Applicability and usefulness of the encounter model-based methodology for safety net assessment

Béatrice Raynaud[(1)], Thierry Arino[(1)], Christian Aveneau[(2)] & Garfield Dean[(3)]

[(1)] Egis Avia (formerly Sofréavia), Toulouse, France
[(2)] Direction des Services de la Navigation Aérienne, Toulouse, France
[(3)] EUROCONTROL Experimental Centre, Brétigny sur Orge, France

Abstract

In the context of STCA standardisation currently under progress in Europe, the I-AM-SAFE project evaluated the applicability and usefulness of the encounter model-based methodology used in the ACAS field in the prospect of establishing quantified performance requirements for STCA.

This paper presents the approach followed-up and the main outcomes of the I-AM-SAFE feasibility study. This feasibility study confirms that the STCA standardisation process can benefit from experience gained in the ACAS field.

Taking into account the main study findings, a more sophisticated framework that would enable the evaluation of STCA performance and safety benefits in the context of joint STCA / ACAS operations is proposed.

Introduction

Background & context

The '**Short-Term Conflict Alert**' (STCA) system is a ground-based safety net intended to assist the controller in preventing collision between aircraft. There exist several STCA implementations in the States of the European Civil Aviation Conference (ECAC) area with no uniform procedures for operational use, optimisation and validation. Under the leadership of the SPIN (Safety nets: Planning Implementation and eNhancement) Task force of EUROCONTROL, STCA standardisation is progressed in Europe.

The airborne safety net, i.e. the 'Airborne Collision Avoidance System' (ACAS), is being operated world-wide regardless of the Air Navigation Services provided in the airspace. To ensure global effectiveness of ACAS, the ICAO Standards And Recommended Practices (SARPs) define ACAS minimum performance requirements together with a methodology to check compliance with these requirements.

This methodology has been applied and refined in various ACAS safety and performance studies of the EUROCONTROL Mode S and ACAS Programme. These include the 'Implication on ACAS Performances due to ASAS implementation' (IAPA) project and the 'ACAS Safety Analysis post-RVSM Project' (ASARP).

Study scope & objectives

The objective of the I-AM-SAFE study [IAS] was to assess the applicability and usefulness of the methodology used in the ACAS field, for establishing quantified performance requirements for STCA.

I-AM-SAFE stands for **I**APA – **A**SARP **M**ethodology for **S**afety net **A**ssessment – **F**easibility **E**valuation.

The work was performed for EUROCONTROL by a consortium of two organisations: Egis Avia and DSNA, who have been involved in ACAS standardisation and safety evaluation for 15 years.

This feasibility study built upon the experience gained through the development of the ICAO performance SARPs for ACAS, and the methodology and tools that supported various ACAS safety and performance studies of both the EUROCONTROL ACAS and Mode S Programme and the French DSNA. These tools consist of a set of models that allow the replication of the environment in which ACAS is being operated in Europe, including the European ‘safety encounter model’ delivered by the ASARP project [ASARP]and the European ‘ATM encounter model’ delivered by the IAPA project [IAPA].

Level of standardisation of STCA & ACAS

The role of STCA in the ATM system

EUROCONTROL in line with ICAO PANS-ATM defines STCA as “*a ground-based safety net intended to assist the controller in maintaining separation between controlled flights by generating, in a timely manner, an alert of potential or actual infringement of separation minima*” [STCA1].[1]

In the event of an alert, the controller is expected to “*assess without delay the situation and if necessary take action to ensure that the applicable separation minimum will not be infringed or will be restored*.” (cf. Specific Requirement STCA-05 in [STCA1]).

It is essential that the controller intervention in response to STCA is as far as practicable effective before entering the intervention timeframe of ACAS, in order to maximise the benefits of both safety nets.

State of the art for STCA performance harmonization

A full-scale investigation of the current practices related to STCA (and other safety nets) in the States of the ECAC area has been conducted by EUROCONTROL [SNETS]. Several areas of concern were identified, for which best practices did not necessarily exist in the state of the art.

Operational requirements for Safety Nets, including STCA, were defined in the EATCHIP Phase III [ORD] Volume 2. More recently, the EUROCONTROL Specification for STCA [STCA1] has defined minimum requirements for the development and use of STCA in the Europe. To achieve these requirements, comprehensive guidance material for a reference STCA system [STCA2] has also been released, which defines principles for STCA parameter optimisation.

With these high-level requirements on STCA capabilities, the ECAC-wide standardisation of STCA is progressing. However, a long path still remains to develop quantified performance requirements ensuring an agreed level of STCA effectiveness. To increase this effectiveness, it will be essential that these performance requirements also take into account the operation of ACAS.

The experience of ACAS standardization

ICAO defines ACAS as “an aircraft system based on secondary surveillance radar (SSR) transponder signals which operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft that are equipped with SSR transponders” (cf. ICAO Annex 2 – Rules of the Air).

ACAS is not designed, nor intended, to achieve any specific ‘Target level of Safety’ (TLS). Instead, the safety benefit afforded by the deployment of ACAS is usually expressed in terms of a ‘risk ratio’ that compares the risk of a ‘Near Mid-Air Collision’ (NMAC) both with and without ACAS. ICAO has defined a set of target ‘risk ratios’ for different scenarios of aircraft equipage in a theoretical airspace described by a ‘safety encounter model’ (cf. ICAO Annex 10 [ACAS]).

ICAO also defines an ‘ATM encounter model’ whose structure derives from that of the ‘safety encounter model’, but which enlarges the featured encounters to situations where the aircraft pass each other with some horizontal miss distance. This encounter model has been used to standardise ATM compatibility requirements for ACAS through the definition of targeted ratios of nuisance alerts.

The evaluation of ACAS performances in Europe

The framework initiated at the ICAO level when defining ACAS minimum performance has been further developed through various ACAS-related projects in Europe. These projects include the ‘full-system safety study’ completed in the ‘ACAS Analysis’ (ACASA) project [ACA1], [ACA2] performed in support to the mandates for the carriage of ACAS II in Europe, and more recently the ‘ACAS Safety Analysis post-RVSM’ (ASARP) Project following RVSM introduction in Europe.

These projects delivered a comprehensive framework that includes a set of models that allow the replication of the environment in which ACAS is being operated in Europe. These models consist essentially of a ‘**safety encounter model**’, models of pilot reaction in response to RAs and a model of

[1] Note that there is agreement at international level to change this definition to read “… *assist the controller in preventing collision between aircraft by generating* …” in order to better reflect the intended use of STCA.

altimetry errors applicable in the European airspace. An ACAS simulator uses these models to test ACAS performance in operationally realistic scenarios. A contingency tree then puts the simulated performance into a wider context including hazardous events.
As shown in Figure 1, these models are used to determine the risk that remains when ACAS is being operated. Distinction is made between the 'logic system risk' that consider the risk associated with the operation of ACAS in the modelled airspace and the 'full-system risk' that also takes into account other hazards that may affect the safety of ACAS.

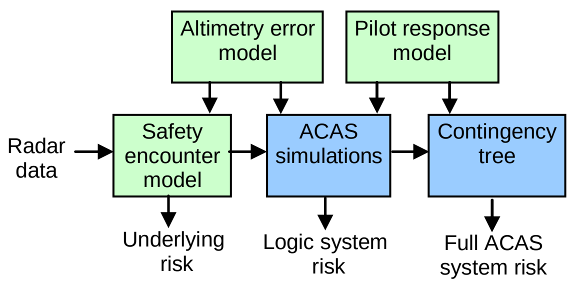

Figure 1: Framework for the evaluation of the safety of ACAS

Within the scope of the IAPA project, the framework for the evaluation of the performances of ACAS was enriched with the delivery of an '**ATM encounter model**' featuring the current ATM operations in Europe.
The IAPA ATM encounter model is a powerful tool for evaluating ATM changes and their potential interaction with ACAS. Its scope is far greater than that of the ICAO ATM encounter model and its usefulness extends beyond just the study of the 'Implication on ACAS Performances due to ASAS implementation' made in the IAPA project.

I-AM-SAFE study approach

Overall approach

As shown in Figure 2, the overall approach taken in the I-AM-SAFE study builds on the methodology and tools that supported previous ACAS studies in Europe, and notably on the European 'safety encounter model' delivered by the ASARP project and the European 'ATM encounter model' delivered by the IAPA project.

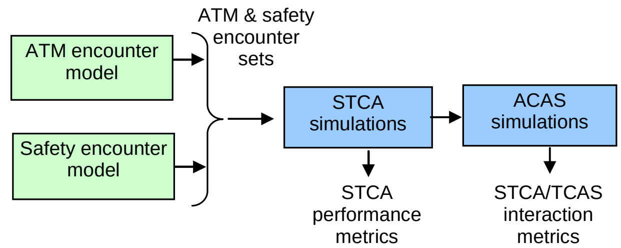

Figure 2: Framework for the study of STCA performances

For the purposes of the study, a simplified STCA model has been implemented, which complies with the essential features of the reference STCA system defined by EUROCONTROL [STCA2]. This model was used to simulate STCA behaviour in encounters generated from the safety and ATM encounter models. Four sets of STCA configuration parameters were investigated during the study, which spanned the full range of parameter values recommended by EUROCONTROL.
ACAS simulations were also performed to help assess the relevance of the STCA alerts, identify missing alerts and provide elements on the STCA / ACAS interaction issue.
Because of the investigative nature of the project, the STCA performance metrics evaluated during the study did not consist of complex performance indicators. The focus was on the general trends that could be observed in terms of STCA alert occurrences, warning times and durations depending on the scenarios. An insight was also obtained on the level of interaction with ACAS alerts.
The study also investigated the effect of possible influencing factors, including:

- the STCA configuration parameters;
- the origin of the encounters (i.e. the ATM or the safety encounter model); and
- encounter severity in terms of separation infringement at closest approach.

Safety and ATM encounter models

The 'ATM encounter model' and the 'safety encounter model' are mathematical models, which capture the properties of encounters that are representative of ATM operations in Europe. Their main advantage is that they can be used to generate an arbitrarily large set of encounters (representing several years of traffic) whose properties are characteristic of the European airspace.
Although they share the same general features and advantages, the encounters that matter are different for each of the two models:

- the ‘ATM encounter model’ characterises **day-to-day encounters** involving two aircraft in conflict. The encounters that matter correspond to situations in which the ATC separation minima are generally preserved, possibly thanks to one or more aircraft manoeuvres that ensure separation; and
- The ‘safety encounter model’ is focused on **risk bearing encounters** involving two aircraft on a close encounter course. The encounters that matters are those in which there exists a risk of mid-air collision or in which the response of pilots to ACAS RAs can result in a risk of mid-air collision.

Based on the radar data used to build the models, it can be estimated that the encounters captured by the ‘ATM encounter model’ occur about 4 times every flight-hour in Europe, whereas those captured by the ‘safety encounter model’ occur about once every 6,000 flight-hours (or every 2 days of observation by a typical radar) in Europe.

Reference STCA model

The STCA model developed in support of the study was kept as simple as possible. The three main functions implemented consisted of:

- A ‘Coarse Filter’ that finds pairs of system tracks that are of potential concern and that require further processing;
- A ‘Fine Filter’ that closely examines each pair of tracks and predicts if they are likely to come into conflict. Within the scope of the I-AM-SAFE study, this filter was limited to a ‘Linear Prediction Filter’; and
- An ‘Alert Confirmation’ module that determines if an alert is required, either because of the proximity of the conflict or because the conflicting situation predicted earlier has not been solved.

This simple implementation does not include many of the optional features defined in the EUROCONTROL guidance material for STCA [STCA2]. The only optional feature (option A) implemented was the possible use of CFL (Cleared Flight Level) in the vertical prediction of the ‘Linear Prediction Filter’.

With regard to the input surveillance data provided to the STCA model, basic and nominal assumptions were taken (e.g. altitude tracking in 25 ft increments, or smoothed speed vector).

Basic STCA performance metrics

A set of basic STCA performance metrics have been investigated during the study, which were related to the encounters themselves, the alert occurrences, the warning times associated with the alerts, and the alert durations. To investigate the STCA / ACAS interaction issue, basic metrics were also defined, which related to the occurrences and timing of the alerts issued by the two safety nets.

Basically, three classes of encounters were considered as follows:

- serious encounters with less than half the ATC separation minima:

  (HMD < ½ sep min) AND (VMD < ½ sep min)

  with HMD for ‘Horizontal Miss Distance’
  and VMD for ‘Vertical Miss Distance’

- non-serious encounters with a separation infringement but more than half the ATC separation minima:

  [(½ sep min ≤ HMD < sep min) AND
  (VMD < sep min)]
  OR
  [(HMD < sep min) AND
  (½ sep min ≤ VMD < sep min)]

- encounters without separation infringement:

  (sep min ≤ HMD) OR (sep min ≤ VMD)

The separation minima applicable by ATC were assumed to be 1,000 feet[2] in the vertical dimension and respectively 3 NM in TMA and 5 NM in en-route for the horizontal plane. For the sake of simplicity, the encounter classification was determined at the ‘Closest Point of Propinquity’ (CPP). This point is defined as the local minimum in the ‘propinquity’ distance (ρ) between two aircraft. This measure scales the horizontal and vertical distances (h and v) between the aircraft according to the respective separation minima (H and V).

$$\rho = \sqrt{(h/H)^2 + (v/V)^2}$$

Although simpler than the five categories of encounter defined in [STCA2], this classification was considered relevant enough for the purposes of the I-AM-SAFE study.

[2] A tolerance margin of 250 feet was allowed on the vertical separation between two level aircraft at adjacent FLs. Level aircraft were assumed to fly with a vertical rate lower than 200 fpm at closest approach.

Main study outcomes

General

To assess the relevance of the encounter model-based approach for establishing STCA performance requirements, two encounter sets were generated using respectively the 'safety encounter model' and the 'ATM encounter model':

- 200,000 safety encounters representing about 12.09×10^8 flight hours or about 100 years of ECAC traffic; and
- 440,000 ATM encounters representing about 110,090 flight-hours or 3 days of ECAC traffic.

Both encounter sets correspond to a different breakdown in terms of altitude distribution, and more important for the I-AM-SAFE study purposes in terms of proportions of separation infringements. As shown in Figure 3, about half of the safety encounters correspond to a separation infringement, whereas almost all ATM encounters (i.e. 98.6% of the TMA encounters and 99.6% of the en-route encounters) correspond to a situation without any separation infringement.

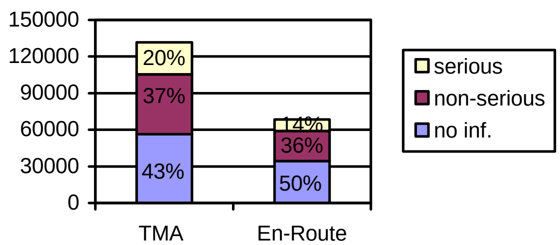

Figure 3: Overview of the safety encounter sets

Relevance of the simplified STCA model

Operational realism

The study demonstrated the operational realism of the reference STCA model implemented during the project despite its simplicity.

It also pointed out the potential interest of implementing other optional features described in the EUROCONTROL guidance material for STCA. For instance, encounters were observed triggering an alert on-time (according to the parameters of the 'Linear Prediction Filter'), but which could be considered late from an operational perspective.

This was particularly the case for slow convergence encounters in which the alert was delayed (typically, when using the low values of STCA configuration parameters) beyond the infringement of the ATC separation minima. The possibly reduced effectiveness of STCA in slow convergence situations is a known issue. A number of possible mitigation means exists, none of which were implemented in the simplified STCA model.

The study also highlighted the influence of the input surveillance data on the STCA alerts. A non-negligible proportion of non-continuous[3] alerts (i.e. between 2% and 3% depending on the encounter set and the STCA parameters) was observed in simulation. This behaviour was shown to result from the quantisation of the input surveillance data (e.g. the altitude quantisation in 25 ft) during encounters with a small overlap between the intervals of lateral and vertical separation violation determined by the 'Linear Prediction Filter'.

Areas of improvement

To improve the realism of the data provided to STCA, it might be of interest to implement a surveillance model that would be representative of current surveillance performances in Europe. Performance aspects that might require specific attention include the accuracy and the latency of the track information provided to STCA (e.g. position errors resulting from the late detection of manoeuvring aircraft, etc).

Consideration might also be given to the implementation of the various options described in the EUROCONTROL guidance material [STCA2], e.g. the 'Current Proximity Filter' (option B) or the 'Turning Prediction Filter' (option C), in order to qualify their impact on the performance of STCA in specific encounter situations. Another optional feature that exists in some STCA systems which can overcome some of the problems of late alerts when the aircraft are vertically slow closing is the use of vertical rate uncertainties.

Relevance of the ATM and safety encounter models

The encounter model-based methodology was demonstrated to be applicable and useful to evaluate the performance of STCA, and the possible interaction issues with ACAS, although some adaptations would be required to specifically address STCA.

---

[3] Non-continuous alerts are characterised by one or more intermediate switch-offs before the end of the conflict.

Relevance the safety encounter model

The safety encounter model proved to be more appropriate than the ATM encounter model for evaluating the safety benefits of STCA since it provided a larger number of relevant encounters. As an illustration, Figure 4 shows the number and the percentage of alerts observed with the safety encounters depending on the considered airspace (i.e. TMA or en-route) and the scenario of STCA configuration (i.e. with or without the use of CFL and with low or high values of STCA parameters).

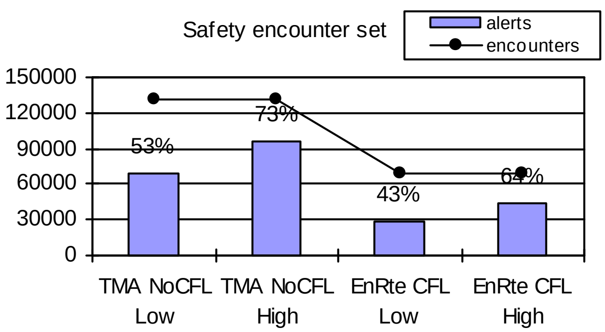

Figure 4: Alert occurrences with the safety encounter model

The safety encounter model also provided more reliable warning time statistics. However, due to its focus on collision risk bearing encounters, it exaggerated the alert rates, and the interaction that exists between STCA and ACAS, in current ATM operations.

Relevance the ATM encounter model

The 'ATM encounter model' proved to be useful for evaluating the compatibility of STCA with day-to-day ATM operations, especially for assessing alert rates. Its main characteristic was the small proportion of alerts simulated whatever the scenario of STCA configuration and parameters, as shown in Figure 5.

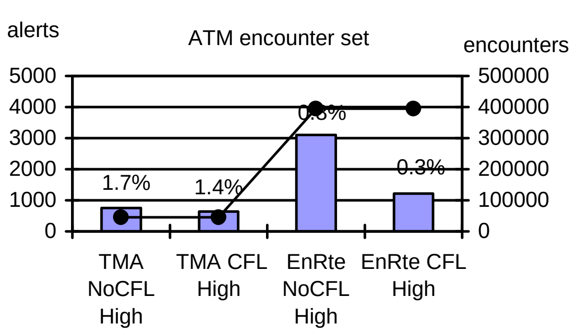

Figure 5: Alert occurrences with the ATM encounter model

Areas of improvement

The environment in which the STCA is being operated is of particular importance when evaluating STCA performances. The study highlighted some areas in which the modelling of this environment could be improved.

To allow at the same time for the evaluation of STCA effectiveness and the determination of representative alert rates, it would be of interest to develop an ATC incident-based encounter model (derived from real incidents that occurred in Europe) that would encompass the interest of both the safety and ATM encounter models without their limitations. This encounter model would need to capture the properties of both safety-related encounters and day-to-day encounters likely to generate STCA alerts.

It might also be of interest to model the possible controller reaction in response to an STCA alert apart from the encounter model itself. Such modelling (as done for the pilot response to RAs when evaluating ACAS performances) would allow the evaluation of the effectiveness of STCA through its ability to alert the controller with sufficient warning time.

Finally, to allow a precise evaluation of the impact of the CFL option on the safety benefits of STCA, it would be required to refine the modelling of the CFL data using operational statistics on the frequency of incorrect or neglected input of CFL by the controller.

Relevance of the of STCA performance metrics

The basic performance metrics evaluated during the study provided some insight on the likelihood and relevance of STCA alerts and their level of interaction with ACAS alerts. However, the simulation results have to be taken with care due to the limitations of the simulated environment noted above.

Relevance of the alert statistics

The study highlighted the influence of the encounter characteristics (i.e. risk bearing situations or day-to-day conflicts in TMA or en-route), the STCA configuration (i.e. with or without the use of CFL) and parameters (i.e. high or low values), as well as the quality of the data provided to STCA, on the likelihood and relevance of the alerts.

Relevance of the warning time metrics

The determination of the warning time provided by an alert has been demonstrated to be essential when evaluating the effectiveness of STCA.
Different warning time metrics were evaluated during the study using:

- two different methods of calculation using either the 'actual trajectories' eventually observed in the encounters, or 'predicted trajectories' (using the prediction mechanism of the STCA model); and
- three different reference points, i.e. the 'Time of Separation Infringement' (TSI), 'Time of Separation Violation' (TOV) calculated by the STCA at the time of the alert and the time of closest approach measured at CPP.

These different metrics provided different, yet consistent, measures of the warning time provided by the STCA alerts. As an illustration, Figure 6 shows the warning time distributions observed on the safety encounters in en-route (when using high values of STCA parameters and the CFL option).

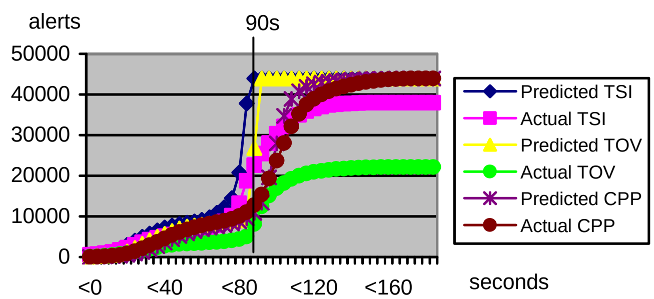

Figure 6: Warning time distributions with the safety encounter model – En route, High with CFL

The simulation results confirmed that the warning time determined using the 'predicted (or actual) TOV', and even more that determined using the 'predicted (or actual) CPP', tend to overestimate the look-head time left to the controller to maintain, or restore, the separation between the aircraft.
The warning time before the 'predicted TSI' proved to be a conservative metric for evaluating the time left to the controller to intervene even in encounters with late manoeuvres. The warning time before the 'actual TSI' may constitute an alternative warning time metric less sensitive to the quality of the trajectory data, but more sensitive to late manoeuvres that affect the separation between the aircraft.

Areas of improvement

The study pointed out the need for more sophisticated metrics that would allow for the evaluation of STCA performances while taking into account, in an appropriate manner, the possible controller reaction in response to the alerts (e.g. delay reaction time to determine and then communicate avoiding action to the pilot) and possibly the ability of this controller reaction to prevent the issuance of ACAS RAs.
Further, the encounter and alert classification need to be improved to take into account not only the aircraft separation at closest approach, but also the relative profile of the aircraft (e.g. convergent or divergent trajectories) and possibly the encounter geometry (e.g. level-off, altitude bust, etc).

Enhanced framework for STCA performance evaluation

Taking into account the study findings, a more sophisticated framework that would enable the evaluation of STCA performance and safety benefits while taking into account the effect of ACAS operations has been proposed.
This framework shown in Figure 7 builds upon the encounter model-based methodology and the various areas of improvement identified during the study.

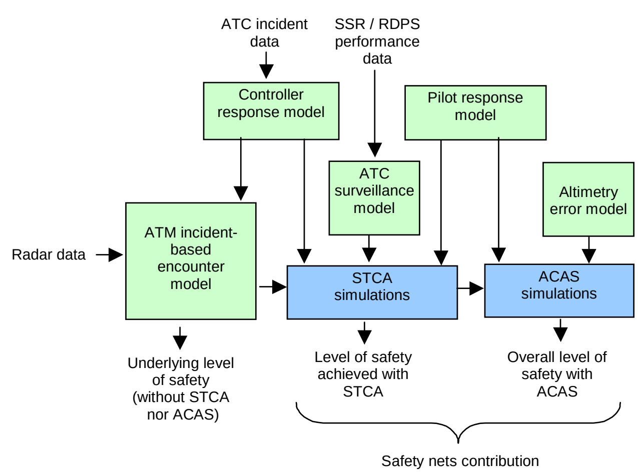

Figure 7: Possible framework for the development of STCA performance requirements

In a nutshell, the approach would consist of simulating the behaviour of STCA, the subsequent controller intervention, as well as the pilot's reaction to this intervention and possibly that of ACAS. This would enable the determination of the contribution of each safety net, separately, and also in combination.

This framework would need to be complemented with agreed and consolidated performance metrics that will support the evaluation of STCA effectiveness and the establishment of minimum performance requirements. Finally, objective criteria for encounter and alert classification will have to be established.

Conclusions & recommendations

Main study outcomes

This feasibility study confirms that the STCA standardisation process can benefit from the experience gained in the ACAS field. Indeed, both systems raise similar issues to a certain extent. Further, the possible interaction between the two safety nets is an area of concern that needs particular attention.

Although quite simple, the STCA performance metrics evaluated during the study (using the two encounter models available at this stage) have shown the potential of the encounter model-based methodology for evaluating STCA performances and the possible interaction issues with ACAS.

In summary, the results of this feasibility study are very promising and areas of improvements have been identified to better address the issues related to STCA.

Recommendations for future work

To maximise safety benefits, it is recommended that the standardisation of STCA be supported by a comprehensive evaluation of the effectiveness of STCA and its possible interaction with ACAS.

Analysis of real ATC incidents should first be conducted, as far as possible using different STCA implementations in Europe, to build up the required understanding of the current situation, in terms of:

- typical sequences of events during these ATC incidents;
- the main environment and causal factors influencing the effectiveness of STCA, and the possible interaction with ACAS; and
- the behaviour of controllers and pilots in response to the alerts generated by the two safety nets.

The further development of quantified performance requirements for STCA should be supported by a methodological framework such as the one evaluated in the I-AM-SAFE project with some adaptations to specifically address STCA including:

- the modelling of all encounter situations, and only those, where STCA and/or ACAS are likely to play a role;
- the separate modelling of controller intervention in response to STCA and subsequent pilot's reaction; and
- a more in-depth modelling of STCA behaviour, including the effect of optional STCA features and the quality of the input surveillance data.

Finally, the development of Standard and Recommended Practices for STCA should be supported by complementary studies addressing the human factors and safety issues related to the joint operation of STCA and ACAS, so as to optimise the unavoidable interactions between the two safety nets.

References

[ACAS] ICAO, Annex 10, Volume IV, Surveillance Radar and Collision Avoidance Systems – 3rd edition, July 2002.

[ACA1] ACASA Project – Final report on studies on the safety of ACAS in Europe – EUROCONTROL ACAS Programme – ACASA/WP1.8/210D, Version 1.3, March 2002.

[ACA2] ACASA Project – European Encounter Model – EUROCONTROL ACAS Programme – Specifications, ACASA/WP1.1/186, Version 2.1, December 2001.

[ASARP] Final report on the safety of ACAS II in the European RVSM environment – EUROCONTROL – Edition 1.1, May 2006.

[IAPA] IAPA Project Final Report – Synthesis and guidelines – EUROCONTROL – Edition Number 1.2, October 2005.

[IAS] I-AM-SAFE Feasibility Study Report – EUROCONTROL – Version 1.1, March 2007.

[ORD] Operational Requirements Document for EATCHIP Phase III ATM Added Functions - Volume 2: Safety Nets – EUROCONTROL – Edition Number 2.0, January1999.

[SNETS] Survey of Practices in Safety nets, Summary Report – EUROCONTROL – Edition Number 1.0, February 2005.

[STCA1] EUROCONTROL Specification for Short Term Conflict Alert – Edition 0.6, December 2006.

[STCA2] EUROCONTROL Guidance Material for Short Term Conflict Alert – Edition Number 1.0, December 2006.