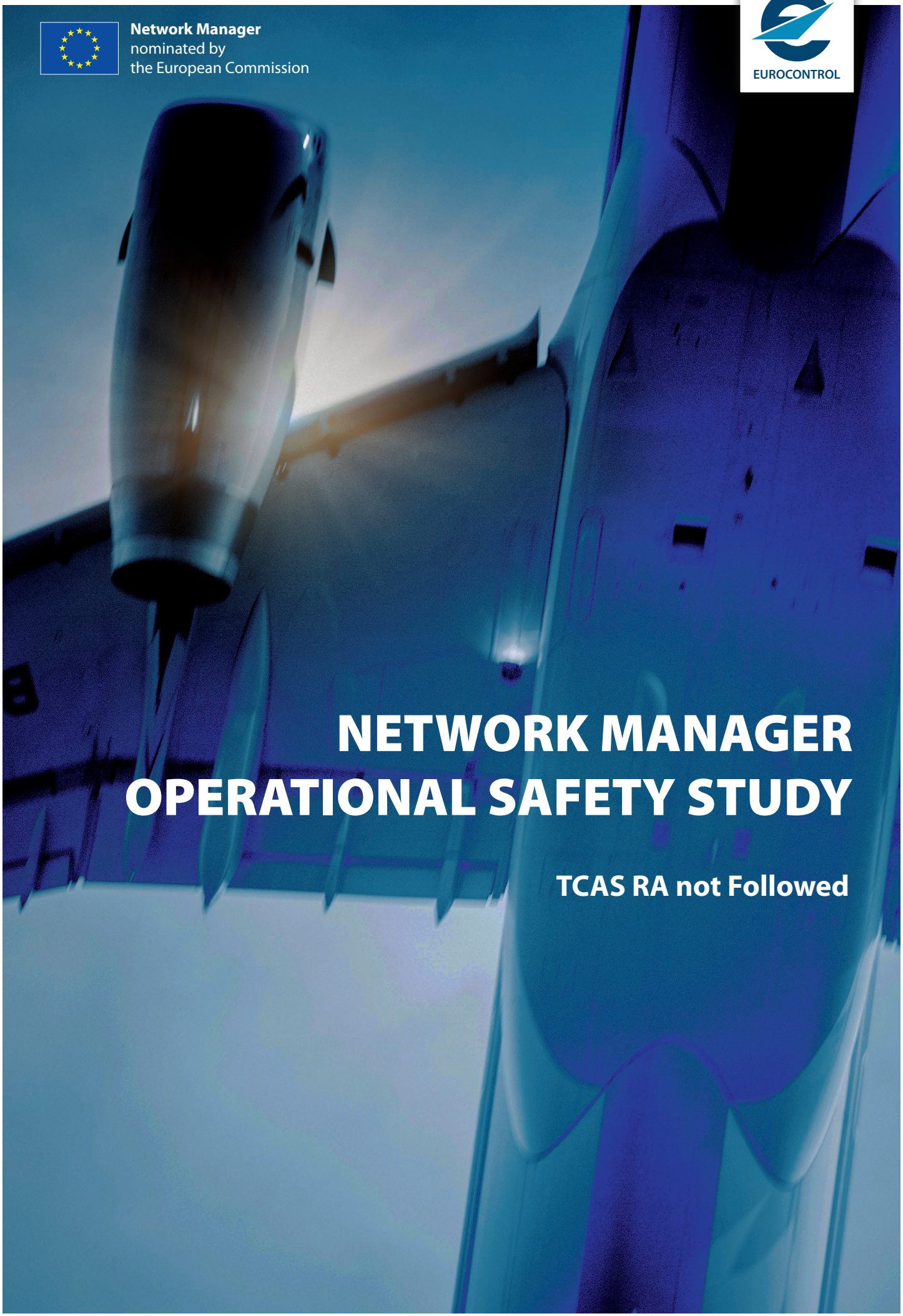

Network Manager
nominated by
the European Commission

EUROCONTROL

NETWORK MANAGER OPERATIONAL SAFETY STUDY

TCAS RA not Followed

Document characteristics

Document Title	Document Subtitle (optional)	Edition Number	Edition Validity Date
NETWORK MANAGER Operational Safety Study	TCAS RA not Followed	1.0	01/09/2017

Abstract
As required by NM IR, EU Reg 970/2014 dated 12 September 2014, the NM identifies the Network 'Top 5' operational safety risk priorities. Operational safety studies have been launched covering all of the 'Top 5' risk priorities. The present study aims to serve as a reference for the Network actors in case they undertake operational safety analysis and improvement activities covering the identified risk priority area.

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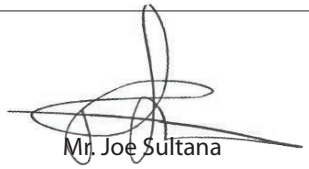
Director NM	 Mr. Joe Sultana	01.09.2017

Edition history

The following table records the complete history of the successive editions of the present document.

Edition No.	Edition Validity Date	Author	Reason
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0.3	29/052017		Pilot Survey Results
0.4	20/08/2017		DNM Review
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1. Executive summary

The EUROCONTROL Safety Improvement Sub-Group (SISG), reporting to the EUROCONTROL Safety Team, is tasked with identifying the 'Top 5' ATM Operational Safety Priorities. EUROCONTROL Network Manager is subsequently tasked with the production of Operational Safety Studies for each of the agreed 'Top 5' ATM Operational Safety Priorities.

SISG performed a series of reviews during summer 2015 and involved a series of dedicated workshops with 14 ANSPs, representing a large part of European air traffic. The two areas of specific interest selected by EUROCONTROL Safety Team are:

- Preventing mid-air collision en-route.
- Preventing runway collision.

With regards to en-route safety, 90 separation minima infringements were analysed. This represents a sample size of 36% of all Severity A and B events reported via the EUROCONTROL Annual Summary Template (AST). Seven (7) of the 90 events were classified as Severity A, 2 of which involved a failure to follow a TCAS Resolution Advisory (RA). Both of these events crossed through all managed barriers and were, therefore resolved only by Providence. As a result of this analysis, "TCAS RA Not Followed" was selected as being one of the 'Top 5' priority areas. The complete list of the current 'Top 5' priority areas is shown below for reference.

- Risk of operation without transponder or with a dysfunctional one.
- Sudden High Energy Runway Conflict.
- Controller Detection of potential runway conflict.
- "Blind spot" – inefficient conflict detection with the closest aircraft.
- TCAS RA Not Followed.

The methodology employed to create the Operational Safety Study was as follows:

- Generate a set of generic scenarios from possible scenario sources, mechanisms and outcomes.
- Consider what barriers exist that if implemented and deployed correctly could prevent a "TCAS RA Not Followed" event.
- Consider what barriers exist that if implemented and deployed correctly could mitigate the impact of a "TCAS RA Not Followed" event.
- Analysis of each generic scenario against the potential barriers to establish which of these barriers could be most effective over the whole range of scenarios.
- Review a set of actual events to confirm that the barriers suggested by the generic analysis validate that the same barriers should be the most effective in the live environment.
- Carry out an online survey of pilots that elicit responses to aid our understanding of why pilots sometimes do not follow a TCAS RA.
- Consider current industry best practice and known future developments.
- Draw conclusions from the study and make recommendations to stakeholders.

This study concluded that:

- The study is principally validated by an online Pilot Survey, supported by IATA, that elicited 3800 responses from 90 countries.
- The generic study identified only 3 barriers available to Flight Deck crew that could potentially prevent TCAS RAs from not being followed correctly. All of these barriers are only effective for a small number of generic scenarios. However, since one type of scenario is prevalent in the actual operation i.e. TCAS not followed due to visual acquisition; training and promotion of expected pilot response could be effective.
- This study identified only one barrier available to Flight Deck crew that could potentially mitigate the impact of pilots not following TCAS RAs correctly and that is Autopilot/Flight Director capability to fly the RA.
- According to the Pilot Survey, around 36% of pilots reported experiencing at least one TCAS RA situation within the 5 year period covered by the survey
- According to the Pilot Survey, around 15% of the pilots that reported encountering at least one TCAS RA within the 5 year period covered by the survey, reported not following an RA for various reasons.
- The percentage of TCAS RAs that are not followed is likely to be around 11%.
- According to the Pilot Survey, a decision not to follow an RA due to visual acquisition of the apparent intruder accounts for more than 70% of all RAs not followed without a valid reason.
- According to the Pilot Survey, neither having a Traffic Advisory (TA) prior to the RA, nor the type of RA was reported to make any significant difference to the likelihood of an RA being followed.

Recommendations are made that:

- IATA, Pilot Associations, Aircraft Operators and Regulators review the findings of this study and consider undertaking operational safety analysis and improvement activities for "TCAS RA Not Followed".
- IATA, Pilot Associations, Aircraft Operators and Regulators consider actions to support an increased active use of FDM in the monitoring of TCAS RA compliance and the provision of feedback to training organisations and flight crew involved.
- European ANSPs and the EUROCONTROL Safety Improvement Sub-Group (SISG) monitor occurrences involving "TCAS RA Not Followed" to determine changes in frequency and severity.
- All European stakeholders monitor and support the development of tools and procedures that may assist in the prevention and/or mitigation of "TCAS Not Followed" events.
- All European stakeholders promote and emphasise the requirement and importance of following TCAS RA commands despite an apparent intruder being visually identified and monitored (subject to the overriding safety of the aircraft).

2. Introduction

2.1 What is the purpose of this document?

The purpose of this report is twofold:

- To document the operational safety study on one of the 'Top 5' Network Manager operational safety priorities – "TCAS RA Not Followed".
- To serve as a reference for the Network actors in case they undertake operational safety analysis and improvement activities for "TCAS RA Not Followed" events.

2.2 What are the Network Manager 'Top 5' ATM Operational Safety Priorities

2.2.1 Risk of operation without transponder or with a dysfunctional one

Operations without transponder or with a dysfunctional one constitute a single threat with a potential of "passing" through all the existing safety barriers up to "see and avoid".

2.2.2 Sudden High Energy Runway Conflict

The scenario typically involves rapidly developing situation of runway entry in front of a high energy landing or taking-of aircraft at position where the available reaction time is close or less than the needed reaction time for detection, communication and collision avoidance manoeuvre.

2.2.3 Controller detection of potential runway conflict

Some Runway Incursion incidents could be prevented if controllers had better means to detect that the runway was occupied.

2.2.4 "Blind spot" – inefficient conflict detection with the closest aircraft

Loss of separation "Blind Spot" events are typically characterised by the controller not detecting a conflict with the closest aircraft. They usually occur when a controller is focussed on a "future situation" and has filtered out the most immediate aircraft.

2.2.5 TCAS RA Not Followed

Losses of Separation in the En-Route environment sometimes involve "TCAS RA not followed by one or more flight crews". Coordinated RA generation and response is an essential safety barrier; however, some events include a failure to follow the RA correctly or not following the RA at all.

2.3 How were the 'Top 5' identified?

The Network Manager identifies Network safety issues to enable aviation stakeholders to identify existing hazards and anticipate new operational risks.

Our ultimate goal is to keep the Network safe and able to increase its capacity and efficiency.

The EUROCONTROL Safety Improvement Sub-Group (SISG), reporting to the EUROCONTROL Safety Team, is tasked to identify the 'Top 5' ATM Operational Safety Priorities. The SISG followed a structured two-step process of operational safety prioritisation. Firstly SISG identified a list of priority areas.

The first step was to define broad priority areas for further prioritisation.

Based on the availability of reliable safety information, two risk areas were selected for detailed review:

- Runway Incursion
- Loss of Separation En-Route.

SISG performed a series of reviews during 2015 which involved a series of dedicated workshops with 14 ANSPs, representing a large part of European air traffic. It can be concluded that the analysed sample of incidents is sufficiently representative for the overall population of incidents in Europe.

Comprehensive barrier models – Safety Functions Maps (SAFMAPs) - were developed and populated with representative data from the participating ANSPs. The incident data is for high severity (classified as 'A' and 'B') events, which are on one side thoroughly investigated and on the other side – highly informative because the incident scenarios 'test' the majority of the available safety barriers.

As a result of the SAFMAP analysis, the 'Top 5' priority areas were suggested, agreed by SISG and endorsed by the Safety Team:

- Risk of operation without transponder or with a dysfunctional one.
- Sudden High-Energy Runway Conflict.
- Controller detection of occupied runway.
- "Blind spot" – inefficient conflict detection with the closest aircraft.
- TCAS RA Not Followed.

2.4 Why was "TCAS RA Not Followed" selected?

The sample of events analysed by EUROCONTROL includes 90 significant separation minima infringements for the En-Route phase of flight, of which 7 classified as severity A and 83 are classified as severity B.

The EUROCONTROL data shows a total of 248 Severity A or B events in the same period. Thus, the sample includes 36% of all reported events.

49 / 90 loss of separation events were resolved in the ATC domain, leaving 41 events to be resolved in the Pilot domain.

37/41 events were resolved either by the event being outside the range of TCAS intervention or by actual TCAS pilot response.

4 events remained. 1 event was resolved by late visual collision avoidance. Collision was only avoided in the remaining 3 events by Providence (luck).

Review of the 7 Severity A events:

- 3 incidents involved the ATCO not preventing a potentially conflicting aircraft to be overlooked when clearing or instructing another one – "blind spot".
- **2 incidents involved flight crew not following the flight profile commanded by a TCAS RA.**
- 1 incident involved an operation without a functional transponder.
- 1 incident involved air-ground communication misunderstanding.
- So, whilst "TCAS Not Followed" events are infrequent, nearly 30% of the most severe events in the sample involve this phenomenon.

It was therefore decided to select "TCAS RA Not Followed" as a subject for an Operational Safety Study.

2.5 How big is the problem across the Network?

A detailed study provided by one major European short-haul operator, suggests that a TCAS RA is received once in every 6500 flight hours or 3300 sectors. Data from IATA puts the figure at around one every 5500 flight hours. This figure may however be slightly skewed by a prevalence of TCAS RAs on Approach in USA involving a different traffic mix than Europe. How many of these TCAS RAs were not followed? This depends on the definition used to scope "not followed".

IATA studies of global TCAS RAs not followed put the percentage at around 4% of all RAs. An IATA analysis of European only data placed the percentage at only 1%; however, both of these studies were based on searching for key words in databases and not analysis of individual events.

Data collected in 2011 indicates that, taking all types of "not followed", the rate of non-conformity is closer to 35% in En-Route airspace. This was broken down into 21% inappropriate vertical speed, 11% no reaction and 3% opposite sense reaction.

Thus, conflicting data sources suggest that the scale of TCAS RAs not being followed correctly could be anywhere between 1% and 35%.

It was concluded in the planning stage of this study that the best source of information is the pilots themselves. A voluntary online survey was proposed and was supported by IATA and a number of European aircraft operators.

3. TCAS II Version 7.1

TCAS II Version 7.0 has been available since 1999. Based on an extensive analysis of version 7.0 performance, two changes were identified to improve the TCAS logic in Version 7.1.

3.1 Improvements made in TCAS v7.1 from v7.0.

3.1.1 New "Level Off Level Off" RA

Many cases were found in which pilots did not respond correctly to the "Adjust Vertical Speed, Adjust" (AVSA) RAs. Pilots increased their vertical rate instead of reducing it, consequently causing a deterioration of the situation (see Figure 1). The Adjust Vertical Speed RA was the RA whose aural annunciation did not clearly communicate what exact manoeuvre was required. It was also the most common RA, representing up to two-thirds of total RAs, all of which increased the potential for incorrect pilot response.

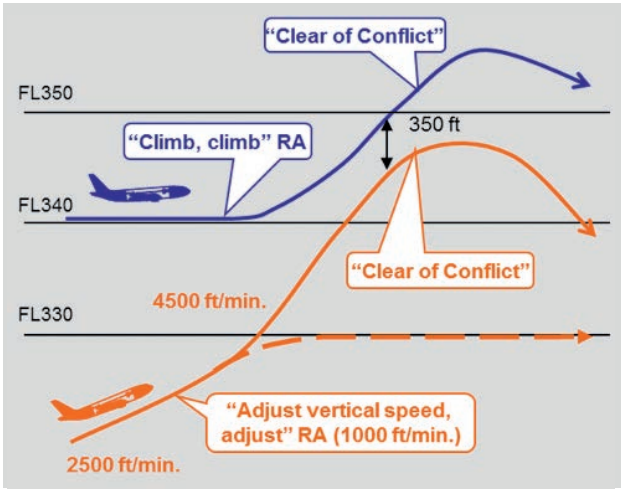


Figure 1: Unintentional opposite response to Adjust Vertical Speed RA in version 7.0.

Additionally, there have been numerous cases of level bust when pilots following the Adjust Vertical Speed RA went through their cleared level, often causing a follow up RA for the other aircraft above or below (see Figure 2).

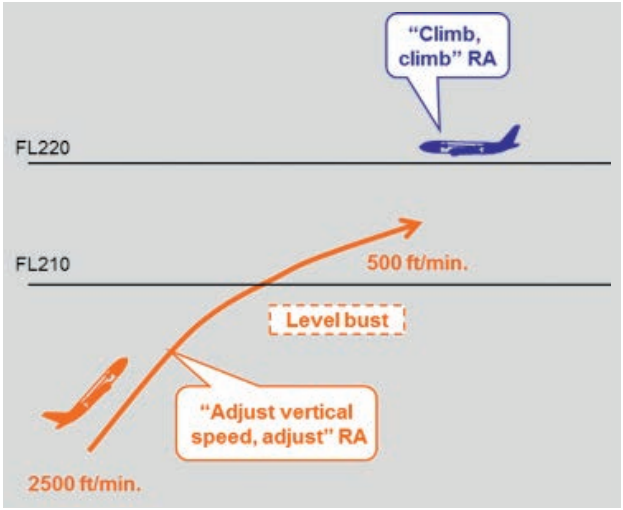


Figure 2: Level bust resulting from the response to Adjust Vertical Speed RA in version 7.0.

To address these issues, in version 7.1 the AVSA RA has been replaced with a new "Level off, level off" RA. The AVSA RA in version 7.0 required a reduction of the vertical rate to 0, 500, 1000, or 2000 ft/min depending on the geometry of the situation. The "Level Off, Level Off" RA requires a reduction of vertical rate to 0 ft/min. The level off is to be achieved promptly, not at the next standard flight level. The aural message "Level off, level off" has the benefit of being intuitive and the associated manoeuvre corresponds to the standard levelling off manoeuvre.

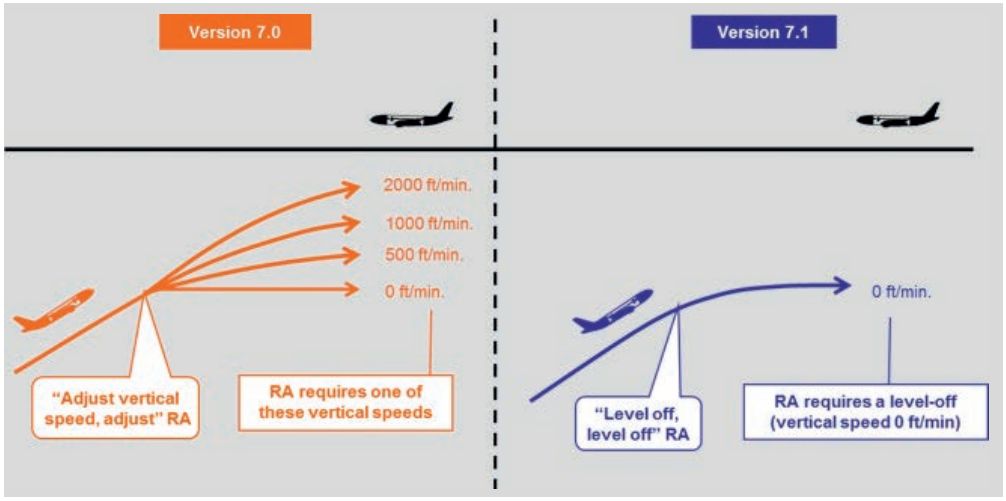


Figure 3: Comparison of Adjust Vertical Speed (version 7.0) and Level Off (version 7.1) RAs.

Additionally, replacing the multiple climb/descent rates of the AVSA RA, the "Level Off, level Off" RA should minimise the altitude deviations induced by TCAS (level busts while "flying the green arc" – see Figure 4).

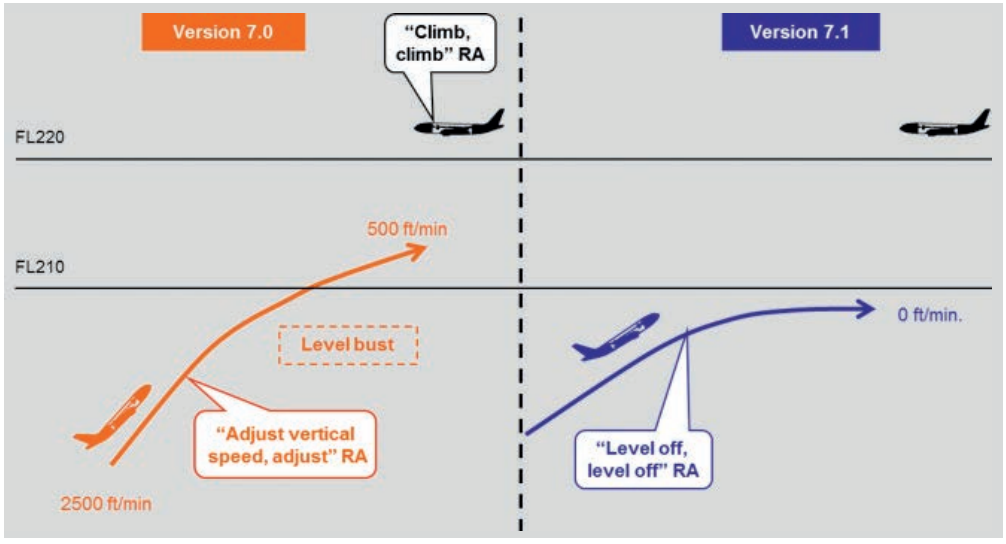


Figure 4: Comparison of Adjust Vertical Speed (version 7.0) and Level Off (version 7.1) RAs: minimised altitude deviations.

3.1.2 Improved reversal logic

The design of TCAS II version 7.0 allowed for reversal RAs (i.e. "Climb, climb NOW" and "Descend, descend NOW") to be issued in coordinated encounters (i.e. both aircraft TCAS II equipped) when the current RA is no longer predicted to provide sufficient vertical spacing.

After version 7.0 was introduced a weakness in the sense reversal logic was discovered in "vertical chase with low vertical miss distance" geometries: version 7.0 failed to reverse an RA if two aircraft converging in altitude remained within 100 feet (see Figure 5). This scenario could occur when one aircraft was not following the RA or was not TCAS II equipped, and followed an ATC instruction or performed an avoidance manoeuvre based on visual acquisition.

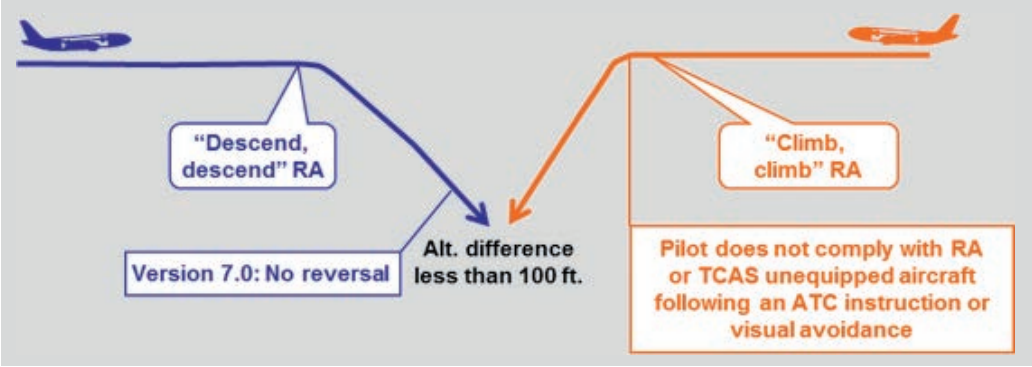


Figure 5: Geometry in which version 7.0 does not reverse an RA.

When version 7.1 detects that an aircraft is not responding correctly to an RA, it will issue a reversal RA to the aircraft which manoeuvres in accordance with the RA (i.e. "Climb, climb NOW" or "Descend, descend NOW" RA) and will change the sense of RA issued to the aircraft that is not responding correctly to be compatible with the reversal, e.g. "Maintain vertical speed, maintain" RA (see Figure 6). The feature will be activated only if at least 4 seconds remain before CPA, because a reversal RA triggered in the last 4 seconds gives little chance for correct pilot's response, and only if at least 10 seconds have elapsed since the initial RA, because a reversal RA triggered too early does not give the pilot enough time to comply with the initial RA.

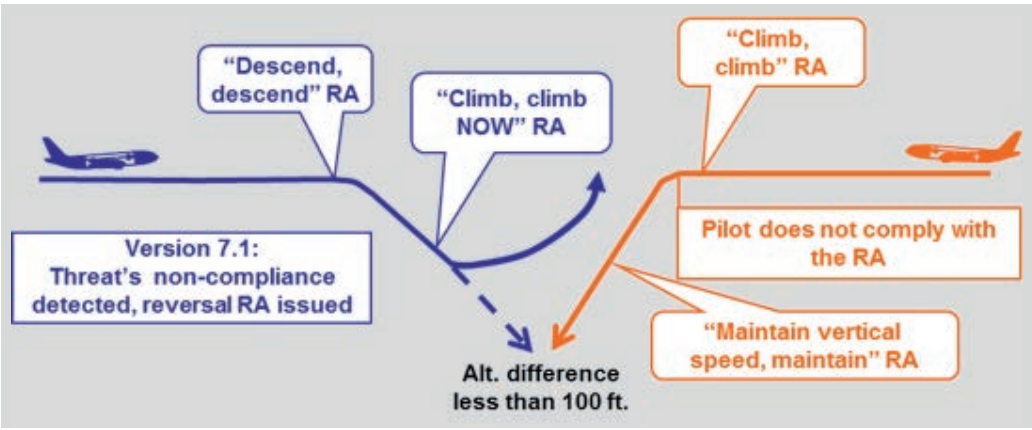


Figure 6: Improvement of reversal logic in version 7.1 (both aircraft equipped).

In single equipage encounters, version 7.1 recognises the situation and will issue a reversal if the unequipped threat aircraft moves in the same vertical direction as the TCAS II equipped aircraft.

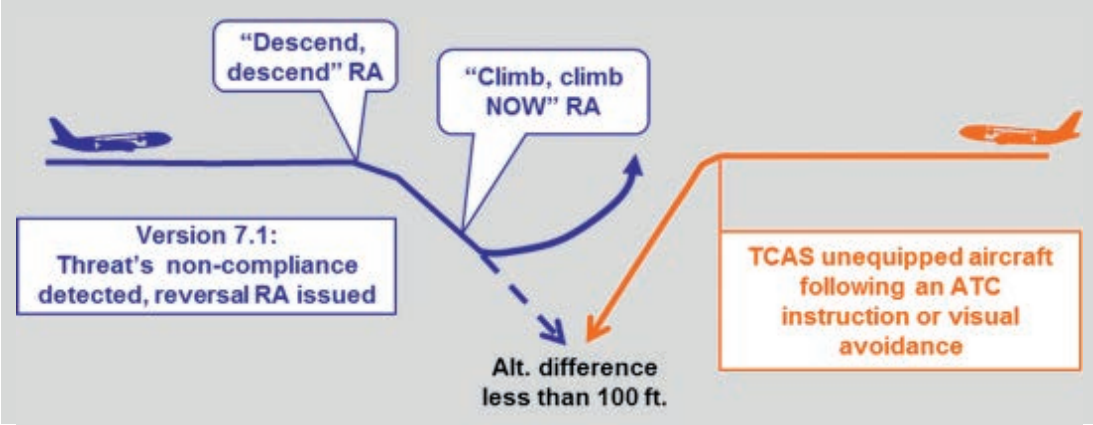


Figure 7: Improvement of reversal logic in version 7.1 (only one aircraft equipped).

3.2 Cockpit presentation

It may be useful for the non-flying community e.g. air traffic controllers, to see and understand what the pilot sees and hears during a TCAS RA event.

The traffic display depicts the position of nearby traffic, relative to own aircraft. It indicates the relative horizontal and vertical position of other aircraft based on the replies from their transponders.

Displayed traffic information also indicates Proximate, TA, and RA status. The primary purpose of the traffic display is to aid the flight crew in the visual acquisition of transponder equipped aircraft. The secondary purpose of the traffic display is to provide the flight crew with time to prepare to manoeuvre the aircraft in the event an RA is issued.

A majority of the traffic displays also provide the pilot with the capability to select multiple ranges and to select the altitude band for displayed traffic. These capabilities allow the pilot to display traffic at longer ranges and with greater altitude separation while in cruise flight, while retaining the capability to select lower display ranges in terminal areas to reduce the amount of display clutter.

Examples of traffic displays are shown in Figures 8, 9 and 10 below.

Figure 8: TCAS traffic display example - dedicated display.

Figure 9: TCAS traffic display example – IVSI combined with TCAS traffic display.

Figure 10: TCAS traffic display example – Electronic Flight Instrument System (EFIS).

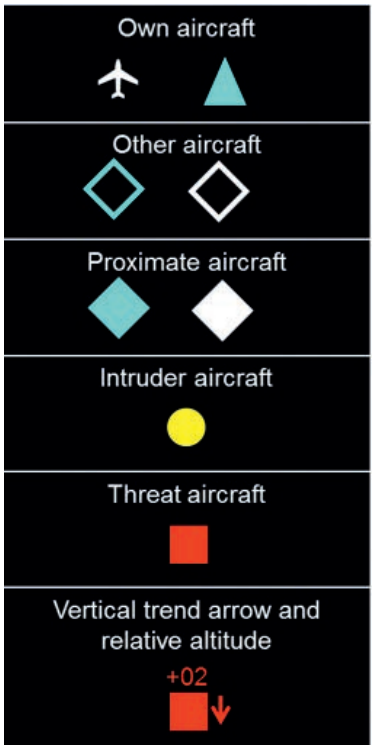


Figure 11: Standardised traffic

On the TCAS traffic display both colour and shape are used to assist the pilot in interpreting the displayed information.

Own-aircraft is depicted as a white or cyan (light blue) aircraft-like symbol. The location of own aircraft symbol on the display is dependent on the display implementation.

Targets are displayed by different symbols, according to their threat status:

- Hollow cyan (light blue) or white diamond – for other traffic.
- Solid cyan (light blue) or white diamond – for proximate traffic.
- Solid yellow or amber circle – for intruders (i.e. aircraft which trigger a TA).
- Solid red square – for threats (i.e. aircraft which trigger an RA).

Traffic within 6 NM and 1200 ft of own aircraft, are called Proximate traffic and are differentiated from other traffic by a solid white or cyan (light blue) diamond. In the event of an advisory, this symbol indicates that the aircraft is not the intruder generating the advisory, when the closest traffic may not necessarily be the most threatening. Each symbol is displayed according to its relative position to own aircraft. The display accuracy depends on the selected scale. When the 10 NM scale is in use the positional accuracy is approximately ±1 NM in range and approximately ±10 degrees in bearing.

Vertical data is also shown next to the relevant symbol (when the intruder is reporting altitude). The relative altitude is displayed in hundreds of feet, above the symbol if the intruder is above own aircraft and below the symbol in the opposite case. In some aircraft, the flight level of the intruder can be displayed instead of its relative altitude. Additionally, an "up" or "down" trend arrow is shown when the target aircraft is climbing or descending, respectively, at more than or equal to 500 ft/min.

3.2.1 RA display: classical instrumentation (IVSI)

The traffic display is incorporated into the centre of the Instantaneous Vertical Speed Indicator (IVSI) – see Figure 9 and Figure 10. A 2-NM radius circle is shown by dots or lines around the own aircraft symbol.

An RA is shown by the display of a red arc, which indicates the range of vertical rates, which are to be avoided. When appropriate, a green arc, shown next to the red arc, indicates to the pilots that they should manoeuvre the aircraft to reach the required vertical rate, shown in the green arc. If there is more than one threat, two red arcs may flank the range of the required vertical rates.

3.2.2 RA Display: Electronic Flight Instrument System (EFIS)

There are two Primary Flight Display (PFD) concepts:

- Display on the artificial horizon – a resolution advisory is shown by a red or orange isosceles trapezoid delineating an area showing the flight attitude values which are to be avoided. This provides direct guidance on the pitch angle to be achieved by the pilots. This form of display does not include any green fly-to area.

- Display on the Vertical Speed Indicator – the RA is shown in the same way as in "classic" cockpits. A red area marks the range of vertical rates to be avoided; a green area indicates to the pilots the required vertical rate.

Figure 12 shows examples of TCAS II advisories as shown on IVSI and Electronic Flight Instrument System (EFIS) instrumentation. A full list of TCAS II advisories can be found in the EUROCONTROL ACAS Guide.

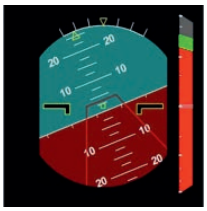
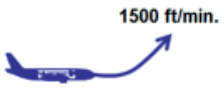
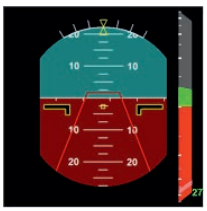
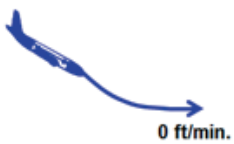
Advisory and aural annunciation	IVSI	EFIS	Manoeuvre
Climb "Climb, climb"			
Level Off (upward sense initial RA) "Level off, level off"			

Figure 12: Examples of TCAS II advisories

3.3 Required pilot actions

In the event of an RA, pilots shall respond immediately by following the RA as indicated unless doing so would jeopardise safety of the aircraft. The aural annunciation depends on the RA issued. The threat aircraft symbol on the traffic displays changes to a red solid square and the ranges of the vertical rates to be avoid and the required vertical rate are displayed on appropriate instruments (cf. ICAO PANS OPS, Doc 8168, vol. I, Chapter 3, 3.2).

Pilots are required to respond to the first RA within 5 seconds and any subsequent RAs within 2.5 seconds. Pilots must not manoeuvre contrary to the RA. If a TCAS RA manoeuvre is contrary to other critical cockpit warnings, pilots should respect those other critical warnings – responses to stall warning, wind shear, and GPWS/TAWS take precedence over an TCAS RA, particularly when the aircraft is less than 2,500 feet above ground level (AGL).

3.3.1 RA and visual acquisition

Pilots sometimes do not follow an RA as they believe they have the threat aircraft in sight and judge there will be sufficient separation. In this respect, ICAO provisions are quite clear that in the event of an RA, the pilot must respond immediately by following the RA unless doing so would jeopardise the safety of the aircraft. That provision applies in all airspace classes and all meteorological conditions. In real-time the pilot has little chance to assess whether the traffic acquired visually is in fact the one against which the RA has been generated or its trajectory.

3.3.2 Inappropriate pilot responses

In some instances pilots ignore RAs or respond in the opposite sense. The main causes are performing their own avoidance manoeuvre (based on visual acquisition or own judgement); misinterpretation of RA display or RA aural annunciation; or giving priority to ATC instruction. Pilots must respond to all RAs a timely manner, applying the vertical rate required by the RA as accurately as possible in the circumstances and must never manoeuvre in an opposite sense to a RA.

3.3.3 RA inhibitions

If a TCAS RA occurs when the aircraft is at the maximum altitude for its current weight, the pilots should not assume that they cannot comply with a climb RA because of that. In these cases it is expected that speed will be traded for height. Some aircraft types have built-in inhibits which will preclude Climb RAs at maximum altitudes.

Whether or not inhibitors apply, it is still possible in some cases for an RA to exceed the capabilities of the aircraft. If a stall warning is generated, a response to stall warning takes precedence over a TCAS RA.

For all aircraft, pre-defined limitations apply at lower altitudes to prevent RAs in proximity to the ground (see Table 1). RAs are inhibited based on radar (radio) altimeter reported heights. Hysteresis values of +100 feet (for climbing aircraft) and –100 feet (for descending aircraft) ensure that the inhibition state does not oscillate rapidly should the aircraft be flying close to the nominal altitude boundary but periodically passing above and below that boundary (e.g. when flying over hilly terrain).

Alert type	Alert inhibited below
Increase Descent RA	1550 ft (±100 ft) AGL
Descend RA	1100 ft (±100 ft) AGL
All RAs	1000 ft (±100 ft) AGL
All TCAS aural alerts	500 ft (±100 ft) AGL

Table 1: TCAS alert generation inhibitions.

4. The Generic Process

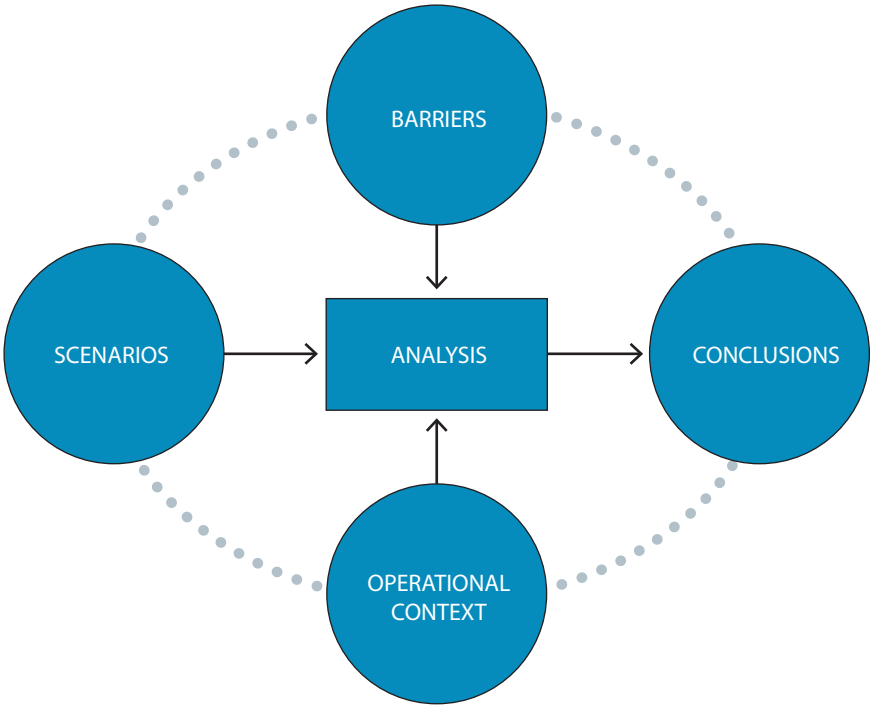


Figure 13 above provides an overview of the generic steps in the Operational Safety Study.

A generic process was designed to analyse ATM Operational Safety Priorities (the 'Top 5') as to provide a common methodology for assessment and evaluation. The process starts with three preparatory steps:

- Identification of the operational context pertaining to the operational area considered.
- Definition of the operational scenarios.
- Identification of safety barriers (both preventing and mitigating the effect of the event).

Once all those data are collated an analysis of effectiveness of barriers against the identified operational scenarios will be performed and correlated with analysis of real life occurrences. Once the analysis is complete the study will provide the conclusions.

5. Operational Context

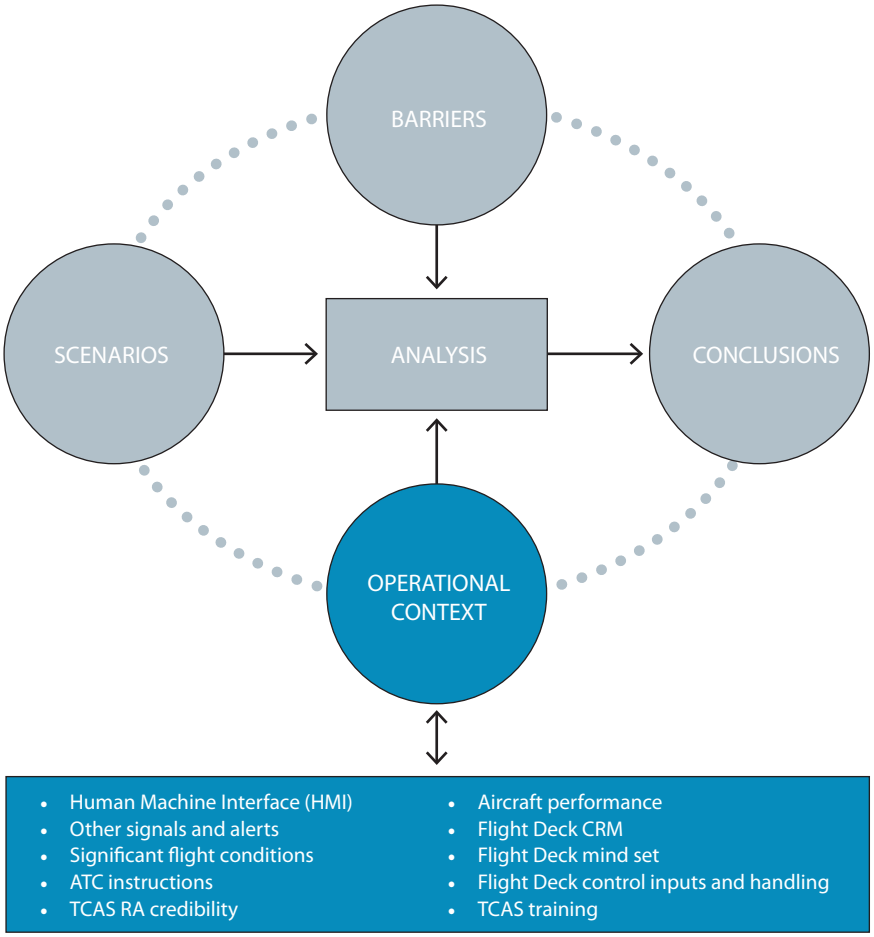


Figure 14: Operational Context in the Analytical Framework

The Operational Context is the total situational scenario present at the time of a TCAS RA that may impact on the decisions and actions of the flight crew.

5.1 Operational Context Factors

The operational context may include any or a combination of the following factors:

- Human Machine Interface (HMI).
- Other signals and alerts.
- Significant flight conditions.
- ATC Instructions.
- TCAS RA credibility.
- Aircraft Performance.
- Flight Deck CRM.
- Flight Deck mind set.
- Flight Deck control inputs and handling.
- TCAS Training.

5.1.1 Human Machine Interface (HMI)

This includes any factor concerning the perception and interpretation of the TCAS HMI and annunciations. The appearance and functionality of the TCAS HMI may differ depending on aircraft fit.

The look and method of presentation of the TCAS HMI must meet the requirements of TCAS MOPS but may vary in detail according to the aircraft manufacturer and associated supplier.

5.1.2 Other signals and alerts

The presence of other Flight Deck signals and alerts simultaneous to the TCAS RA may affect Flight Deck response. Any factor associated with other warnings which upon recognition of either, TCAS will automatically operate in TA-Only mode and all TCAS aural annunciations will be supressed:

- TAWS (EGPWS)/GPWS.
- Wind-shear warning.

5.1.3 Significant Flight Conditions

The timing and assessed urgency of significant flight conditions may lead flight crew to react to an RA differently. This includes any factor concerning concurrent significant flight conditions. These are professional judgement calls balancing the requirement to follow the TCAS RA against significant conditions:

- Stall warning or Buffet.
- Negative wind-shear without warning.
- Proximity to Significant CB activity and currents.
- Severe weather.
- Proximity to terrain.

5.1.4 ATC Instructions

The presence of ATC instructions that contradict the TCAS RA could influence flight crew action.
Prior ATC instruction to turn being actioned when the RA occurs.
This includes any factor concerning conflicting ATC instructions.
Receipt of an ATC instruction either just before or during the response to the TCAS RA may instil uncertainty or result in the flight crew not following the flight profile demanded by TCAS or by a delayed response:

- ATC instruction to climb/descent in the opposite sense to that required by the TCAS RA.
- ATC instruction to turn whilst flight crew are executing the RA.
- ATC instruction to ignore the RA.
- Prior ATC instructions to turn being actioned when the RA occurs.

5.1.5 TCAS RA Credibility

The frequency and the credibility of TCAS alerts could influence flight crew action.
This includes any factors concerning a flight crew assessment of TCAS RA credibility:

- RA perceived as false (self-tracking, corrupted or incorrect data).
- RA assessed as a Nuisance Alert (real but deemed to be irrelevant).
- Rapid succession of different RAs (as in the case of encounter with military fast jet).

5.1.6 Aircraft Performance

Assessments by the flight crew of the available performance of the aircraft when an RA is triggered may constrain their response.
This includes any factor concerning actual or perceived aircraft performance limitations.

- High climb/descent rate.
- Low climb/descent rate.
- Limited options at high level (coffin corner, fuel temperature, heavy or not clean).

5.1.7 Flight Deck CRM

Seniority issues and who is actually flying the aircraft and from which seat could influence flight crew output.
This includes any factor concerning flight crew interactions, hierarchy and relations.
It is possible that there may be different or delayed responses to the depending upon seniority issues, physical position of the crew member acting as pilot flying (PF) and the working relationship of the crew.

- Significant authority gradient on the Flight Deck.
- Physical position of crew member acting as pilot flying (PF).
- Temporary absence of one pilot from the Flight Deck (or taking in-seat controlled rest) at the time of the RA.

5.1.8 Flight Deck mind-set

The mind-set of the flight crew immediately prior to and during the TCAS RA may influence their actions.
This includes any factor concerning the mind-set or expectations of the crew immediately beforehand. A crew may change or limit its response accordingly:

- Expectation of an RA, following a Traffic Advisory or ATC advice.
- Expectation of an RA based on previous experience.
- Perceived pressure not to delay flight e.g. RA during approach that would result in a go-around.
- Limited response or no action upon visual acquisition.
- Limited response during Initial climb or final approach.
- Autopilot (AP) engaged or not at the time
- Requirement/No requirement to disconnect AP to fly the RA

5.1.9 Flight Deck control inputs and handling

This includes any factor concerning control inputs and handling of the aircraft, such as an inappropriate vertical speed approaching the selected level. A crew may change or limit its response accordingly:

- Inappropriate high vertical speed.
- Control inputs in an inappropriate order.
- Over-reliance on automation e.g. being behind the aeroplane.

5.1.10 TCAS Training

The scope, completeness and recency in TCAS training could influence the response to a TCAS RA.
This includes any factor concerning the training of TCAS.
TCAS should be included in recurrent training sessions and flight crews should be tested to ensure they are fully conversant with TCAS procedures, capabilities and limitations, and know how to respond correctly to RAs:

- The type of training e.g. simulator, CBT.
- Scope of TCAS training e.g. number of contacts, expectation.
- Completeness of TCAS training i.e. coverage of all types of RA.
- Frequency of training scenario updates.
- Frequency of pilot training in TCAS manoeuvres.

6. Generic Scenarios

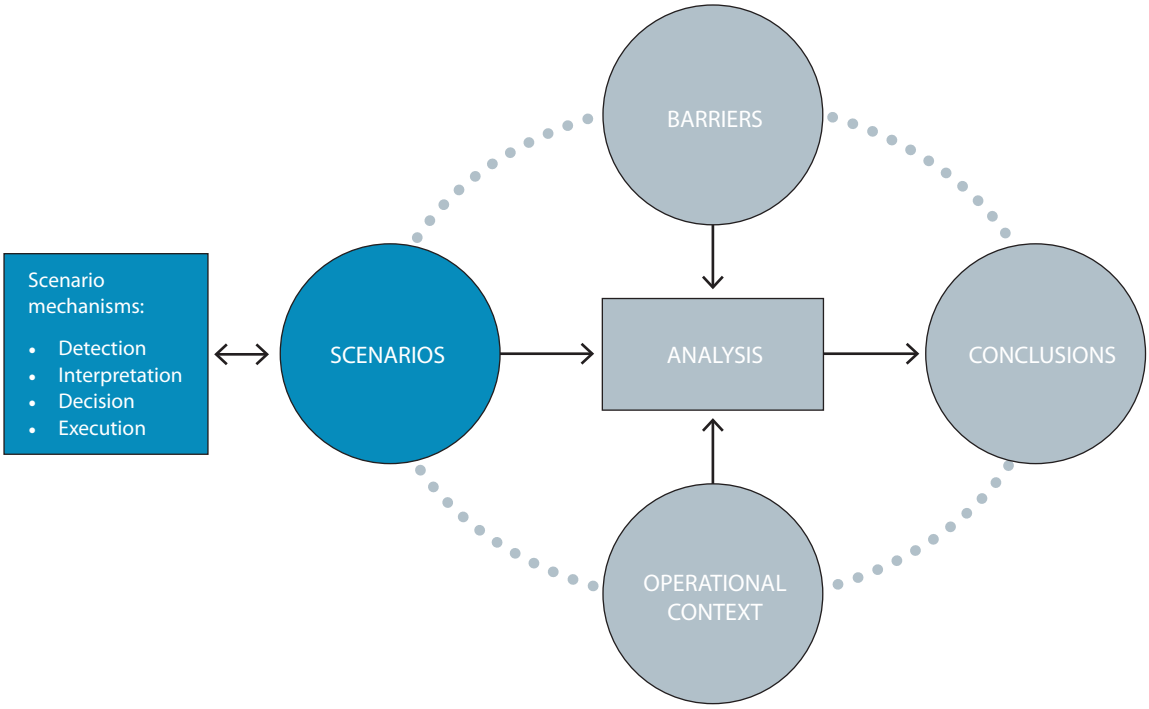


Figure 15: Scenario Mechanisms in the Analytical Framework

Generic operational scenarios are needed to deconstruct the complexity of analysis. Scenario definition is specific to help decide the efficiency of the safety barriers whilst generic enough to keep their number relatively small. The definition of generic operational scenarios takes the form of a synthesis of two sources (top-down and bottom-up) of information:

- A systematic analytical break-down of the operational scenario into sub-scenarios. This is based on all theoretically possible combinations of the scenario (1) mechanisms, (2) sources and (3) outcomes.

- A review of the publicly available information from investigation reports of accidents and serious incidents investigated following the provisions of ICAO Annex 13 and confidentially provided data in respect of less significant incidents.

6.1 Analytical deconstruction of "TCAS RA not followed

6.1.1 Scenario Mechanisms

A failure to follow an TCAS RA alert correctly could be triggered at any one of four Scenario Mechanisms:

1. DETECTION – the flight crew do not detect the TCAS RA alert correctly or react in the belief that an TCAS RA has been triggered when it has not.

.

2. INTERPRETATION – the flight crew have detected the TCAS RA alert but do not interpret the TCAS HMI correctly and therefore do not fly the flight profile demanded.

3. DECISION – the flight crew have detected the TCAS RA alert and understand the flight profile demand, however they may choose not to carry out the required actions.

4. EXECUTION – the flight crew have detected the TCAS RA alert, understand the flight profile demanded and decide to follow the TCAS RA but do not complete the action required correctly.

6.1.2 Scenario Sources

The OPERATIONAL CONTEXT list produces the SCENARIO SOURCES:

1. **Detection**
   a) HMI
   b) Other signals and alerts
   c) Flight Deck Mind-set

2. **Interpretation**
   a) HMI
   b) Flight Deck CRM
   c) Crew TCAS training

3. **Decision**
   a) Other signals and alerts
   b) ATC Instructions
   c) TCAS credibility
   d) Aircraft Performance
   e) Flight Deck mind-set
   f) Significant Flight Conditions
   g) Crew TCAS training

4. **Execution**
   a) HMI
   b) Delayed or Inadequate Response
   c) Unintentional Response
   d) Aircraft Performance effects
   e) Flight Deck CRM
   f) Crew TCAS training
   g) Flight Deck mind-set
   h) No or limited response possible due short duration of RA
   i) Flight Deck control inputs and handling

6.1.3 Scenario Outcomes

The Scenario Outcome may be any of four possible outcome types.

1. No action taken in response to TCAS RA
2. Flight profile change is less than that required by TCAS RA
3. Flight profile change is in excess of that required by TCAS RA
4. Flight profile change is in the opposite sense than that required by TCAS RA

The Scenario Outcomes are elucidated by their Mechanisms and Sources as tabulated as Table 2 below:

Table 2: TCAS RA Not Followed Scenarios

1. TCAS RA not followed due lack of Detection	1a	Lack of Detection of TCAS RA due HMI issues
	1b	Lack of Detection of TCAS RA due presence of other signals and alerts
	1c	Lack of Detection of TCAS RA due Flight Deck Mind-set
2. TCAS RA not followed due Misinterpretation	2a	Misinterpretation of TCAS RA due HMI issues
	2b	Misinterpretation of TCAS RA due Flight Deck CRM
	2c	Misinterpretation of TCAS RA due crew TCAS training
3. TCAS RA not followed due pilot decision	3a	Decision not to follow RA due to other signals and alerts
	3b	Decision not to follow RA due to contradictory ATC Instructions
	3c	Decision not to follow RA due TCAS credibility issues
	3d	Decision not to follow RA due aircraft performance issues
	3e	Decision not to follow RA due to Flight Deck mind-set
	3f	Decision not to follow RA due to Significant Flight Conditions
	3g	Decision not to follow RA due to inadequate TCAS Training
4. TCAS RA not followed due pilot execution	4a	TCAS RA not executed as demanded due to HMI Issues
	4b	TCAS RA not executed as demanded due to late or inadequate response
	4c	TCAS RA not executed as demanded due to unintentional response
	4d	TCAS RA not executed as demanded due to aircraft performance issues
	4e	TCAS RA not executed as demanded due to Flight Deck CRM
	4f	TCAS RA not executed as demanded due to inadequate TCAS training
	4g	TCAS RA not executed as demanded due to Flight Deck mind-set
	4h	TCAS RA not possible to execute due duration of RA less than reaction time
	4i	TCAS RA not executed as demanded due to Flight Deck control inputs and handling

7. Barriers

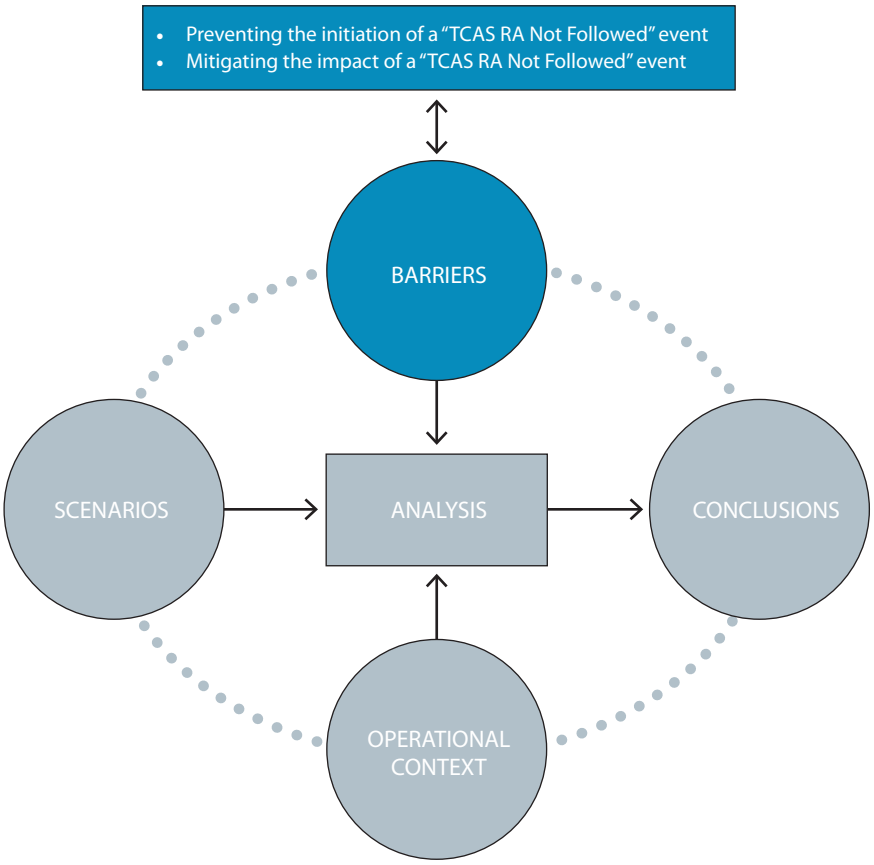


Figure 16: Barriers in the Analytical Framework

7.1 Barriers are opportunities in some situations

The barriers are not recommendations. The Barriers included in this risk review have been identified as possible ways that detection of a potential "TCAS RA not followed" event could be employed and/or the consequences mitigated.

Their inclusion does not imply that they are relevant to all situations and neither does it imply that promotion of their adoption by aircraft operators would necessarily be appropriate in all circumstances. It may be possible to identify more potentially useful barriers than are included here. In order to define the barrier there is a need first to define the generic barrier groups for reducing the risk of detection of potential "TCAS RA Not Followed" events. The figure below represents a generalised SAFMAP for Mid-Air Collision En-Route.

This generalised SAFMAP is derived from the Level 0 Mid-Air Collision SAFMAP V2016 and is the most generic barrier model for preventing Mid-air collisions because of situations of "TCAS RA not followed".

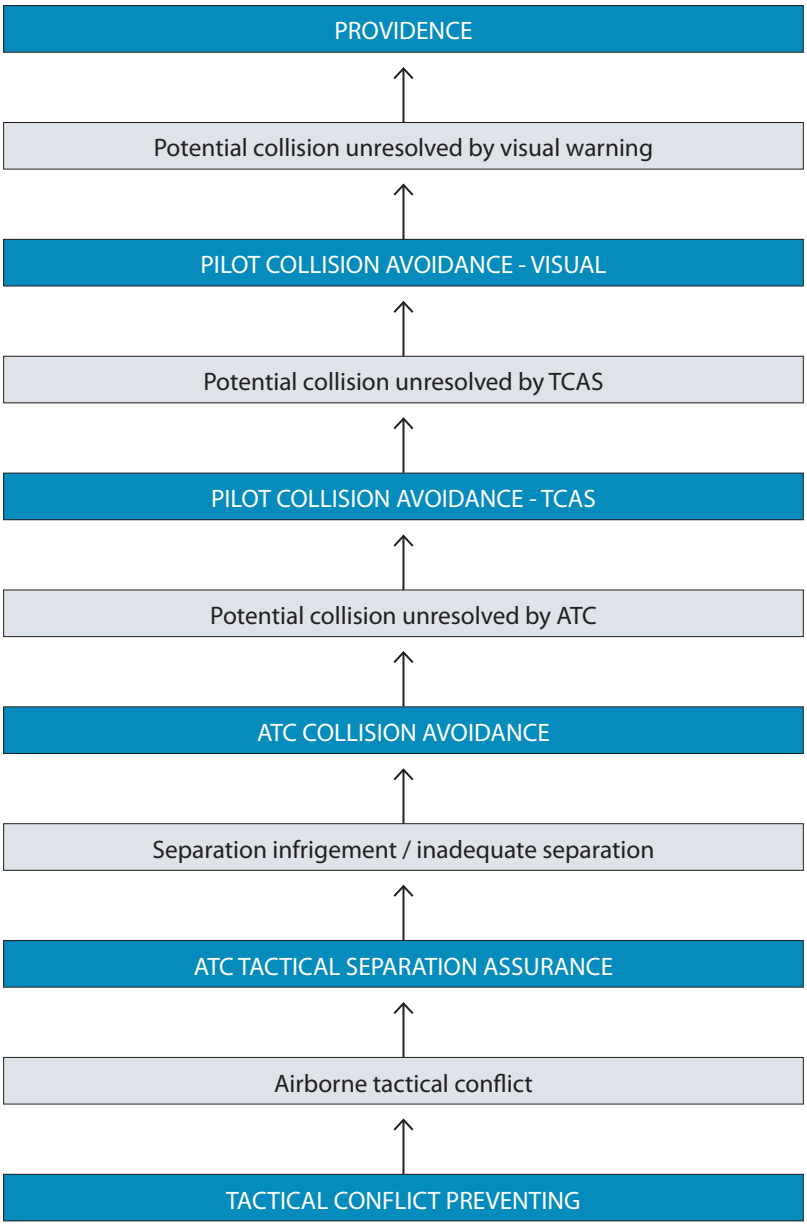


Figure 17: A Barrier Model for Mid-air Collision Avoidance

7.2 Two types of barriers

There are two major sets of barriers which can reduce the risk associated with "TCAS RA not followed" events. These barriers are identified based on a wide literature search and consultation.

- Prevention of "TCAS RA Not Followed": These barriers, when deployed and employed correctly, are capable of preventing a "TCAS RA not being followed".

- Mitigation of the outcome of "TCAS RA Not Followed": These barriers, when deployed and employed correctly, are capable of alerting Pilots to a potential conflict during the initial stages of an event involving not following the commands of an activated TCAS RA, in sufficient time to act in order to prevent a collision.

7.3 Barriers preventing the initiation of a "TCAS RA Not Followed" event (PB)

Table 3: Preventing Barriers

Barriers that could prevent a "TCAS RA Not Followed" event from initiation	PB1	Following a TCAS TA: TCAS RA Prevention Functionality by Auto Pilot reducing rates of climb/descent approaching selected level.
	PB2	Enhanced TCAS Training to include multiple tracks, crossing and reversal RAs,
	PB3	Training and Enforcement of SOPs requiring TCAS RAs to be followed unless the safety of the aircraft would be compromised.

7.4 Barriers mitigating the impact of a "TCAS RA Not Followed" event

Table 4: Mitigating Barriers

Barriers mitigating the safety risk of a "TCAS RA Not Followed" event	MB1	Autopilot/Flight Director capability to fly the RA

8. Analysis of Barriers in Generic Scenarios

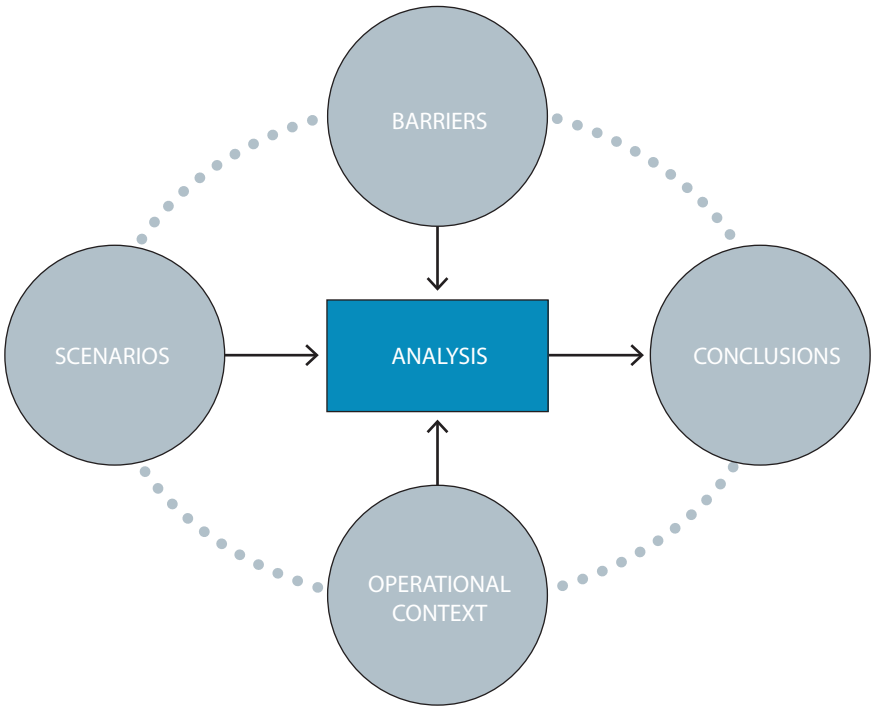


Figure 18: Analysis in the Analytical Framework

8.1 Prevention Barrier Assessment

The first step of the analysis consists of assessing the potential effectiveness of the prevention barriers in the defined operational scenarios. The high level assessment considers the operational scenarios and is based on expert judgement. The barriers are assessed individually; the analysis does not consider the interactions of more than one barrier acting in combination.

8.1.1 Colour Code Used in the Barrier Analysis

Table 5: Colour Coding for Barrier Efficiency

Red	Barrier that is either inefficient or is not intended for the operational scenario
Yellow	Barrier that is partially effective for the operational scenario OR only effective under certain conditions
Green	Barrier that is effective and efficient for the operational scenario.

8.1.2 Barrier Analysis Tables

Table 6: Preventing Barrier Analysis (1)

	1a	1b	1c	2a	2b	2c	3a	3b	3c	3d	3e	3f	3g
PB1: Following a TCAS TA: TCAS RA Prevention Functionality by Autopilot reducing rates of climb/descent approaching selected level.													
PB2: Enhanced TCAS Training to include multiple tracks, crossing and reversal RAs.													
PB3: Training and Enforcement of SOPs requiring TCAS RAs to be followed.													

Table 6: Preventing Barrier Analysis (2)

	4a	4b	4c	4d	4e	4f	4g	4h	4i
PB1: Following a TCAS TA: TCAS RA Prevention Functionality by Autopilot reducing rates of climb/de-scent approaching selected level.									
PB2: Enhanced TCAS Training to include multiple tracks, crossing and reversal RAs									
PB3: Training and Enforcement of SOPs requiring TCAS RAs to be followed.									

8.1.3 Effectiveness of the Prevention Barriers

In order to organise the results, a scoring system was considered. The main purpose is to give a comparison scale and an indication on how effective a barrier can be across all considered scenarios and not to provide an absolute ranking (the higher the score doesn't necessarily equate to a more effective barrier).

The scoring system utilised to rank the applications is as follows: zero points for an ineffective barrier (red), one point for a partially effective barrier (yellow) and three points for and effective barrier. Effectiveness is rated on a scale of:

- 76% - 100% Very High
- 51% - 75% High
- 26% - 50% Medium
- 1% - 25% Low

Table 8: The ranking for the Preventing Barriers; this ranking indicates which are the barriers that are more effective in most operational scenarios.

Barriers	Barrier Description	Score	Effectiveness
PB1	Following a TCAS TA: TCAS RA Prevention Functionality by Autopilot reducing rates of climb/descent approaching selected level.	9	LOW
PB2	Enhanced TCAS Training to include multiple tracks, crossing and reversal RAs.	4	LOW
PB3	Training and Enforcement of SOPs requiring TCAS RAs to be followed	12	LOW

Table 6 shows that little is available to prevent a potential "TCAS RA not followed" event from being initiated.

Training and enforcement of SOPs requiring TCAS RAs to be followed in all circumstances (PB3) could prevent the events whereby pilots detect and interpret the RA but make a decision not to follow it. This could be backed up by increased active use of FDM in the monitoring of TCAS events.

8.2 Mitigation Barrier Assessment

Table 9: Mitigating Barrier Analysis (1)

	1a	1b	1c	2a	2b	2c	3a	3b	3c	3d	3e	3f	3g
MB1: Autopilot/Flight Director Capability to fly the RA													

Table 10: Mitigating Barrier Analysis (2)

	4a	4b	4c	4d	4e	4f	4g	4h	4i
MB1: Autopilot/Flight Director Capability to fly the RA									

Table 11: Mitigating Barrier Effectiveness

Barriers	Barrier Description	Score	Effectiveness
MB1	Autopilot/Flight Director Capability to fly the RA.	49	VERY HIGH (78%)

The analysis of the only barrier identified that may mitigate the outcome of a "TCAS RA not followed" event shows that it could, if deployed and allowed to operate to design, have a significant impact on the outcome of TCAS RA events.

At present, this capability is only available on new models from one manufacturer, with a retrofit being available for older fleet aircraft. Currently, it is unlikely that this capability will become available from any other manufacturer due to patenting issues.

9. Illustrative examples of actual "TCAS RA not followed" events

The actual safety events described are either in the public domain or have been supplied with the permission of the relevant authorities. In order to dis-identify all stakeholders whilst maintaining the safety lessons, the following editorial actions have been taken:

- No location, Aircraft Operator, ATCC or ANSP is specified.
- The aircraft involved in each event are denoted solely by the aircraft type.
- No airway, reporting point or routing is specified. In cases where a description of operational situation is helpful, such details may be fictitious whilst maintaining the general relationship that needs to be described.

Because the reports used in this section came from various sources, they varied in the level of detail provided (e.g. note very report provided details on timing of Traffic Advisories or Clear of Conflict messages) which is reflected in the description of events below.

Figures depicting the events below are not to scale.

9.1 Event 1: Increased rate of descent contrary to RA to follow ATC instruction with visual acquisition.

Table 12: Event 1 Factsheet

Aircraft:	B757 (A)
Type of Initial TCAS RA:	Adjust Vertical Speed to zero (Level Off in V7.1)
Pilot Action:	Increased rate of descent
Why:	Decision (3e): Visual acquisition. Obeyed ATC instruction
Type of Subsequent TCAS RA	Maintain Vertical Speed (descent)
Pilot Action:	Correct – Continued Descent

Aircraft:	B757 (B)
Type of Initial TCAS RA:	Descend
Pilot Action:	Correct - Descend
Why:	
Type of Subsequent TCAS RA	Climb
Pilot Action:	Correct - Climb

B757 (A) was at FL390 in the vicinity of B757 (B) aircraft at FL370. Both aircraft were heading southwest with B757 (A) a mile to the west of B757 (B). The ATC controller gave B757 (A) a direct routing and following a request for immediate descent, clearance to FL250. (Note: a request for immediate descent is a common precursor to "Controller Blind Spot error").

The controller reported that at this point, the radar display label for B757 (B) was showing FL400 (not FL370) and the one for B757 (A) was showing FL390. The Flight Progress Strips were, however, correctly marked.

The B757 (B) crew noted from its TCAS display that the aircraft above was beginning a descent and TCAS activation followed, first a TA and then a "Descend, descend" RA and then soon afterwards a reversal "Climb, climb NOW" RA. The two RAs were followed and clear of conflict reported to ATC.

The B757 (A) crew, descending at 3300 ft/min., would have received an RA to **"Adjust vertical speed, adjust"** to 0 ft/min. at the same time as the B757 (B) aircraft received their TA.

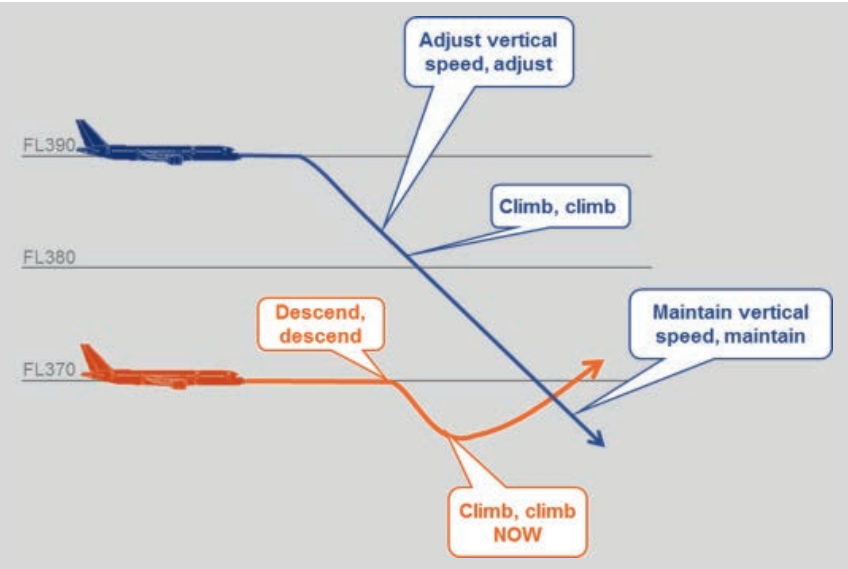


Figure 19: Event 1 Reconstruction

Note that with TCAS v7.1 today this RA would have been **"Level off, level off"**.

One second later, coordinated RAs were annunciated requiring a climb by B757 (A) and a descent by B757 (B), both at a rate of 1500 ft/min. The B757 (B) aircraft began descent but the B757 (A) aircraft, still above the other aircraft, ignored the RA and continued descent at an increased rate of 4200 ft/min. with the other aircraft in sight.

The effect of this had been to trigger the reversal "Climb, climb NOW" RA for the B757 (B) aircraft simultaneously with a "Maintain vertical speed, maintain" RA (see 8.8.8 below) for the B757 (A) aircraft which had by now passed through the level of the B757 (B) aircraft. "Clear of conflict" was annunciated six seconds later. Minimum separation was 0.8 NM as B757 (A) descended through the level of B757 (B).

Investigation of the radar system found that it fitted the characteristics of garbling seen in non-Mode S radars when the oblique distances between each aircraft and the respective radars are very similar. The label for the B757 (B) aircraft temporarily disappearing from the radar screen and being replaced by two labels, one showing the correct level of FL370 and another showing FL405, with the B757 (A) aircraft still showing FL390.

9.2 Event 2: Reversed TCAS RA resolution to follow ATC resolution.

Table 13 Event 2 Factsheet

Aircraft:	A 319
Type of Initial TCAS RA:	Crossing Maintain vertical speed
Pilot Action:	Correct - Descend
Why:	
Type of Subsequent TCAS RA	Increase descent
Pilot Action:	Correct – Continued Descent

Aircraft:	PRM1
Type of Initial TCAS RA:	Crossing Climb
Pilot Action:	Correct Climb initially but reversed action to Descend
Why:	Decision (3b) Interrupted TCAS resolution to follow ATC resolution
Type of Subsequent TCAS RA	
Pilot Action:	

An A319 lost separation against a Raytheon 390 (PRM1). Late ATC attempts to resolve the conflict were pre-empted by coordinated TCAS RAs but during them, the PRM1 crew elected to reverse their initial TCAS RA climb whilst it was still annunciated, in favour of an ATC instruction to descend. This action very significantly reduced the separation which would otherwise have prevailed.

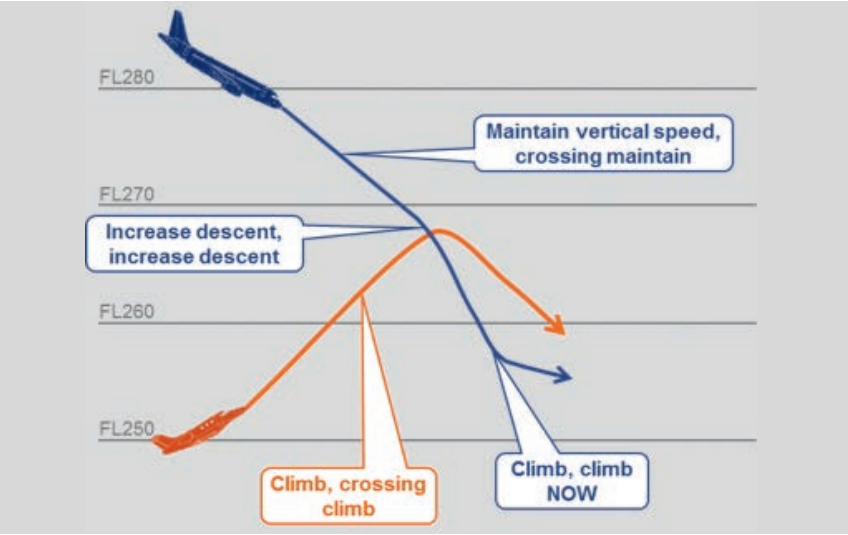


Figure 12: Event 2 Reconstruction

The A319 was tracking 220° and in the descent to FL250. ACC A controller had then entered FL280 into the system before handing the aircraft over to ACC B with whom there was a standing agreement for silent transfers at FL 280 without explicit coordination. Unfortunately ACC A had mistakenly cleared the A319 to FL250. Neither he nor his colleagues on the sector noticed the discrepancy between the flight level clearance given by radio and the one entered into the system. When the A319 crew subsequently checked in with ACC B in the descent to FL250 and gave this cleared level, neither of the two controllers involved noticed that the level stated was different to the one on the system. Meanwhile, the PRM1 was tracking 060° in the climb to FL270 on a trajectory that would cross less than a mile to the south of the A319. As the A319 descended below FL280 towards the climbing PRM1, STCAs were activated successively in both ACCs.

The A319 received a TCAS RA to **"Maintain vertical speed, crossing maintain"**. This was followed and resulted in descent at 1500-2000 ft/min. contrary to an ATC instruction which had just been received to stop descent at FL270.

A TCAS RA was annunciated for the PRM1 two seconds later to **"Climb, crossing climb"** which was followed and required a slight increase in the prior rate of climb to achieve 1500-2000 ft/min.

However, 9 seconds after this annunciation and with it still displayed, ATC instructed the aircraft to descend to FL 260 and the crew disregarded the RA - which continued unchanged for a further 23 seconds - and began a descent at a higher rate than the A319 which then received an RA to **"Increase descent, increase descent"**.

The ATC controller, after giving the PRM1 the instruction to descend rather than climb, subsequently realised that a coordinated TCAS RA must be in progress and instructed the aircraft to "follow TCAS, opposite traffic one mile, follow TCAS".

Six seconds later, at Closest Point of Approach the A319 was 50 feet below and 0.6 NM horizontally from the PRM1 with both aircraft still descending. As the cross took place the RA on the A319 changed to a Reversal "Climb, climb NOW" requiring a climb rate of 1500-2000 ft/min. Thereafter, separation increased as their tracks diverged and "Clear of conflict" was annunciated onboard both aircraft 8 seconds later.

During the time when a TCAS RA was active, the PRM1 crew had twice read back ATC instructions which were both contrary to the RA but did not inform ATC that a TCAS RA had been received. Despite flying in VMC, neither aircraft crew reported having acquired the other aircraft visually at any point.

9.3 Event 3: No Response to RA on approach due misinterpreted visual acquisition of VFR traffic No NN

Table 14: Event 3 Factsheet

Aircraft:	RJ100
Type of Initial TCAS RA:	Climb
Pilot Action:	No Action
Why:	Decision (3e) Misinterpretation of Visual Information. Believed that VFR traffic was already vertically clear
Type of Subsequent TCAS RA	Reverse descent
Pilot Action:	Correct – Continued Descent

Aircraft:	Ultralight
Type of Initial TCAS RA:	Not equipped
Pilot Action:	
Why:	
Type of Subsequent TCAS RA	
Pilot Action:	

An ultra-light single engine aircraft on a VFR flight obtained a clearance from TWR to cross the control zone at 3000 feet. Less than 2 minutes later, an Avro RJ100 called the tower reporting established on ILS. At this time, the RJ100 was approximately 800 feet above the ultra-light.

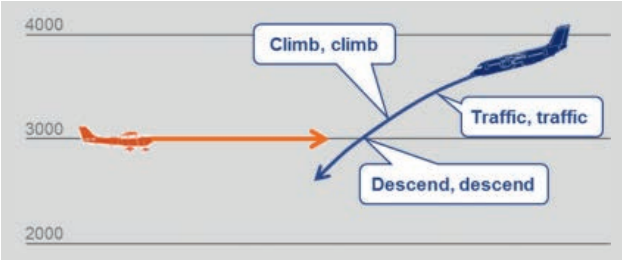


Figure 21: Event 3 Reconstruction

The TWR controller gave traffic information to the RJ100 crew about the VFR aircraft in their 11 o'clock position at a distance of 3 NM, moving left to right. The RJ100 crew responded that they had the traffic in sight. Twenty seconds later, TWR gave traffic information to the ultra-light pilot on the RJ100 now in his 2 o'clock position, 2 NM, descending 600 feet above. The pilot responded that he could not see the RJ100.

When the RJ100 was passing through 3450 feet, it got a TA. After 11 seconds, when the RJ100 was passing through 3200 feet it received a "Climb, climb" RA against the ultra-light. Based on visual acquisition, the RJ100 pilot judged that the ultra-light was already above. Therefore, he decided to descend to fly below the ultra-light rather than climb as advised by the RA. While the RJ100 was descending, the RA reversed to **"Descend, descend NOW"**.

At the time of the RA, the ultra-light was in fact 200 feet below the RJ100 at the distance 1.2 NM. The RA changed to Descend when both aircraft were at the same altitude at a distance of 0.64 NM. Shortly thereafter, the two flight paths crossed. At the Closest Point of Approach, the spacing between the aircraft was just 0.07 NM and 200 feet.

9.4 Event 4: Late response to ATC resolution, ignored subsequent RAs to continue with ATC resolution.

Table 15: Event 4 Factsheet

Aircraft:	B777
Type of Initial TCAS RA:	Crossing Climb
Pilot Action:	No Action
Why:	Decision (3g) Following ATC resolution. Did not respond to contrary TCAS RA
Type of Subsequent TCAS RA	Adjust Vertical Speed (Level Off in v7.1)
Pilot Action:	No Action

Aircraft:	Not stated in the report
Type of Initial TCAS RA:	n/a
Pilot Action:	
Why:	
Type of Subsequent TCAS RA	
Pilot Action:	

A B777 came within 200 feet vertically and 0.61 NM laterally of another aircraft after climbing significantly above the SID stop altitude of 4000 feet believing clearance was to Flight Plan level (FL310). The crew responded to ATC avoiding action to descend and then disregarded **"Climb, climb"** RA and subsequently **"Adjust vertical speed, adjust"** RA (which would be **"Level off, level off"** RA in v7.1) which were subsequently announced.

The level information given on the SID plate included a requirement to "MAINTAIN 4000' or as assigned by ATC". However, this information had been missed. The PF stated that he had scrolled "to the pictorial portion of the chart and zoomed in to check on the track and distances". He missed the separate text box. He had concluded that there were no altitude restrictions and set the initial FPL cruising altitude of FL310 on the MCP.

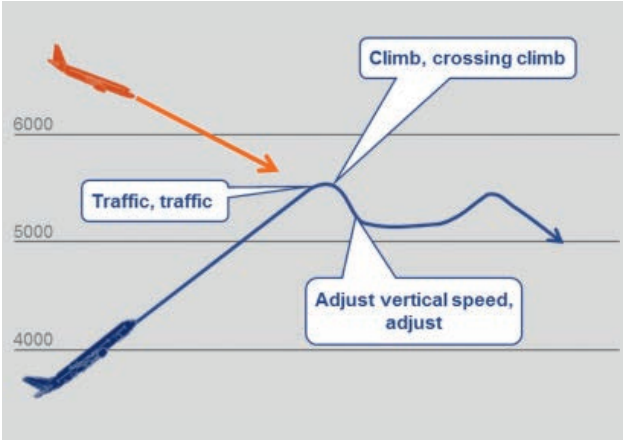


Figure 22: Event 4 Reconstruction

Once airborne, initial contact with ATC was followed by a radar heading to take up after passing 2500 feet; the read back of this clearance did not include the altitude that the aircraft was climbing to. The climb was continued through the 4000 feet stop altitude and passing 5600 feet, a TCAS TA was annunciated followed by an ATC instruction delivered "in an urgent tone" to descend to 5000 feet. The PF disconnected the AP and initiated the descent and soon after this a TCAS **"Climb crossing, climb"** RA was annunciated. The traffic was passing 6000 feet descending to its cleared level of 5000 feet. The B777 crew did not follow its RA and after 19 seconds, with the aircraft still descending, the RA changed to an **"Adjust vertical speed, adjust"** RA. This type of TCAS RA would be **"Level off, Level off"** in v7.1.

The AVSA RA continued until "Clear of conflict" followed 8 seconds later and the aircraft started to level off at 5000 feet.

When ATC instructed the aircraft to descend to 5000 feet, this altitude was not set on the MCP so that when the aircraft reached 5000 feet, another unauthorised climb began and it took another query from ATC before the crew realised this error.

During post-event interviews, it was apparent that all crew members expected that there would be some intermediate altitude to level off at before being cleared to FL310. The PF said that when he did not see any intermediate altitude on the SID chart, he thought that it would be given to him by ATC later. The Departure Clearance given by ATC concluded with the phrase "climb via SID". The R/T phrase "climb via" is deemed to include the stop altitude as well as the route and neither are repeated when including a SID in the Departure Clearance.

This was the first time the PF had experienced a Crossing Climb RA in actual flight and the first time the other two pilots had experienced any RA in actual flight.

9.5 Event 5: Aircraft on Go Around preferred to keep departing traffic in sight rather than follow RA in close proximity to terrain.

Table 16: Event 5 Factsheet

Aircraft:	CRJ200
Type of Initial TCAS RA:	Descend
Pilot Action:	No Action
Why:	Decision (3f) Maintaining visual contact with traffic. Proximity to terrain deemed to carry more risk.
Type of Subsequent TCAS RA	
Pilot Action:	

Aircraft:	A320
Type of Initial TCAS RA:	Climb
Pilot Action:	Correct Action
Why:	
Type of Subsequent TCAS RA	
Pilot Action:	

The crew of a Bombardier CRJ200 on a visual go around took visual avoiding action overhead the aerodrome to ensure separation from an Airbus A320 which had just been cleared to line up and take-off by ATC. Both aircraft received TCAS RAs. Minimum achieved separation from radar was 0.17 NM metres and 260 feet vertically.

The TWR controller had, after checking with the crew of the departing A320 that they were ready for an immediate take off with "no stopping on the runway", cleared the A320 to enter the runway and take-off. The CRJ, at approximately 3 NM from the runway threshold, was told "continue with approach landing assured". When the CRJ was at about 1.5 NM from the threshold, the crew decided that separation from the rolling A320 was insufficient and initiated a go around. Almost immediately after this, the TWR controller instructed the crew to make a go around.

30 seconds after issuing the go around instruction to the CRJ, the TWR controller had instructed the CRJ crew to commence an early left turn "when safe and able". By this time, the A320 was passing 1300 feet and the CRJ had already reached the Missed Approach altitude of 1800 feet and levelled off.

The CRJ crew deviated slightly to the right to keep the A320 climbing ahead and below in sight. As the A320 climbed towards the same level, a coordinated TCAS RA was triggered. The A320 received a "Climb, climb" RA, whilst the CRJ received a "Descend, descend" RA. The CRJ crew reported later that, at this point, the A320 was approximately 5° to 10° to the left of them and slightly below them.

The PF of the CRJ elected to continue with a right turn and not to follow the RA, which would have put the aircraft in close proximity to terrain with the possibility of Enhanced Ground Proximity Warning System (EGPWS) activation. Having the traffic visual, he considered that the safer option was not to follow the RA. As the A320 passed through the level of the CRJ a few seconds later, the CRJ turned right 0.5 NM behind the A320.

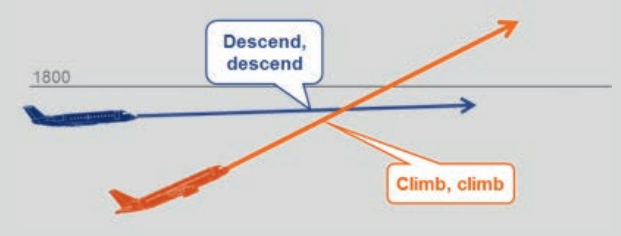


Figure 23: Event 5 Reconstruction

9.6 Event 6: No action taken on a "Descend" RA against traffic climbing below, in belief that descending towards climbing traffic increased risk.

Table 17: Event 6 Factsheet

Aircraft:	B777
Type of Initial TCAS RA:	Crossing Descend
Pilot Action:	No Action
Why:	Decision (3g) Believed that a "Descend instruction against a target below was dangerous. Lack of TCAS training
Type of Subsequent TCAS RA	Increase Descent
Pilot Action:	As above
Type of 2nd Subsequent TCAS RA:	Climb
Pilot Action:	Correct response began but CoC followed immediately

Aircraft:	C550
Type of Initial TCAS RA:	Not equipped with TCAS II
Pilot Action:	
Why:	
Type of Subsequent TCAS RA	
Pilot Action:	
Type of 2nd Subsequent TCAS RA:	
Pilot Action:	

A Cessna Citation C550 on the ground requested start up and departure clearance. The SID has an ultimate altitude limit of 4000 feet, however there is an intermediate stop at 3000 feet until it digresses from the track of inbound aircraft descending to 4000 feet for a neighbouring airport. The TWR controller cleared the Citation to climb on the SID to 3000 feet after take-off. The pilot read back "4000 feet" (having not seen the 3000 feet restriction on the SID plate) and this incorrect read-back was not detected. The Citation was not equipped with TCAS II. Once airborne the aircraft started to climb to 4000 feet at a rate of 3300 ft/min.

As the Citation got airborne off runway 27 turning north, a B777 was vectored on a southerly heading for an ILS approach to its destination. The B777 was cleared to descend to 4000 feet. The B777 and the C550 were also on different radio frequencies.

As the C550 was passing through 3000 feet, the B777 crew got a TCAS TA. Although not required, the B777 pilot reported the TA to ATC, "We have a traffic alert". During this radio transmission a **"Descend, crossing descend"** RA was generated.

The controller handling the B777 controller saw the conflict developing and, suspecting that an RA had already have been issued, he asked the B777 crew if they could climb back to 5000 feet, rather than instructing them to climb. Soon after that the RA on board the B777 strengthened to **"Increase descent, increase descent"**. The controller due to handle the C550 did not receive the aircraft on frequency until it had already passed 3000 feet and STCA was flashing.

Just seconds before they passed each other, the B777 receives a reversal "Climb, climb NOW" RA. The B777 crew began to respond to this RA but by then the Citation is already behind. The B777 crew did not respond to either of the previous RAs and levelled off at 4000 feet. The Captain of the B777 stated that seeing the other aircraft on the TCAS display he was concerned that the "crossing descent" demand would put his aircraft closer to the C550.

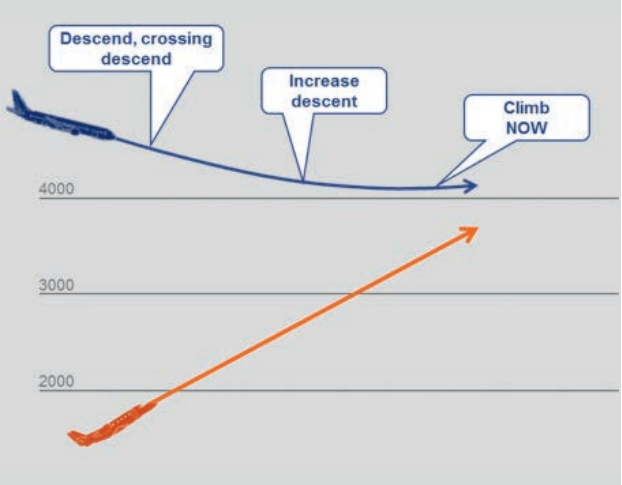


Figure 24: Event 6 Reconstruction

Later, one crew member reported seeing the C550 briefly in and out of the clouds. The C550 pilot did not see the B777. The aircraft passed each other on a reciprocal headings just 0.5 NM apart horizontally and 100-200 feet vertically.

9.7 Event 7: Continued descending on approach against visual but unknown VFR traffic; which turned and descended towards subject aircraft.

Table 18: Event 7 Factsheet

Aircraft:	BAe125
Type of Initial TCAS RA:	Climb
Pilot Action:	No Action
Why:	Decision (3f) Continued descending on approach against visual but unknown VFR traffic
Type of Subsequent TCAS RA	Reverse Descent
Pilot Action:	No specific response as descending anyway.

Aircraft:	C152
Type of Initial TCAS RA:	Not equipped
Pilot Action:	
Why:	
Type of Subsequent TCAS RA	
Pilot Action:	

A British Aerospace 125 business jet approached its destination (located outside controlled airspace), maintaining 2000 feet on the extended runway centreline on a visual approach. A Cessna 152 on a VFR flight on a track 90° crossing track was also maintaining 2000 feet.

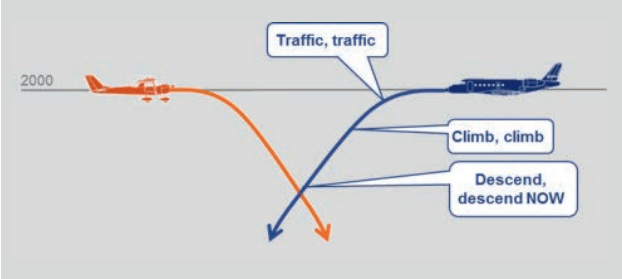


Figure 25: Event 7 Reconstruction

When the C152 neared the extended runway centreline, it made a turn away from the airport, thus putting both aircraft on a head-on track at the same altitude.

Soon after, the BAe125 started its descent for landing. Almost simultaneously, the Cessna also started to descend. When both were passing 1900 feet, the BAe125 got a TA against the C152. Some 10 seconds later, when both were descending through 1700 feet, the BAe125 got a "Climb, climb" RA. The BAe125 crew did not respond to the RA continuing the descent as they had seen the C152 but did not appreciate that it was also descending. After 13 seconds, as the aircraft continued to descend head-on, the RA reverses to "Descend, descend NOW". Soon after, they pass each other with a horizontal spacing of 0.2 NM at the same level.

Had the initial RA been followed, the vertical miss distance between the aircraft would have increased to over 250 feet.

The RA was not followed and that led to the reduction of the vertical miss distance between the aircraft compared to what following the RA would have achieved. The intentions of the intruder were not known. The C152 pilot was unaware of the BAe125 and did not see it until the last moment.

10. Pilot Survey

10.1 The Need for a Survey

It was concluded in the planning stage of this study that a pilot survey was needed to:

- Characterise the reasons for "TCAS RA Not Followed".
- Outline any difference in the context of "TCAS RA followed" and "TCAS RA Not Followed" situations.
- Scope the magnitude of the problem without aiming at precise frequency of occurrence calculations.

A voluntary online survey was proposed and was supported by IATA and a number of European aircraft operators that elicited 3800 responses from 90 countries.

10.2 Survey Design

The design of the survey framework and the promotion of it were performed in collaboration between EUROCONTROL Network Manager and IATA and were supported by many organisations and individuals.

The pilots were asked to recall if they had experienced a TCAS RA event in the past 5 years. A total of 55 questions were encompassed in a set of 5 Sections:

Section 1: Recalling a TCAS RA (in the past 5 years).
Section 2: Detail a TCAS RA possible to follow and followed.
Section 3: Detail a TCAS RA not possible to follow or was not precisely followed.
Section 4: Demographic information.
Section 5: TCAS training.

10.3 Survey Methodology

In cases where pilots answered "no" to whether they had experienced a TCAS RA event in the past 5 years, they were automatically redirected to Section 4 and 5. If pilots reported they had encountered a TCAS RA in the past 5 years, depending on whether they had reported to have "followed the TCAS RA" or not, they were directed accordingly to either Section 2 or 3. Once Sections 2 or 3 had been addressed, the pilots were directed to Section 4 and 5, which applied to all respondents independent of their TCAS RA experience. As the survey was anonymous, not all questions in Section 4 were mandatory.

10.4 Survey Responses

A total of 3800 pilots from 95 countries responded to the survey call. The invitation was distributed through multiple channels and because of that the invitation reach is considered representative. There is no information available to argue about the significance of the sample of those that answered the survey from those that were invited and did not. EUROCONTROL Network Manager confidential benchmarking with some major European aircraft operators confirmed that there is a reasonable assurance that the results can be considered as valid.

From the 3800 pilots that responded to the Survey, 1387 (36.5%) reported to have "encountered a TCAS RA situation in the past 5 years". 194 (5.1%) reported experiencing a TCAS RA that was not followed either at all or not as commanded. This equates to 14.7% of all pilots that reported experiencing any TCAS RA.

The results based on the respondents' answers to each question are presented as ratios from those that answered the particular question. The number of respondents to each question is not one and the same as, because of the large scale of the survey, some respondents abandoned at some point when answering the survey questions.

For example, 3800 pilots answered Section 1, Question 1, but only 1321 from the 1387 that reported to have "encountered a TCAS RA situation in the past 5 years" reached the question about the number of TCAS RA situations encountered during the last 5 years. Similarly, the valid rate for those indicating that they have been involved in TCAS RA situation when it was "not possible to follow RA or RA was not precisely followed" is calculated based on those that answered the question – 1321 - and not on those that responded in the beginning – 1387 – to have encountered TCAS RA.

The drop-off can be explained by several factors: unwillingness to continue because of perceived sensitivity of the information asked; unwillingness to continue because of the length of the survey; problems with internet connectivity; and technical problems with navigating further on the survey platform (e.g. browser compatibility issues). The drop-off rate is considered to be within the expected and acceptable range for this type of survey.

10.5 Significant Answers that inform why some TCAS RAs are not followed.

In the Survey Analysis below, only those questions and answers are detailed that are considered to be of significance in terms of the number of responses and in the interpretation of the overall study aim to inform why some TCAS RA events are not followed.

10.5.1 Recalling a TCAS RA

The following questions were asked.

- Within the last 5 years, have you experienced a TCAS RA situation?
- Approximately how many TCAS RA situations have you experienced during the last 5 years?
- Within the last 5 years, have you been involved in a TCAS RA situation when it was not possible to follow an RA or one was not precisely followed?

Table 19: Recalling a TCAS RA situation

Within the last 5 years, have you experienced a TCAS RA situation?		
Answer Options	**Response Percent**	**Response Count**
Yes	36.5%	1387
No	63.5%	2413
Total		**3800**

Out of 3800 pilot responses, 1387 (36.5%) reported to have encountered a TCAS RA situation in the past 5 years, as detailed in Table 19. 1321 of the 1387 respondents continued and answered question 2 about the number of TCAS RA situations encountered during the last 5 years.

Table 20: Recalling frequency of TCAS RAs

Approximately how many TCAS RAs have you experienced during the last 5 years?		
Answer Options	**Response Percent**	**Response Count**
1	57.5%	760
2	30.0%	395
3 or more	12.5%	166
Total		**1321**

It follows that at least 2048 RAs were experienced by the 1321 respondents. (760 x 1, 395x2, 166 x3).
The exact number was not asked.

Table 21: Recalling not following TCAS RA

Within the last 5 years, have you been involved in a TCAS RA situation when it was not possible to follow an RA or one was not precisely followed?		
Answer Options	**Response Percent**	**Response Count**
Yes	14.7%	194
No	85.3%	1127
Total		**1321**

14.7% of the pilots that reported to have encountered a TCAS RA indicated that they had been involved in TCAS RA situation when it was "not possible to follow RA or RA was not precisely followed".

When asked how many RAs were not followed, 28% of the previous respondents decided not to answer, leaving only 139 responses.

Table 22: Recalling frequency of TCAS RAs not followed

Approximately how many TCAS RA situations "not possible to follow" or "not precisely followed" have you experienced in over the last 5 years?		
Answer Options	**Response Percent**	**Response Count**
1	85.6%	119
2	10.8%	15
3 or more	3.6%	5
Total		**139**

From Table 20 we know that at least 2048 RAs were reported.

Table 21 shows us that 194 respondents reported having at least one RA not followed. Only 139 of these 194 respondents answered the question about how many RAs were not followed. From Table 13 and 4 we can extrapolate that at least 219 RAs were not followed. *(194 + 15 + 10)*

The exact number of RAs Not Followed was not captured in the survey, as only 72% (139) of the cohort (194) answered so the data has a degree of uncertainty. There is no reason to believe that the relative spread of responses is not the same for the remaining 28%. In this way the projected number of RAs not followed is 85.6% x 194 x 1 + 10.8% x 194 x 2 + 3.6% x194 x 3 = 166 + 42 + 21 = 229

The percentage of RAs that are not followed is therefore likely to be around 11% *(229/2048)*.

Conversely, it should be remembered that the Survey answers are all based on Voluntary Reporting. The respondents are reporting events which in many cases are in contradiction to ICAO and company regulations and standard practices. It may be therefore that the actual number of TCAS RAs are higher than those reported to this study.

10.5.2 Comparison of TCAS RAs that were followed with TCAS RAs that were not followed

Section 2 asked questions about TCAS RAs that were followed. Section 3 asked the same questions about TCAS RAs that were not followed.

- What was your position at the time of the RA?
- Were you the Pilot Flying at the time of TCAS RA?
- How was the aircraft being flown up to the time of the TCAS RA?
- What was the TCAS type when event occurred?
- Did you have a TCAS TA before the RA?
- Was the TA briefed with the other crew members?
- What was the TCAS RA type?
- Was the TCAS RA communicated to ATC?
- Did the RA change?
- If so, what was the subsequent TCAS RA type?
- Who made the decision to follow/not follow the RA?
- How was the RA flown?
- If not flown, what was the action after the RA has been announced?

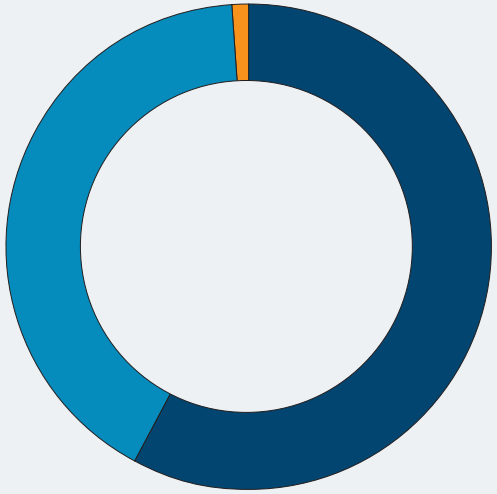
Many of the answers did not show any significant difference between RAs that were followed and RAs that were not followed and, therefore, do not aid our understanding of reasons why TCAS RAs are not followed. These questions and answers are detailed in the Appendix.

It is most useful to compare the answers given in Section 2 about TCAS RAs that were followed, directly with the equivalent answers given in Section 3 about TCAS Ras that were not followed.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 1

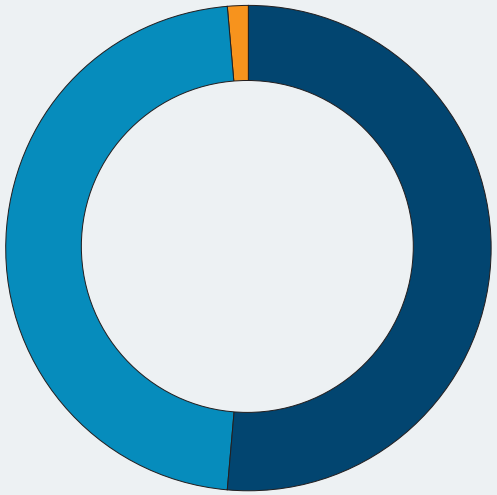
What was your position at the time?		
Answer Options	**Response Percent**	**Response Count**
Captain	57.9%	578
First Officer	41.2%	411
Relief Pilot	0.9%	9
Total		**998**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 2

What was your position at the time?		
Answer Options	**Response Percent**	**Response Count**
Captain	51.6%	82
First Officer	47.2%	75
Relief Pilot	1.2%	2
Total		**159**

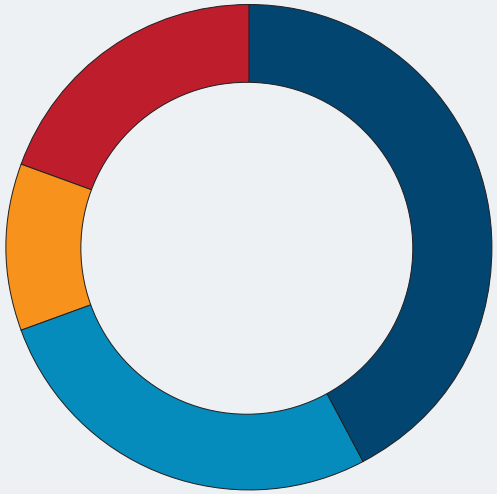


Exhibits 1 and 2 show a small change in the position of the reporter. First Officers reported more "TCAS RAs Not Followed". This could be explained by the willingness of junior officers to report the actions of other Flight Deck members.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 3

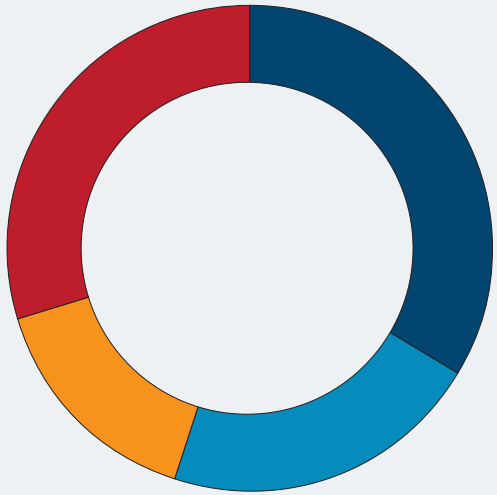
What was the aircraft type when the event occurred?		
Answer Options	**Response Percent**	**Response Count**
Airbus	42.0%	417
Boeing	27.5%	273
Embraer	11.1%	110
Other	19.4%	193
Total		**993**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 4

What was the aircraft type when the event occurred?		
Answer Options	**Response Percent**	**Response Count**
Airbus	33,.%	52
Boeing	21.%	34
Embraer	15.9%	25
Other	29.3%	46
Total		**157**

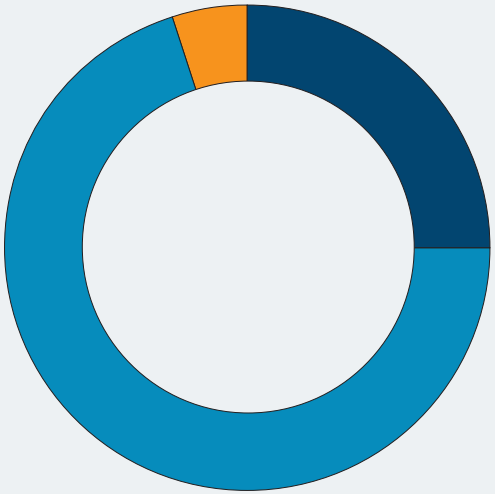


Exhibits 3 and 4 show an interesting reduction in the number of both Boeing and Airbus aircraft involved in "TCAS RAs Not Followed".
It was hypothesised that one or the other may be a factor, however this is shown not to be the case. There is an increase from 30% to 45% for events involving other aircraft types.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 5

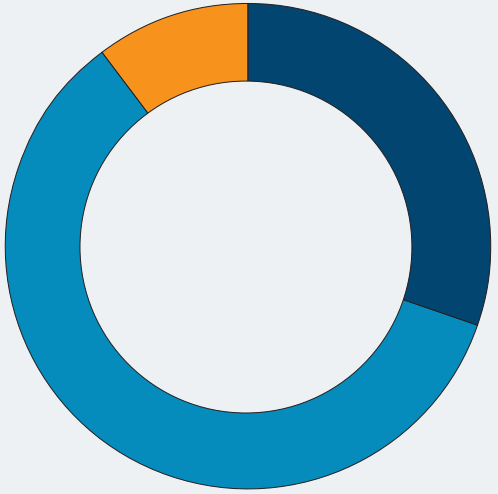
How was the aircraft flown up to the time of the TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
Manually	25.0%	249
Automated	70.1%	700
Combination of both	4.9%	49
Total		**998**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 6

How was the aircraft flown up to the time of the TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
Manually	30.2%	48
Automated	59.1%	94
Combination of both	10.7%	17
Total		**159**

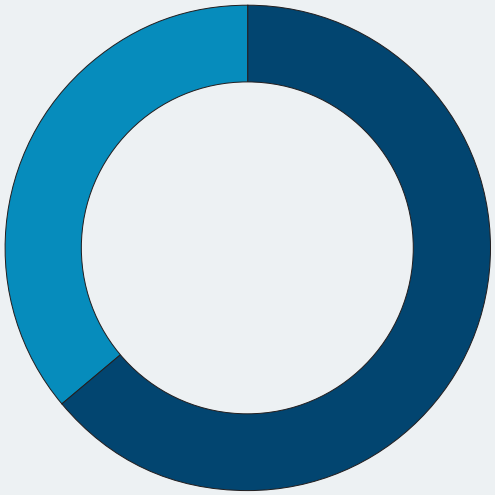


Exhibits 5 and 6 show a small increase from 30% to 40% of "TCAS RAs not followed", to involve aircraft that are being flown manually either completely or partially before the RA.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 7

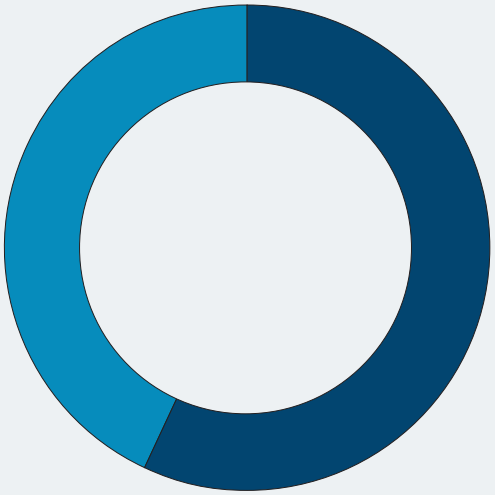
Were you the Pilot Flying at the time of TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
Yes	64.2%	641
No	35.8%	357
Total		**998**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 8

Were you the Pilot Flying at the time of TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
Yes	56.6%	90
No	43.4%	69
Total		**159**

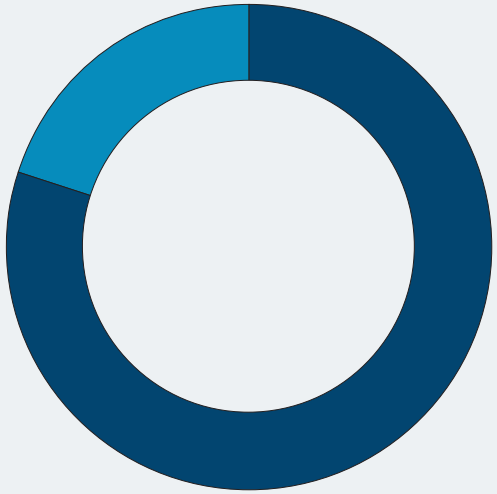


Exhibits 7 and 8 together showing an increase in reports by FOs who were not the Pilot Flying at the time of the TCAS RA.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 9

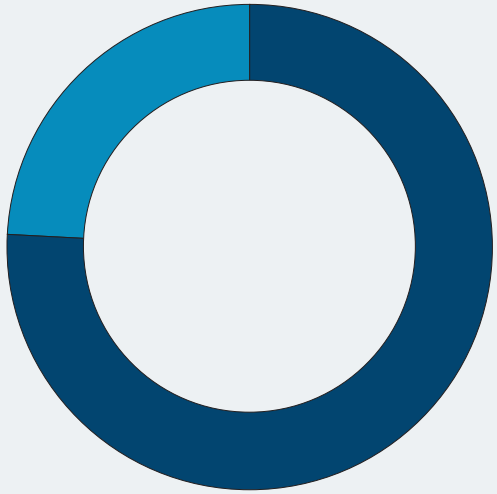
Did you have a TCAS TA before the RA?		
Answer Options	**Response Percent**	**Response Count**
Yes	80.3%	801
No	19.7%	197
Total		**998**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 10

Did you have a TCAS TA before the RA?		
Answer Options	**Response Percent**	**Response Count**
Yes	76.1%	121
No	23.9%	38
Total		**159**

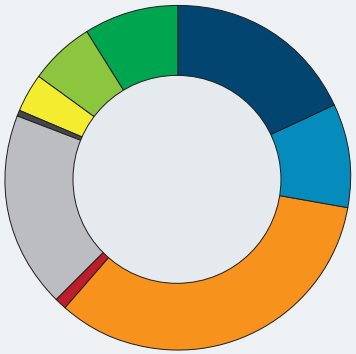


It was hypothesised that the presence or absence of a pre-warning Traffic Alert may influence the pilot response to a subsequent Resolution Advisory. Exhibits 9 and 10 however show no significant difference.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 11

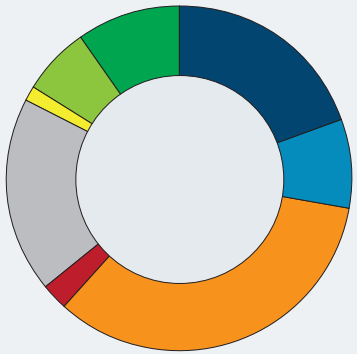
What was the TCAS RA type?		
Answer Options	**Response Percent**	**Response Count**
Adjust vertical speed	18.1%	178
Level off	9.8%	96
Climb	33.7%	332
Crossing climb	0.9%	9
Descend	18.6%	183
Crossing descend	0.4%	4
Maintain vertical speed	3.7%	36
Crossing maintain vertical speed	0.0%	0
Monitor vertical speed	6.1%	60
Other/ I don't remember	8.7%	86
Total		**984**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 12

What was the TCAS RA type?		
Answer Options	**Response Percent**	**Response Count**
Adjust vertical speed	19.7%	31
Level off	8.3%	13
Climb	33.8%	53
Crossing climb	2.5%	4
Descend	18.5%	29
Crossing descend	0.0%	0
Maintain vertical speed	1.3%	2
Crossing maintain vertical speed	0.0%	0
Monitor vertical speed	6.4%	10
Other/ I don't remember	9.6%	15
Total		**157**

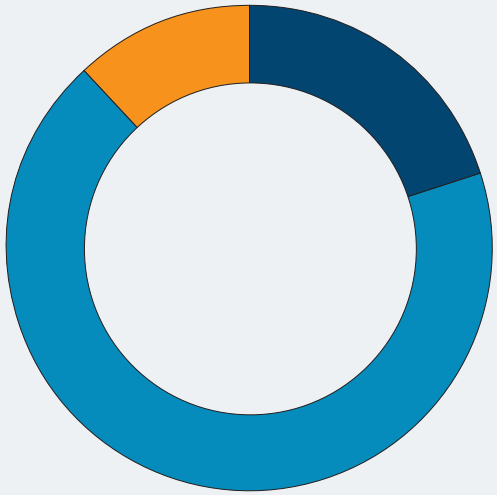


Exhibits 11 and 12 show that the Type of RA has no impact on the likelihood of it being followed.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 13

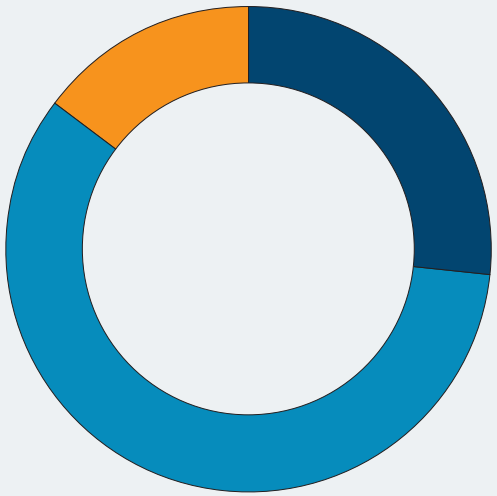
Did the RA change?		
Answer Options	**Response Percent**	**Response Count**
Yes	20.0%	197
No	68.1%	670
I don't remember	11.9%	117
Total		**984**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 14

Did the RA change?		
Answer Options	**Response Percent**	**Response Count**
Yes	26.8%	42
No	58.6%	92
I don't remember	14.6%	23
Total		**157**

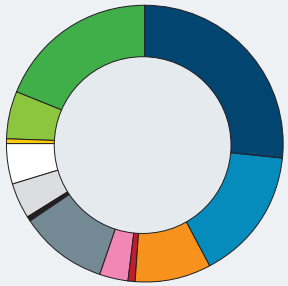


Exhibits 13 and 14 show small increase in the percentage of RAs not followed if the RA changes.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 15

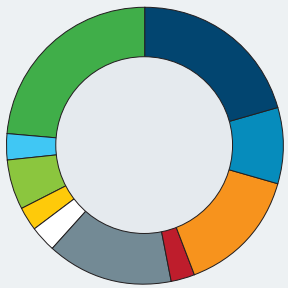
What was the subsequent TCAS RA type?		
Answer Options	**Response Percent**	**Response Count**
Adjust vertical speed	26.9%	52
Level off	15.5%	30
Climb	8.8%	17
Crossing climb	1.0%	2
Increase climb	3.1%	6
Descend	10.4%	20
Crossing descend	0.5%	1
Increase descend	4.2%	8
Maintain vertical speed	4.7%	9
Crossing maintain vertical speed	0.5%	1
Monitor Vertical Speed	5.7%	11
Reversal Climb	0.0%	0
Reversal descend	0.0%	0
Other/ I don`t remember	18.7%	36
Total		**193**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 16

What was the subsequent TCAS RA type?		
Answer Options	**Response Percent**	**Response Count**
Adjust vertical speed	20.6%	7
Level off	8.8%	3
Climb	14.7%	5
Crossing climb	2.9%	1
Increase climb	0.0%	0
Descend	14.7%	5
Crossing descend	0.0%	0
Increase descend	0.0%	0
Maintain vertical speed	2.9%	1
Crossing maintain vertical speed	2.9%	1
Monitor Vertical Speed	5.9%	2
Reversal Climb	2.9%	1
Reversal descend	0.0%	0
Other/ I don`t remember	23.5%	8
Total		**34**

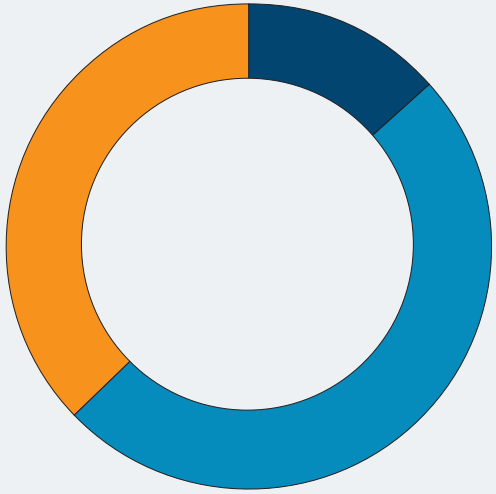


Exhibits 15 and 16 show that the likelihood of a TCAS RA not being followed increases if the subsequent command is for Climb or Descend.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 17

At what flight level or radio altimeter height (for low level events), was the TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
0-3000 feet AGL	13.5%	124
3000 feet AGL- FL200	49.3%	453
Above FL200	37.2%	342
Total		**919**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 18

At what flight level or radio altimeter height (for low level events), was the TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
0-3000 feet AGL	46.4%	64
3000 feet AGL- FL200	34.8%	48
Above FL200	18.8%	26
Total		**138**

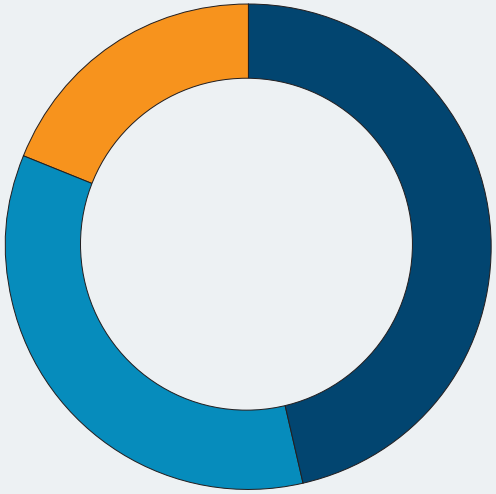


Exhibit 17 and 18 show a substantial shift in the altitude bands for RAs Not Followed v RAs followed. Only 13% of RAs that are followed occur below 3000ft. However, 46% of RAs Not Followed are in this lowest altitude band. This aligns with Table 21 and begins to show a clear relationship of RAs not being followed in the low level phase of flight due to visual acquisition of the intruder aircraft and deciding to continue with visual separation.

10.5.3 Reported reasons not to follow TCAS RA

Table 23

Within the last 5 years, have you experienced a TCAS RA situation?		
Answer Options	**Response Percent**	**Response Count**
TCAS RA not detected due to Human Machine Interface issues	0.8%	1
TCAS RA not detected due to other signals and alert	0.8%	1
TCAS RA misinterpreted due to HMI issues	0.0%	0
Decision not to follow due to other signal and alerts	1.5%	2
Decision not to follow due to contradictory ATC instructions	3.8%	5
I did not trust the TCAS RA system	4.6%	6
Decision not to follow due to aircraft performance issues (e.g. maximum level)	1.5%	2
Decision not to follow due to visual acquisition and/or avoidance of the conflicting traffic	45.0%	59
Proximity to the ground	10.7%	14
Proximity to severe weather	0.0%	0
Short duration RA (RA terminated before a response could be taken)	15.2%	20
This type of RA was not covered in my training	1.5%	2
Because I heard on the frequency that the pilot of the intruder is reacting	3.0%	4
Parallel approaches or closed spaced runways	4.6%	6
Already reacted to TA manually flying in correct direction. less or no action to RA	0.8%	1
Multiple RAs	0.8%	1
Aircraft on autopilot already capturing level. Less or no action to RA	1.5%	2
Late or incorrect response by PF	2.3%	3
Distraction looking for traffic	0.8%	1
Incorrect controls inputs	0.8%	1
Total		**131**

Table 23 clearly shows that the most common reason given for not following a TCAS RA is visual acquisition. This is three times more prevalent than the second highest type, too short duration; and four times more prevalent than the third highest type, proximity to terrain. Between them, these three types of event account for over 70% of TCAS RAs Not Followed.

ICAO documents state that all RAs should be followed unless the safety of the aircraft is at risk.
Three categories above would come under that derogation:

- Proximity to terrain.
- Decision to prioritise other signals and alerts.
- Aircraft performance issues e.g. high altitude.

These 3 types of RAs equate to 13.7% of all RAs Not Followed.
Three other types of RA may be deemed to reasonable not to follow or not possible to follow:

- Short Duration
- Deemed to be False/Incorrect RAs
- Parallel approaches or closely spaced runways

These 3 types of RAs equate to 24.4 % of all RAs Not Followed.

Therefore, **some 38% of RAs Not Followed might be for legitimate reasons.**

Table 24: Reasons not to follow TCAS RA

What was the reason not to follow the TCAS RA? (Potentially no valid reasons)		
Answer Options	**Response Percent**	**Response Count**
Decision not to follow RA due to visual acquisition and/or avoidance of the conflicting traffic	72.8%	59
Decision not to follow RA due to contradictory ATC instructions	6.2%	5
Heard and/or observed the pilot of the intruder resolving encounter	4.9%	4
Late or incorrect response by PF	3.7%	3
Aircraft on autopilot already capturing level. Less or no action to RA	2.5%	2
This type of RA was not covered in my training	2.5%	2
TCAS RA not detected due to other signals and alert	1.2%	1
TCAS RA not detected due to Human Machine Interface issues	1.2%	1
PF already reacted to TA manually flying in correct direction less or no action to RA	1.2%	1
Multiple conflicting RAs	1.2%	1
Distraction looking for traffic	1.2%	1
Incorrect controls inputs	1.2%	1
Total		**81**

Table 24 shows that a decision not to follow an RA due to visual acquisition of the apparent intruder accounts for more than 70% of all RAs not followed without a valid reason.

Table 25: Types of TCAS RA per level band

TCAS RA not followed: At what flight level or radio altimeter height (for low events), was the TCAS RA?				
Answer Options	**0-3000 ft. AGL**	**3000 ft. AGL- FL200**	**Above FL 200**	
Climb, %	24 – (48.0%)	14 - (28.0%)	12 – (24.0%)	**50**
Descend, %	16 – (64.0%)	6 – (24.0%)	3 – (12.0%)	**25**
Adjust vertical speed, %	7 - (29.2%)	12 – (50.0%)	5 – (20.8%)	**24**
Level off, %	4 - (36.4%)	5 – (45.4%)	2 – (18.2%)	**11**
Monitor vertical speed, %	6 – (66.7%)	1 – (11.1%)	2 – (22.2%)	**9**
Crossing climb, %	-	3 – (75.0%)	1 – (25.0%)	**4**
Maintain vertical speed, %	1 – (100.0%)	-	-	**1**
Total	**58**	**41**	**25**	**124**

Table 25 gives the additional information that 69% of RAs not followed below 3000ft are either to climb or descend. The response for "Descend below 3000ft" matches the answer given in Table 24 for reason not to follow the RA as "proximity to ground".

Table 26: Reasons not to follow TCAS RA per level band

Reason not to follow RA/ flight level or radio altimeter height:			
Answer Options	**0-3000 ft. AGL**	**3000 ft. AGL- FL200**	**Above FL 200**
Decision not to follow RA due to visual acquisition and/or avoidance of the conflicting traffic	32	20	6
Short duration RA (RA terminated before a response could be taken)	7	7	6
Proximity to terrain	12	1	0

Table 26 confirms the prevalence of not following TCAS RAs due to visual acquisition at all Flight levels. The level of inability to follow RAs due to their short duration is constant across all altitude bands.

Table 27: Actions after TCAS RA has been announced

What was the reason not to follow the TCAS RA? (Potentially no valid reasons)		
Answer Options	**Response Percent**	**Response Count**
No manoeuvre	46.0%	64
Less than the required RA rate	35.2%	49
More than the required RA vertical rate	13.0%	18
In opposite sense to the RA	5.8%	8
Total		**139**

Table 27 confirms the actions expected for findings that the majority of TCAS not followed events involve either visual acquisition, short duration or proximity to terrain. More than 80% of TCAS RA not followed events result in either no action being taken or less than the required action.

10.5.4 Demographics

Section 4 asked questions about demographics:

- Name, organisation, email (all optional)
- Type of operator
- Base Country of operation
- Total Hours flown
- Hours flown on type
- How does the aircraft represent TCAS commands

Only this last question (that was not a pure demographical characteristic) on Flight Deck equipage is significant.

Table 28: Representation of TCAS RA

TCAS RA not followed: How does your aircraft visually represent the TCAS RA commands?		
Answer Options	**Response Percentage**	**Response Count**
On both the Attitude Indicators and Vertical Speed Indicators	45.5%	61
On the Vertical Speed Indicators	43.3%	58
On the Attitude Indicators	11.2%	15
In opposite sense to the RA	5.8%	8
Total		**134**

10.5.5 TCAS Training

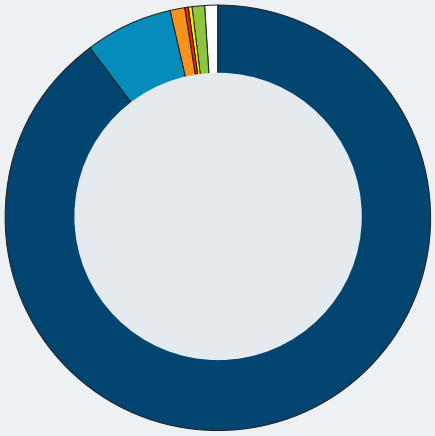
Section 5 asked questions about TCAS training.

- How often are you tested on your response to TCAS RA?
- What is the type of training?
- In simulation, is more than one aircraft shown on the TCAS display that may become the target aircraft?
- In simulation, are you pre-warned that the exercise will include a TCAS RA?
- What type of TCAS RAs were included in your training?

SECTION 2: TCAS RA possible to follow and followed

Exhibit 19

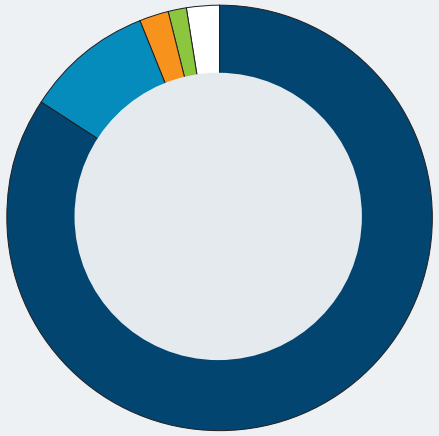
How often are you tested on your response to TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
once a year	89.9%	834
once per 2 years	6.8%	63
once per 3 years	1.2%	11
once per 4 years	0.1%	1
once per 5 years	0.2%	2
more than once per 5 years	1.0%	9
never	0.9%	8
Total		**928**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 20

How often are you tested on your response to TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
once a year	84.3%	113
once per 2 years	9.7%	13
once per 3 years	2.2%	3
once per 4 years	0.0%	0
once per 5 years	0.0%	0
more than once per 5 years	1.5%	2
never	2.2%	3
Total		**134**

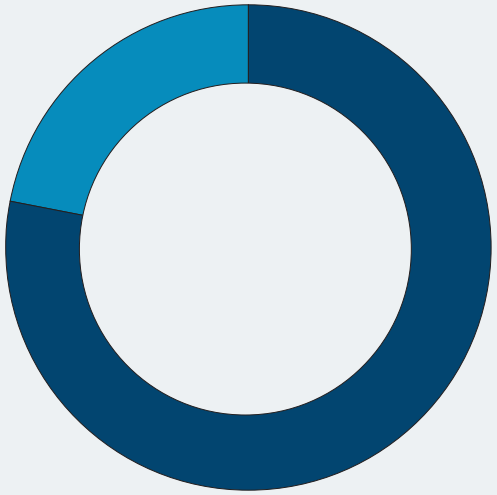


Exhibits 19 and 20 show a small difference in training recency. More frequent training accords with less TCAS RA events not followed. Almost 5% of pilots involved in such events report either no training or not within the last 5 years.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 21

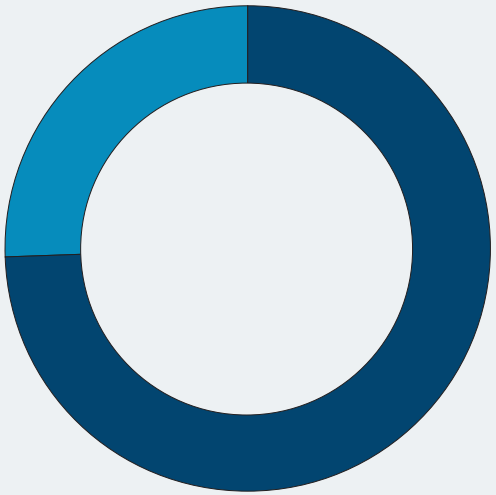
In simulation, is more than one aircraft shown on the TCAS display that may become the target aircraft?		
Answer Options	**Response Percent**	**Response Count**
Yes	78.3%	713
No	21.7%	198
Total		**911**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 22

In simulation, is more than one aircraft shown on the TCAS display that may become the target aircraft?		
Answer Options	**Response Percent**	**Response Count**
Yes	74.6%	97
No	25.4%	33
Total		**130**

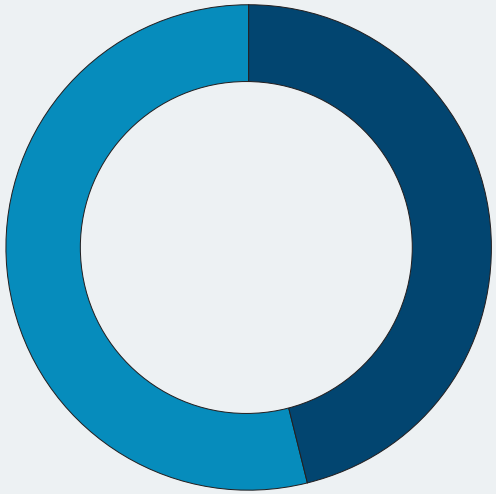


Exhibits 21 and 22 show a small difference, but given the considerable difference in response numbers there may be no significance.

SECTION 2: TCAS RA possible to follow and followed

Exhibit 23

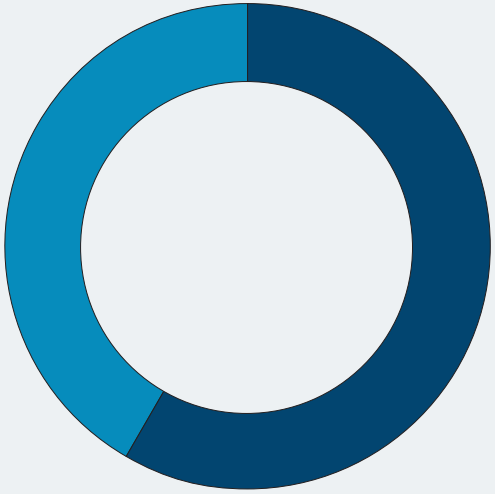
In simulation, are you pre-warned that the exercise will include a TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
Yes	46.2%	421
No	53.8%	490
Total		**911**



SECTION 3: TCAS RA not possible to follow or RA was not precisely followed

Exhibit 24

In simulation, are you pre-warned that the exercise will include a TCAS RA?		
Answer Options	**Response Percent**	**Response Count**
Yes	58.5%	76
No	41.5%	54
Total		**130**



Exhibits 23 and 24 suggest that pilots who, in training, are not pre-warned that a TCAS RA is coming, react better in live situations.

Table 29

TCAS RA not followed: How does your aircraft visually represent the TCAS RA commands?	
Answer Options	**Response Percentage**
Adjust vertical speed	2309
Level off	1579
Climb	2333
Increase climb	1843
Crossing climb	930
Descend	2254
Increase descend	1769
Crossing descend	835

Table 29 shows that no one type of TCAS RA is trained more than 80% each time. The less common, but perhaps more demanding RAs such as Crossing Climb/Descend are only trained around 30% of the time. There were no responses that reported Reversal of RAs being trained.

10.6 Survey Highlights

There are several important observations that can be made from the survey:

- 3800 pilots responded. 1387 (36.5%) reported having experienced a TCAS RA situation in the past 5 years.
- At least 2048 RAs were experienced by the 1321 respondents. (The exact number was not asked).
- 14.7% of the pilots that reported encountering a TCAS RA indicated that they had been involved in at least one TCAS RA situation when it was "not possible to follow the RA or the RA was not precisely followed".
- At least 229 RAs were not followed. (The exact number was not asked).
- The percentage of RAs that are not followed is likely to be around 11%.
- There is a reduction in the number of both Boeing and Airbus aircraft involved in TCAS RAs Not Followed. There is a matching increase from 30% to 45% for events involving other aircraft types.
- There is a small increase for RAs not being followed, from 30% to 40%, in events where the aircraft are being flown manually prior to the RA.
- The presence or absence of a pre-warning Traffic Alert had no influence on the pilot response to a subsequent Resolution Advisory.
- The Type of RA has no impact on the likelihood of it being followed.
- More than 80% of TCAS RA Not Followed events result in either no action being taken or less than the required action.
- The most common reason given for not following a TCAS RA is visual acquisition. This is three times more prevalent than the second highest type, too short duration; and four times more prevalent than the third highest type, proximity to terrain. Between them, these three types of event account for over 70% of TCAS RAs Not Followed.
- A decision not to follow an RA due to visual acquisition of the apparent intruder accounts for more than 70% of all RAs not followed without a valid reason.
- 46% of RAs not followed are below 3000ft. Most of these involve a decision not the follow the RA after visual acquisition of the apparent intruder.
- Pilots who, in training, are not pre-warned that a TCAS RA is coming, are disposed to react better in live situations.
- No one type of TCAS RA is trained more than 80% each time. The less common, but perhaps more demanding RAs such as Crossing Climb/Descend are only trained around 30% of the time.
- 5% of pilots involved in TCAS RA Not Followed events report no TCAS training within the previous 5 years.

11. Industry Best Practice and Future Development

11.1 Autopilot / Flight Director (AP/FD) Capability

An Airbus AP/FD TCAS capability is a guidance mode which allows the aircraft to automatically fly the RA if the autopilot is engaged or the pilot to manually fly the RA by following the flight director commands. The AP/FD capability is currently available for all Airbus aircraft (except A340s).

Broadly speaking, when an AP/FD aircraft receives an RA, the aircraft will automatically change its vertical speed to the vertical speed prescribed by the current RA plus 200 ft/min. (in order to help the flight crew monitoring of the RA response), unless the RA prescribes a null vertical speed (e.g. a Level Off RA), in which case the aircraft will change its vertical speed to 0 ft/min. The manoeuvre starts without delay and has been demonstrated to be equivalent to standard response delays (3 – 5 seconds) and accelerations (0.15 – 0.25 g).

When the RA is terminated, the AP/FD function will guide the aircraft to the selected altitude. All low level TCAS inhibitions are applicable.

11.2 TCAS alerting prevention (TCAP) capability

A TCAS Alert Prevention (TCAP) functionality has been introduced by Airbus to prevent the generation of RAs in 1000-foot level-off geometries. The functionality which is currently available for the Airbus wide body aircraft (and expected to become available on the A320 family of aircraft) uses a new altitude capture law for flight guidance computers, which decreases aircraft's vertical rate towards the selected altitude, once a TA has been generated and the auto-pilot and/or flight director are engaged (see Figure 26).

The TCAP functionality is complementary to the flight guidance computer's conventional altitude capture function.

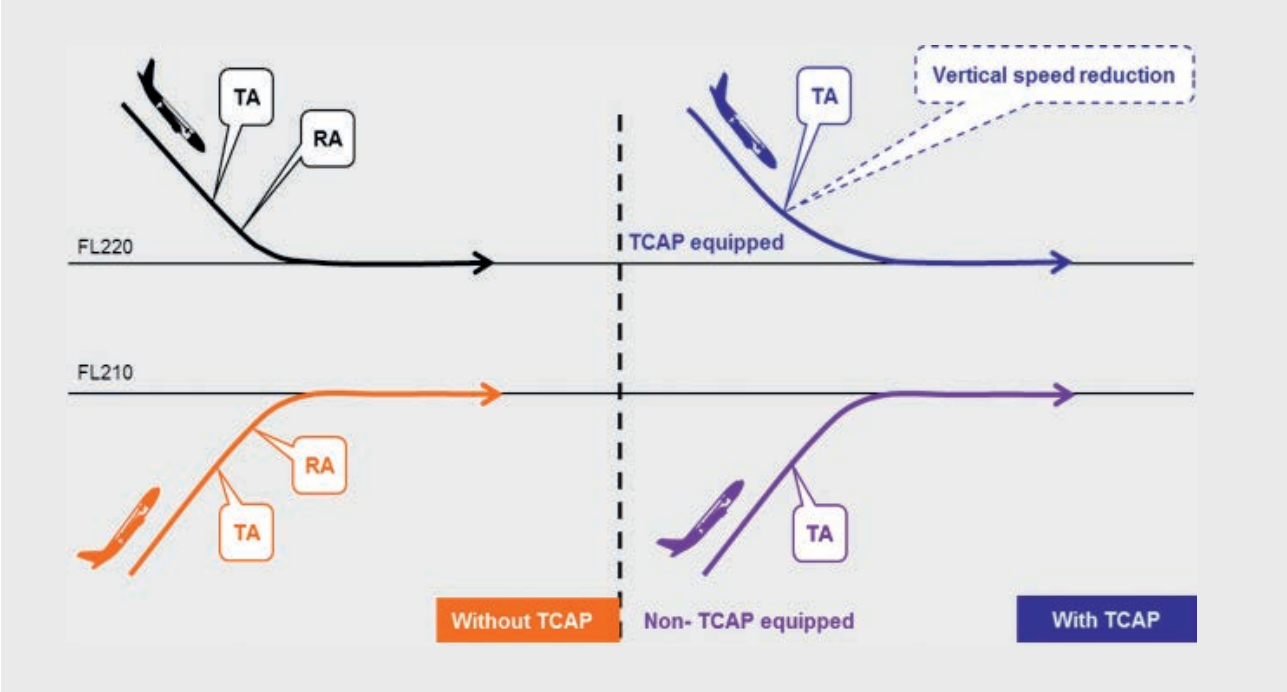


Figure 26: Illustration of an encounter without and with TCAP functionality.

11.3 Future of Collision Avoidance: ACAS X

The Federal Aviation Administration (FAA) has funded research and development of a new approach to airborne collision avoidance (known as ACAS X) since 2008. This approach uses 'dynamic programming' and other computer science techniques (which were not available when TCAS II was first developed) to generate alerts using an off-line optimisation of resolution advisories.

11.3.1 ACAS X Principles

Instead of using a set of hard-coded rules, ACAS X alerting logic is based upon a numeric lookup table optimised with respect to a probabilistic model of the airspace and a set of safety and operational considerations.

The ACAS X probabilistic model provides a statistical representation of the aircraft position in the future. It also takes into account the safety and operational objectives of the system enabling the logic to be tailored to particular procedures or airspace configurations.

This is fed into an optimisation process called "dynamic programming" to determine the best course of action to follow according to the context of the conflict. This employs a rewards versus costs system to determine which action would generate the greatest benefits (i.e. maintain a safe separation while implementing a cost-effective avoidance manoeuvre). Key metrics for operational suitability and pilot acceptability include minimizing the frequency of alerts that result in reversals/intentional intruder altitude crossings or disruptive advisories in non-critical encounters.

The look-up table is used in real-time on-board the aircraft to resolve conflicts. ACAS X collects surveillance measurements from an array of sources (approximately every second). Various models are used (e.g. a probabilistic sensor model accounting for sensor error characteristics) to estimate a state distribution, which is a probability distribution over the current positions and velocities of the aircraft. The state distribution determines where to look in the numeric lookup table to determine the best action to take (which includes the option 'do nothing'). If deemed necessary, resolution advisories are then issued to the pilots.

11.3.2 ACAS X Benefits

The following benefits are foreseen through the introduction of ACAS X:

- Reduction of 'unnecessary' advisories: TCAS II is an effective system operating as designed, but it can issue alerts in situations where aircraft will remain safely separated.
- Adaptability to future operational concepts: Both SESAR and NextGen plan to implement new operational concepts which will reduce the spacing between aircraft. TCAS II in its current form is not compatible with such concepts and would alert too frequently to be useful.
- Extending collision avoidance to other classes of aircraft: To ensure advisories can be followed, TCAS II is restricted to categories of aircraft capable of achieving specified performance criteria (e.g. aircraft must be able to achieve a rate of climb of 2500 ft/min.), which excludes many General Aviation (GA) and Unmanned Aircraft Systems (UAS) or Remotely Piloted Aircraft Systems (RPAS).
- Use of future surveillance environment: Both SESAR and NextGen make extensive use of new surveillance sources, especially satellite-based navigation and advanced ADS-B functionality. TCAS II however relies solely on transponders on-board aircraft which will limit its flexibility to incorporate these advances.
- Safety improvement: It is envisaged that ACAS X will provide an improvement in safety while reducing the unnecessary alert rate.

11.3.3 ACAS X Variants

- ACAS Xa – The general purpose ACAS X that makes active interrogations to detect intruders. ACAS Xa is the baseline system, the successor to TCAS II. The Standards are expected to be ready by 2018 and ACAS X may become available by 2020.

- ACAS Xo – an ACAS X extension designed for particular operations, like closely spaced parallel approaches, for which ACAS Xa is less suitable because it might generate a large number of nuisance alerts. The Standards are also expected to ready by 2018.

- ACAS Xu – an ACAS X extension designed for Remotely Piloted Aircraft Systems (RPAS), incorporating horizontal resolution manoeuvres. Work on Standards has started in 2016 and is expected to be finished in 2020.

- ACAS Xp – A version of ACAS X that relies solely on passive ADS-B to track intruders and does not make active interrogations. It is intended for general aviation aircraft (that are not currently required to fit TCAS II).

12. Conclusions and Recommendations

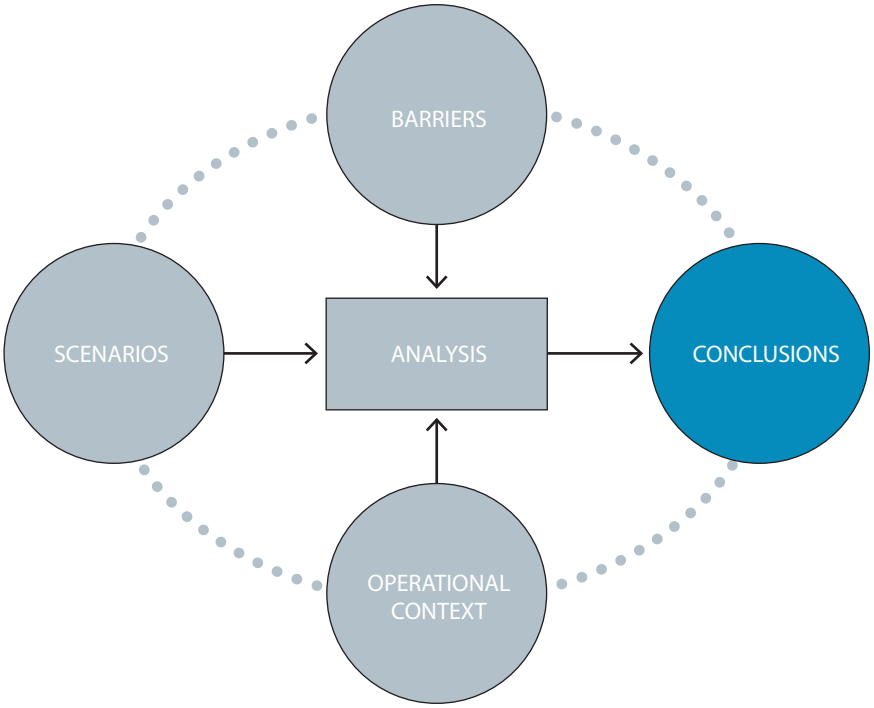


Figure 27: Conclusions in the Analytical Framework

Conclusion 1 This study is principally validated by an online Pilot Survey supported by IATA that elicited 3800 responses from 90 countries.

Conclusion 2 The generic study identified only 3 barriers available to Flight Deck crew that could potentially prevent TCAS RAs from not being followed correctly. All of these barriers are only effective for a small number of generic scenarios. However, since one type of scenario is prevalent in the actual operation i.e. TCAS RA Not Followed due visual acquisition; training and promotion of expected pilot response could be effective.

Conclusion 3 This study identified only one barrier available to Flight Deck crew that could potentially mitigate the impact of pilots not following TCAS RAs correctly and that is Autopilot/Flight Director capability to fly the RA.

Conclusion 4 The main findings of the Pilot Survey suggest that:

a. According to the Pilot Survey, around 36% of pilots reported experiencing at least one TCAS RA situation within the 5 year period covered by the survey.
b. According to the Pilot Survey, around 15% of the pilots that reported encountering at least one TCAS RA within the 5 year period covered by the survey, reported not following an RA for various reasons.
c. The percentage of TCAS RAs that are not followed is likely to be around 11%
d. According to the Pilot Survey, a decision not to follow an RA due to visual acquisition of the apparent intruder accounts for more than 70% of all RAs not followed without a valid reason.
e. According to the Pilot Survey, neither having a Traffic Advisory (TA) prior to the RA, nor the type of RA was reported to make any significant difference to the likelihood of an RA being followed..

Recommendation 1	It is recommended that IATA, Pilot Associations, Aircraft Operators and Regulators review the findings of this study and consider undertaking operational safety analysis and improvement activities for "TCAS RA Not Followed"
Recommendation 2	It is recommended that IATA, Pilot Associations, Aircraft Operators and Regulators consider actions to support an increased active use of FDM in the monitoring of TCAS RA compliance and the provision of feedback to training organisations and flight crew involved.
Recommendation 3	It is recommended that European ANSPs and the EUROCONTROL Safety Improvement Sub-Group (SISG) monitor occurrences involving "TCAS RA Not Followed" to determine changes in frequency and severity.
Recommendation 4	It is recommended that all European stakeholders monitor and support the development of tools and procedures that may assist in the prevention and/or mitigation of "TCAS RA Not Followed" events.
Recommendation 5	It is recommended, in particular, that all European stakeholders promote and emphasise the requirement and importance of following TCAS RA commands despite an apparent intruder being visually identified and monitored (subject to the overriding safety of the aircraft).

Annex 1 - Glossary of Terms

ACAS II – ("ay-cas two") – Provides vertical resolution advisories (RAs) in addition to traffic advisories (TAs).

ACAS X – ("ay-cas eks") – A family of new collision avoidance systems currently under development. It takes advantage of recent advances in 'dynamic programming' and other computer science techniques.

Altitude crossing RA – A resolution advisory is altitude crossing if own ACAS aircraft is currently at least 100 feet below or above the threat aircraft for upward or downward sense advisories, respectively.

Closest Point of Approach (CPA) – The occurrence of minimum (slant) range between own ACAS aircraft and the intruder. Range at CPA is the smallest range between the two aircraft and time at CPA is the time at which it occurs.

Increased rate RA – A resolution advisory with a strength that recommends increasing the altitude rate to a value exceeding that recommended by a previous climb or descend RA.

Resolution Advisory (RA) – An indication given to the flight crew recommending a manoeuvre intended to provide separation from all threats; or a manoeuvre restriction intended to maintain existing separation.

RA sense – The sense of an ACAS II RA is "upward" if it requires climb or limitation of descent rate and "downward" if it requires descent or limitation of climb rate. It can be both upward and downward simultaneously if it requires limitation of the vertical rate to a specified range.

Reversed sense RA – A resolution advisory that has had its sense reversed.

Short Term Conflict Alert (STCA) – A ground-based safety net intended to assist the controller in preventing collision between aircraft by generating, in a timely manner, an alert of a potential or actual infringement of separation minima.

Strengthening RA – A change in RA to another RA that is more restrictive or requires a greater vertical rate but is in the same sense as the previous RA.

TCAS II – Traffic alert and Collision Avoidance System II – an aircraft equipment that is an implementation of the ACAS II standards.

Traffic Advisory (TA) – An indication given to the flight crew that a certain intruder is a potential threat. This indication contains no suggested manoeuvre

Weakening RA – A resolution advisory with a strength that recommends decrease the altitude rate to a value below that recommended by a previous RA, when the initially issued RA is predicted to provide sufficient vertical spacing.

Annex 2 - Abbreviations

ACAS	Airborne Collision Avoidance System
AGL	Above Ground Level
ANSP	Air Navigation Service Provider
AP/FD	Autopilot/Flight Director
ATC	Air Traffic Control
CBT	Computer Based Training
CoC	Clear of conflict
CPA	Closest Point of Approach
EFIS	Electronic Flight Instrument System
FAA	Federal Aviation Administration (USA)
FL	Flight Level
ft	Feet
ft/min.	Feet per minute
GPWS	Ground Proximity Warning System
HMI	Human Machine Interface
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IVSI	Instantaneous Vertical Speed Indicator
NM	Nautical Mile(s)
RA	Resolution Advisory
SAFMAP	Safety Functions Maps
sec	Second(s)
SESAR	Single European Sky ATM Research Programme
STCA	Short Term Conflict Alert
TA	Traffic Advisory
TAWS	Terrain Avoidance and Warning System
TCAP	TCAS Alert Prevention
TCAS	Traffic alert and Collision Avoidance System

Annex 3 - Bibliography

ICAO Publications:

- ICAO Annex 10 – Aeronautical Telecommunications - Volume IV - Surveillance Radar and Collision Avoidance Systems (Fifth edition – 2014).
- ICAO Doc. 4444 – PANS-ATM – Procedures for Air Navigation Services – Rules of the Air and Air Traffic Services (Sixteenth edition – 2016).
- ICAO Doc. 8168 – PANS-OPS – Procedures for Air Navigation Services – Aircraft Operations - Volume I - Flight Procedures (Fifth edition – 2006, amendment 7).
- ICAO Doc. 9863 – Airborne Collision Avoidance System (ACAS) Manual (Second edition – 2012).

EUROCONTROL Publications:

- EUROCONTROL ACAS Guide
- EUROCONTROL ACAS Bulletins 1-21 (published since 2002)
