degrades safety (relative to conflicting traffic and/or traffic below).

The Bulletin also emphasizes time constraints facing the controller when a loss of separation is likely to occur or has occurred.

Indeed, the controller has to :

- Detect the conflict using the available tools (e.g., radar display, short term conflict alert system),
- Assess the situation,
- Develop a solution in a very short period of time,
- Communicate this solution to the aircrew as quickly and clearly as possible.

The detection of a conflict by the controller may be delayed due to tasks with other aircraft under his/her control. Communications with conflicting aircraft may also be delayed due to RTF congestion or misunderstanding between the controller and the pilots.

Conversely, the ACAS II automatically detects any risk of collision.

When a risk of collision is detected, the ACAS II calculates the necessary maneuver and communicates the solution directly to the flight crew via the RA display and an aural message, in ***less than one second***.

In addition, whenever both aircraft are operating ACAS II in RA mode, ACAS II coordinates RA orders.

The Eurocontrol ACAS II Bulletin concludes that :

- **It is important that pilots follow all RA's**, even when :
  - there is an opposite avoiding instruction by the controller (as other aircraft response to a coordinated RA will place both aircraft on a collision path);
  - there is traffic information from the controller (as the vertical situation seen by the controller may be inaccurate, particularly when aircraft are rapidly climbing or descending);
  - there is visual acquisition (experience shows that situation may be incorrectly perceived / assessed); and / or,
  - the conflict occurs close to the top of the flight envelop (climb a little or maintain level flight but do not descend).

These conclusions could constitute some Golden Rules of Collision Avoidance !

2.3.2. Eurocontrol Safety Letter

In November 2002, the Eurocontrol Safety Management group issued a ***Safety Letter*** recalling the elements of an appropriate response to ACAS II Resolution Advisories (RA's).

Figures 3, 4 and 5 summarize the interaction between the pilots and ATC during the three phases of an ACAS event :

- Traffic Advisory (TA),
- Resolution Advisory (RA),
- Clear of Conflict.

Figure 3 confirms that no avoidance maneuver should be initiated on the sole basis of a TA message. Even if pilots notify the ATC of the TA condition, the controller remains responsible for separation.

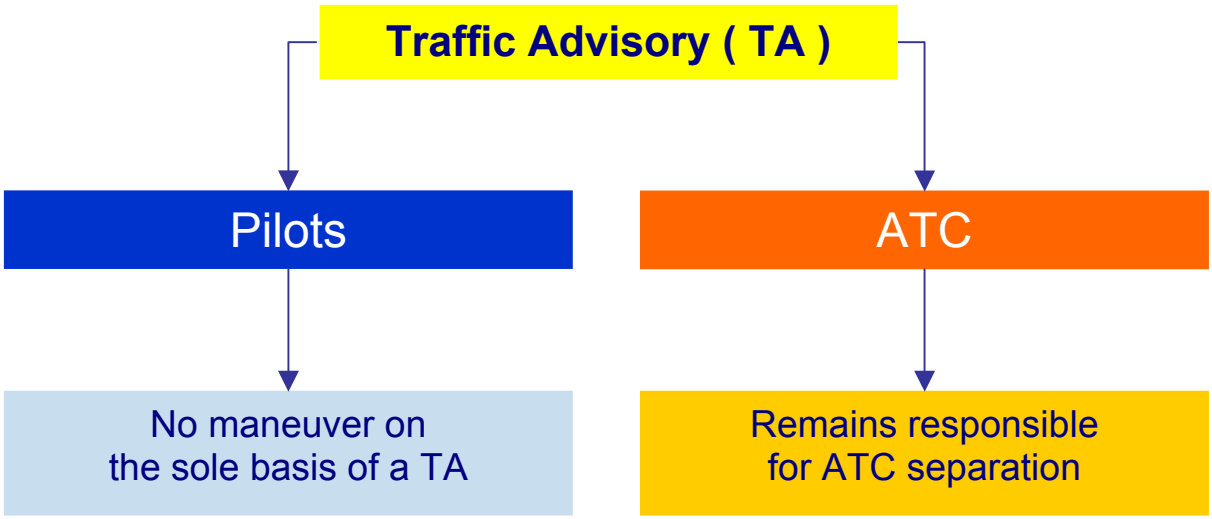

Figure 3

TCAS Traffic Advisory (TA)

(Source : Eurocontrol ***Safety Letter*** – Issue November 2002)

Figure 4 confirms the respective authority and responsibility of the pilots and controller during the response to a RA order.

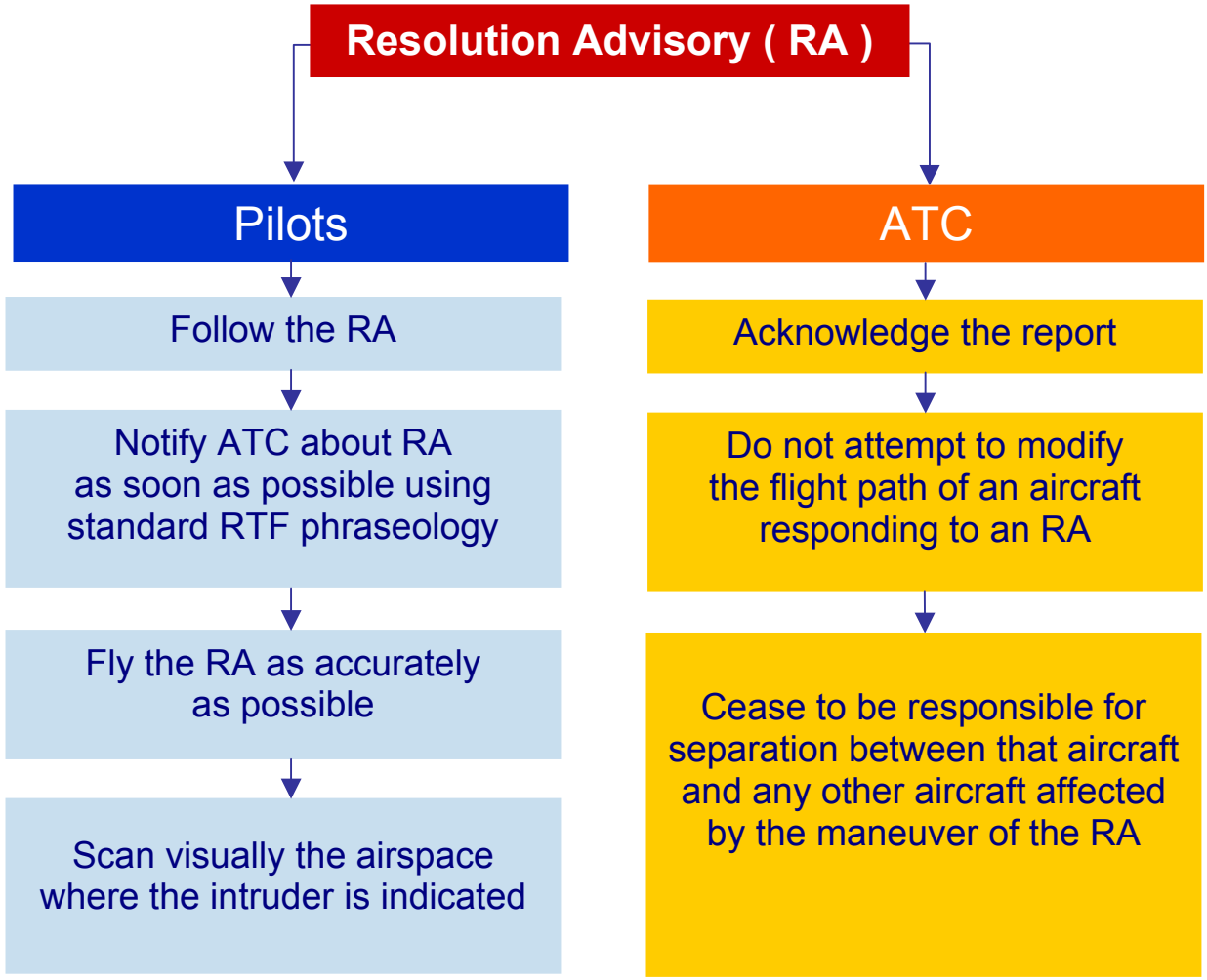

Figure 4

Resolution Advisory (RA)

(Source : Eurocontrol ***Safety Letter*** – Issue November 2002)

Figure 5 confirms the terms of resumption of respective responsibilities after the aircraft is Clear-of-Conflict and returns to the initial clearance or to an alternative clearance issued by the controller.

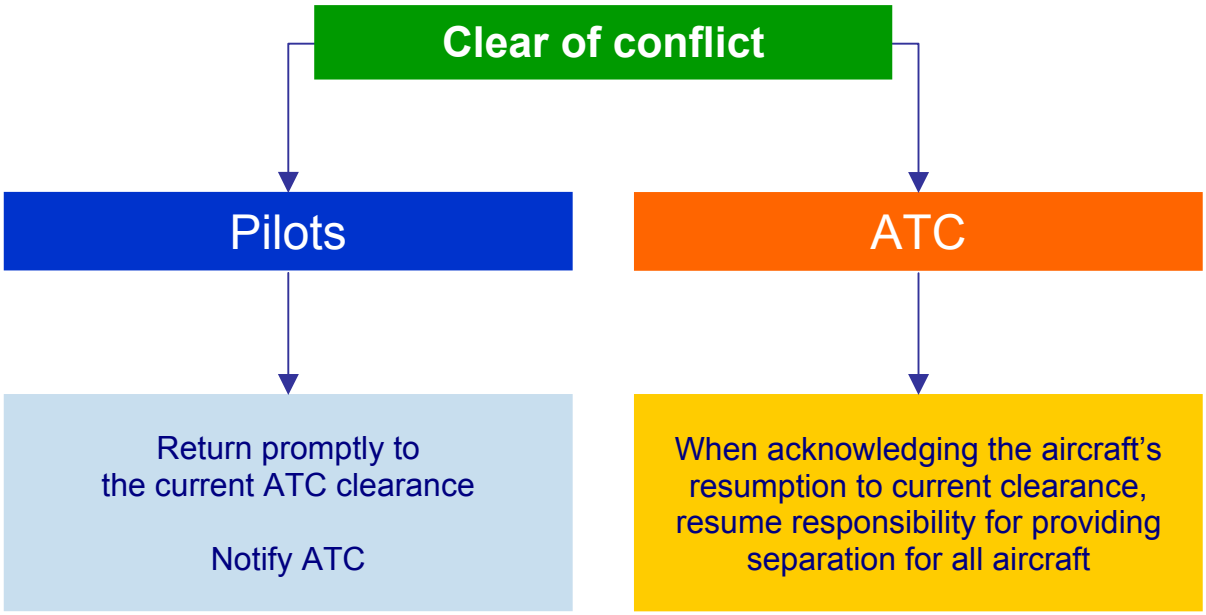

Figure 5

Clear of Conflict

(Source : Eurocontrol ***Safety Letter*** – Issue November 2002)

The Eurocontrol ***Safety Letter*** concludes that :

" Aircraft operators should strongly encourage pilots to follow RA's whilst explaining ACAS constraints and limitations."

It also emphasizes that :

"Pilots should be aware of :

- the potential benefits of reducing rates of climb / descent when approaching their cleared Flight Levels,
- the importance of telling ATC that they are following an RA as soon as possible."

3. UPDATE ON TCAS II / ACAS II / ATC MODE S LEVEL 2 IMPLEMENTATION

3.1. Traffic (Aircraft) Collision Avoidance System (TCAS / ACAS)

3.1.1. ICAO – Definition of an Airborne Collision Avoidance System (ACAS) :

An aircraft system based upon secondary surveillance radar (SSR) transponder signals, which operates independently of ground based equipment, to provide advice to the pilot on potential conflicting aircraft that are equipped with SSR transponders.

Note 1: In this context the term 'independently' means that ACAS operates independently of other systems used by air traffic services, except for communications with Mode "S" ground stations.

Note 2 : SSR transponders referred to above are those operating in Mode "C" or Mode "S".

3.1.2. Background and Objectives

The TCAS II Change 7 / ACAS II was developed to enhance the traffic advisory (TA) and resolution advisory (RA) functions and to comply with the ICAO Annex 10 regarding the reduction of nuisance alerts.

The TCAS II Change 7 / ACAS II accounts, among other enhancements, for RVSM.

To provide coordinated resolution orders to conflicting traffics, the installation of the TCAS II Change 7 / ACAS II requires the simultaneous installation of a Mode S ATC transponder.

3.1.3. Implementation Schedule

Country	TCAS II - 6.04A	TCAS II – Change 7 ACAS II
Europe (ECAC)		In effect
USA	In effect	tbd
China		In effect
Australia		In effect
India	In effect	tbd
Japan		In effect
Worldwide		January 2003

Figure 6

TCAS II – Change 7 / ACAS II - Implementation Schedule

3.1.4. Applicable Regulations

JAA Temporary Guidance Leaflet (TGL) No.8, Revision 2, ACAS II.

3.1.5. Means of Compliance for the Airbus Fleet

The means of compliance for all Airbus aircraft models are defined in the Operators Information Telex (OIT) SE-E/999.0030/98 Rev.3.

3.2. ATC Mode S Level 2

3.2.1. Objectives

The member states of the European Civil Aviation Conference (ECAC) have decided to improve Secondary Surveillance Radar (SSR) operations and overcome the limitations of the Mode A and Mode C transponders by mandating the carriage of a Mode S Level 2 transponder by March 30/2003, for all IFR flights.

The ATC Mode S Level 2 allows the transmission of additional parameters to the ground station and is expected to facilitate air traffic control in saturated areas.

A 5 % increment in traffic capacity is expected from the first phase called *elementary surveillance*, a further 5 % increment in traffic capacity is expected from the second phase called *enhanced surveillance*.

The current Mode S transponders perform the functions of Mode A and Mode C transponders and provide air-to-air data exchange between TCAS-equipped aircraft for coordinated resolution of encounters.

The datalink-compatible Mode S Level 2 transponder is capable of supporting air-ground and ground-air digital communications (i.e., up-link / down-link of short messages).

The Mode S Level 2 transponder is based on the concept of *selective surveillance* in which a unique 24-bit address is allocated to each aircraft.

The Mode S Level 2 transponder with basic functionality and surveillance interrogator (SI) code capability is the minimum standard required for operation with *elementary surveillance (els)* in European airspace after March 30/2003 (with a transition period until March 2004).

The Mode S Level 2 transponder can down-link the following data to 64 different ground stations :

- 24-bit aircraft address;
- Aircraft identification (call sign or registration stated in the ICAO flight plan or Flight No.);
- Surveillance Identifier code (SI);
- Capability report (enabling the transponder data link capabilities to be determined by the interrogator);
- Pressure altitude (in 25 ft increments);
- Flight / ground status; and,
- TCAS II Resolution Advisories (RA's).

To comply with the requirements for *enhanced surveillance* (*ehs*), the following additional parameters need to be transmitted to the ground station :

- Magnetic heading;
- True track;
- True track angle rate;
- Bank angle;
- Aircraft speed;
- Mach number;
- Ground speed;
- Vertical speed; and,
- Selected altitude.

The concept of *elementary surveillance* versus *enhanced surveillance* also depends on the capability of the ground interrogator.

The Mode S Level 2 with SI code capability (s) and extended squitter capability (e) is the standard required for ADS-B capability.

3.2.2. Implementation Schedule

Mode S Level 2	Airspace	Production Aircraft	Aircraft Retrofit
Elementary Surveillance	All IFR Flights in the ECAC airspace	March 30/03 (Transition period until March 2004)	March 2005
Enhanced Surveillance	France Germany United Kingdom	March 30/05	tbd

Figure 7

ATC Mode S Level 2 - Implementation Schedule

3.2.3. Applicable Regulations

- ICAO – Annex 10 – Volume IV,
- ICAO – Amendments to Regional Supplementary Procedures,
- ICAO – Annex 10 – Amendment 76 – Volume III (Digital Data Communication Systems) and Volume IV (Surveillance Radar and Collision Avoidance Systems),
- JAA Temporary Guidance Leaflet (TGL) No. 8 (ACAS II),

- JAA Temporary Guidance Leaflet (TGL) No. 11 (Guidance for operators on training programs for the use of ACAS II),
- JAA Temporary Guidance Leaflet (TGL) No. X (Mode S Level 2 transponder - to be issued),
- JAR-OPS 1.845 and 1.865 and associated AMC's – Communication and navigation equipment.

3.2.4. Means of Compliance for the Airbus Fleet

Mode S Level 2 transponders with elementary surveillance, enhanced surveillance, RA's down-link and ADS-B capability are planned for certification in May 2003.

This certification effort includes compliant transponders, with the above capability, from Honeywell, L3-COM and Rockwell.

The *enhanced surveillance* and ADS-B capability also includes a wiring change in the avionics racks.

Airbus recommendations for retrofit of the ATC Mode S Level 2 have been published in the Operator Information Telex (OIT) AI/SE 999.0182/01.

4. CONCLUSIONS

Safety initiatives and awareness programs sometimes are overtaken by accidents of the type they intended to prevent.

It is our collective duty, as an industry, to rebound on such events and to identify and disseminate the associated lessons-learned.

The information contained in this article is intended :

- To confirm the existing regulatory framework;
- Provide safety-awareness information to enhance pilots' knowledge of rules and procedures; and,
- Encourage operators to review and possibly enhance their national requirements, whenever required.

Any question or exchange of views regarding this article may be addressed to the author (e.mail: michel.tremaud@airbus.com).

5. ACKNOWLEDGEMENTS

Airbus is grateful to Eurocontrol for their safety-awareness efforts and for the permission to quote and reproduce key elements of the following Eurocontrol publications :

- ASAS II Bulletin – Issue July 2002,
- Safety Letter – Issue November 2002.

6. SUMMARY OF AIRBUS REFERENCE DOCUMENTS

Figure 8 provides a summary of the Airbus Operators Information Telexes (OIT) defining the technical solutions developed to comply with the TCAS II – Change 7and ATC Mode S Level 2 requirements.

Operational Requirements	Airbus Reference Documents
TCAS II – Change 7 / ACAS II	OIT SE 999.0030/98 Rev.3
ATC Mode S Level 2	OIT SE 999.0182/01 Rev.0

Figure 8

Summary of Airbus Reference Documents

7. SUMMARY OF REGULATORY REFERENCES

- ICAO – Annex 2 – Rules of the Air :
  - Chapter 2 – Applicability of the Rules of the Air,
  - Chapter 3 – General Rules.
- ICAO – Annex 6 – Operations of Aircraft – Part 1 – International Commercial Air Transport – Aeroplanes :
  - Chapter 6 – ACAS II
- ICAO – Annex 10 – Aeronautical Communications :
  - Volume IV – Chapter 4 – ACAS,
  - Amendment 76 – Volume III and Volume IV.
- ICAO – Annex 11 – Air Traffic Services :
  - Chapter 2 – 2.4.2,
  - Chapter 12 – 12.3.1.2
- ICAO – EUR Regional Supplementary Procedures (Doc.7030).
- ICAO – Doc.7910 (EUR) – Part 1 :
  - Chapter 16.2 – Responsibility for separation during maneuvers in compliance with a resolution advisory.
- ICAO – PANS-OPS (Doc.8168) – Volume 1 – Part VIII – Chapter 3 – Operating Procedures for the Use of ACAS.
- ICAO – PANS-ATM (Doc.4444) – Rules of the Air and Air Traffic Services – responsibility for separation – Standard Phraseology.

- ICAO - State Letter 7/11.12-94/62 (Nov.94) – ACAS Implementation, safety benefits, Training.
- ICAO – State Letter AN11/1/1/23/AN 11/19.1-02/99 (Oct.02) – Proposed Amendments to the ACAS Provisions in Annex 6, Part 1, Chapter 4 and PANS-OPS Doc.8168, Volume 1, Part VIII, Chapter 3.
- JAR-OPS 1.085(G) – Crew responsibility – Captain's emergency authority.
- JAR-OPS 1.398 – use of TCAS (ACJ OPS 1.398).
- JAR-OPS 1.845 and 1.865 (and associated ACJ's) – Communication and navigation equipment.
- JAR-OPS TGL No. 8 – Revision 2 – ACAS II.
- JAR-OPS TGL No.11 – Guidance for operators training programs for the use of ACAS.
- French AIC 16/96 – Deviation from ATC instruction to comply with a RA.
- French AIC 26/02 – Postponement of implementation of Elementary Surveillance until March 2005.

8. SUMMARY OF USEFUL WEBSITES

- www.icao.int
- www.eurocontrol.int/acas
- www.eurocontrol.int/mode_s
- www.eurocontrol.int/rvsm
- www.eurocontrol.int/safety
- www.ntsb.gov/recs/letters
- www.atmb.net.cn/caac/acas