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[EN-044] Safety nets performance assessment: the encounter-model methodology as a cornerstone to provide quantified results for ACAS and STCA

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+J.M. Loscos*, C. Aveneau*
*R&D Department
Direction des Services de la Navigation Aérienne (DSNA)
Toulouse, France
[jean-marc.loscos | christian.aveneau]@aviation-civile.gouv.fr

Abstract: In the context of short term conflict alert (STCA) and airborne collision avoidance system (ACAS) performance assessment in the SESAR programme in Europe, the related SESAR Projects will have to determine safety and performance requirements associated with the proposed steps of evolution of the SESAR Concept of Operations. In particular, it is expected to express quantified safety benefits and minimum performance requirements for both STCA and ACAS as well as to ensure their compatibility in the new operations.

Keywords: Short Term Conflict Alert (STCA), Airborne Collision Avoidance System (ACAS), ACAS/STCA compatibility, safety encounter model, performance assessment

1 INTRODUCTION

This paper presents the encounter-model methodology which is a cornerstone for all the planned assessments and the main outcomes of the initial results produced in the current situation through ACAS study, STCA study and ACAS/STCA compatibility study.

The PASS project specifically addresses the performance and safety benefits evaluation of STCA and ACAS operations. The cornerstone of this work is the refinement of the encounter model-based methodology already used in the ACAS field to support the evaluation of the performance and safety benefits of STCA while taking into account the effect of ACAS operations.

The encounter model methodology is intended to be used for the SESAR projects dealing with “Evolution of Ground-Based Safety Nets” (4.8.1), “Evolution of Airborne Safety Nets (4.8.2)” and “Compatibility between airborne and ground-based safety nets (4.8.3)”. These 3 projects lead by DSNA, France started in June 2010 and will support safety net performance assessment associated with the 3-step evolutions of the ATM CONOPS i.e., time-based operations, trajectory-based operations and performance-based operations.

First results on current operations or near future operations are presented on key performance parameters.

2 BACKGROUND & CONTEXT

2.1 STCA standardisation

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, optimization and validation. Under the leadership of the SPIN SC of EUROCONTROL, STCA standardization is progressed in Europe.

2.2 ACAS standardization

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).

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 standardize ATM compatibility requirements for ACAS through the definition of targeted ratios of nuisance alerts.

2.3 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) [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 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.

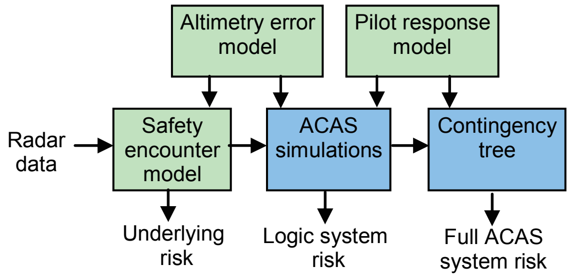

Figure1: Framework for the evaluation of the safety of ACAS

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 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.

2.4 Compatibility

Existing SNETs have been developed independently and airborne SNETs & ground-based SNETs operations are not always compatible.

In particular, ground-based SNETs have been implemented in a local context while ACAS has been implemented globally. In addition, they have been designed in isolation and their design is based on independence and not on compatibility.

SESAR CONOPS envisages new separation modes (i.e. future 3D/4D trajectory management with ground-based separation modes, cooperative air-ground separation and self-separation in mixed environment) for which evolutions of airborne and ground-based safety-nets might be necessary, but there is no guarantee that these developments will improve their compatibility.

SESAR Projects are an opportunity to progress with the compatibility between airborne and ground-based SNETs during their evolution, while preserving their independence.

2.5 I-AM-SAFE project outcomes

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

Although quite simple, the STCA performance metrics evaluated during the study have shown the influence of the encounter characteristics (i.e. risk bearing situations or day-to-day conflicts in Terminal Control Area

(TMA) or en-route), the STCA configuration (e.g. with or without the use of the Cleared Flight Level (CFL)) and parameters, as well as the quality of the data provided to STCA, on the likelihood and relevance of the alerts is significant.

3 THE PASS PROJECT (2007-2010)

In the context of Short-Term Conflict Alert (STCA) standardisation in Europe, EUROCONTROL has launched the PASS project (Performance and safety Aspects of Short-term Conflict Alert – full Study). The project falls within the scope of the SPIN (Safety nets Performance Improvement Network).

3.1 Project Objectives

This 3-year EUROCONTROL project led by Egis Avia in partnership with Deep Blue, DSNA, and QinetiQ aims at

1) Contributing to a better knowledge and understanding of the current situation (monitoring activity)
2) Developing operational, safety and performance requirements for consistent STCA and ACAS operations
3) Undertaking a comprehensive evaluation of the effectiveness of STCA and its possible interaction with ACAS in order to support the standardization of STCA.

3.2 Enhanced framework for STCA performance evaluation

Taking into account the previous findings, a more sophisticated framework that would enable the evaluation of STCA performance and safety benefits while also taking into account the effect of ACAS operations has been proposed and is illustrated in Figure 2.

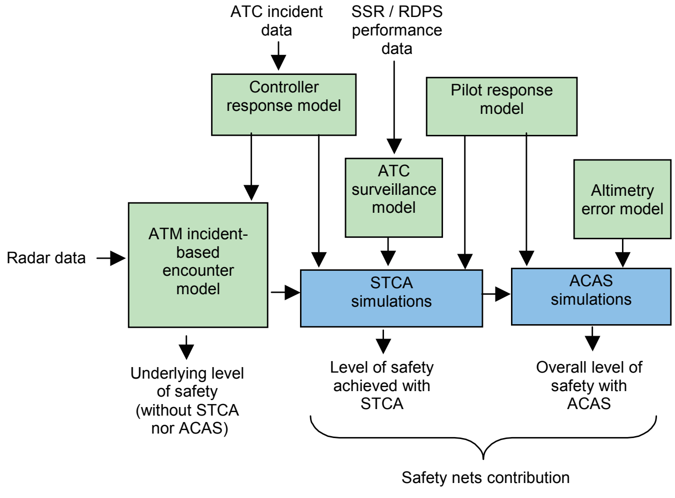

Figure 2: Possible framework for STCA performance assessment

This framework builds upon the encounter model-based methodology and the various areas of improvement identified during the study. It requires the development of a series of models to simulate operationally realistic scenarios of STCA environment and use.

The cornerstone of the approach is the development of an ATC incident-based encounter model (derived from real incidents that occurred in Europe) that would encompass the scope of both the previous safety and ATM encounter models without their limitations.

3.3 Overview of the simulation framework

In order to measure the performance of STCA with the encounter-model based methodology, two key elements are required. The first one is a large set of encounters generated from the PASS ATC incident-based model, which consists of at least 400,000 encounters. The second required element is a set of operational scenarios that describe a series of assumptions related to the ATC surveillance environment, to the STCA and ACAS systems and to the human performance. All of these are parameters to the different models constitutive of the PASS STCA and ACAS simulation framework.

In a first step, an STCA simulation is performed on the generated encounters using one of the agreed operational scenarios. The output of this simulation is a set of modified encounters which, in the case that an STCA alert has been issued by the STCA model, contains the manoeuvre performed by the pilot model in response to the instruction determined by the ATCO model. Comparing these modified encounters to the initial ones enable the computation of STCA performance metrics ([D120]) indicative of the level of safety achieved with STCA alone.

In a second step, an ACAS simulation, using an implementation of TCAS II, is performed on the encounters modified with the responses to any STCA alerts. Any resulting RA is responded to by the pilot model according to the response scheme defined in the operational scenario under investigation. The result of this second step is thus a set of encounters containing potential responses to both STCA and ACAS alerts. Comparing these modified encounters to the initial ones enables the computation of performance metrics on the combination of both safety nets, and is indicative of the level of safety achieved with both STCA and ACAS. These two steps and the simulation framework that has been set up to conduct PASS Phase 2 STCA and ACAS simulations are summarized in Figure 3 below.

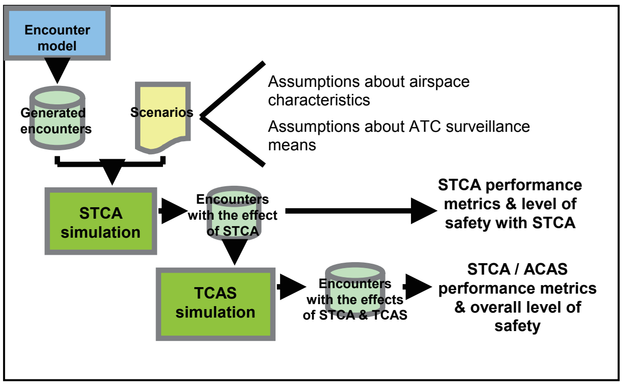

Figure 3: Overview of the STCA and ACAS simulation framework

In principle, the framework described above could be enhanced to allow the simulation of both STCA and TCAS in one sweep, thus better addressing situations where both STCA alerts and ACAS RAs occur. The I-AM-SAFE feasibility study however indicated that these situations are rare ([IAMSAFE]). In addition, the desired outcome of encounters triggering both types of alert generally corresponds to what is achieved with the two-step approach described in Figure 3 given the priority of ACAS RAs over ATC instructions and the different time horizons of the two systems.

The work conducted has enabled the development of a set of models that constitutes a realistic framework in which STCA fast-time simulations can be conducted. These models notably include an encounter model generating theoretical, yet realistic, situations in which STCA might be involved. EUROCONTROL reference STCA system has been implemented in an STCA model that can be configured to suit different approaches towards the operation of STCA. The CNS environment in which STCA is operated is also taken into account, notably with a model of ATC surveillance means. Lastly, the responses brought by human actors involved in STCA occurrences have also been implemented in specific controller and pilot models.

3.4 Encounter modelling

By definition the encounter represents a traffic situation (operationally realistic) involving two aircraft.

The safety encounter model is built as follows:

- Close encounters (with almost no horizontal miss distance) with actual or potential risk of collision
- About 1 close encounter every 6,000 flight-hours (or every 2 days of observation by a typical en-route radar)

The ATM encounter model is built with the following characteristics:

- Encounters occurring in routine operations including ATC intervention to preserve separation
- About 4 encounters per flight-hour ≈ about 18 encounters per sector hour

Modelling of observed encounters (statistical distributions of encounter properties derived from radar data analysis) is supported by the following features, in the plan view associated to the vertical profile in the Figure 4 below.

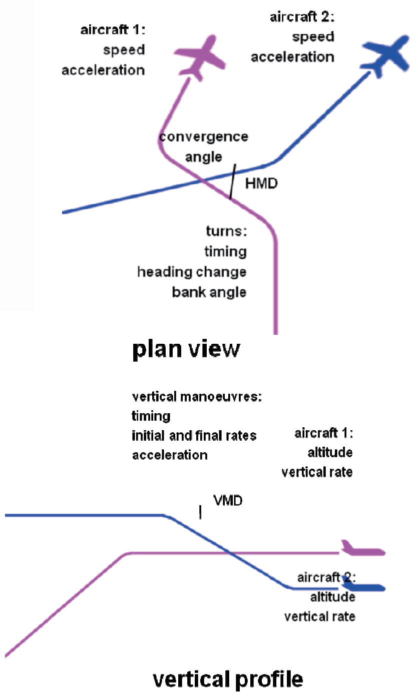

Figure 4: Plan view and vertical profile of encounters showing the characteristics used in the models

Five altitude layers are defined with distinct proportions of aircraft performance classes as shown in the Figure 5 below.

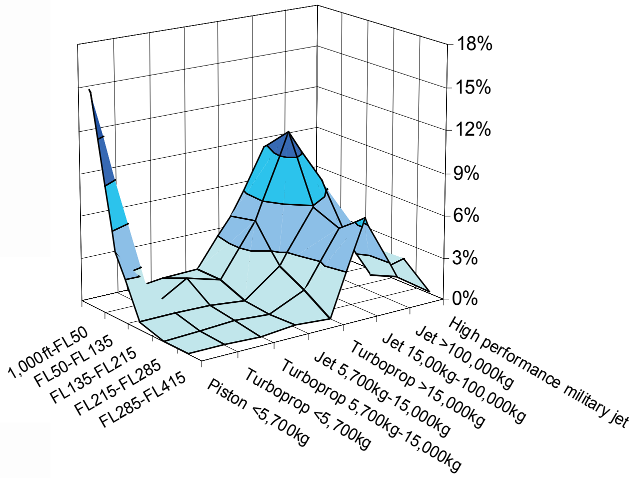

Figure 5: Altitude layers and aircraft classes

The highest percentages represent the most typical aircraft class below FL50 (light piston) and over all altitudes (medium jets).

3.5 Monitoring and modeling STCA, controller and pilot

To start with, it has been necessary to undertake a monitoring phase in order to understand the current situation. An exhaustive analysis of real ATC incidents (more than 100 actual events in the database) was conducted, 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 behavior of controllers and pilots in response to the alerts generated by the two safety nets.

The results enabled modeling of all encounter situations, and only those, where STCA and/or ACAS are likely to play a role. The main feature is the development of an ATC incident-based encounter model (derived from real incidents that occurred in Europe) that would encompass the scope of both the previous safety and ATM encounter models without their limitations.

A range of realistic operational scenarios (with and without ground-based SNETs) for both TMA and en-route airspace has been defined with different human behaviours as observed during monitoring activity.

STCA specifications have been defined by EURCONTROL as well as guidance material in support of local implementation. [STCA1, STCA2]

STCA configurations shown in the Figure 6 below are defined as several STCA "families" identified during monitoring activity with different parameters and optional features:

- More or less time-critical parameters and more or less reduced separation thresholds.
- Distinction between "basic", "standard" or "advanced" implementation

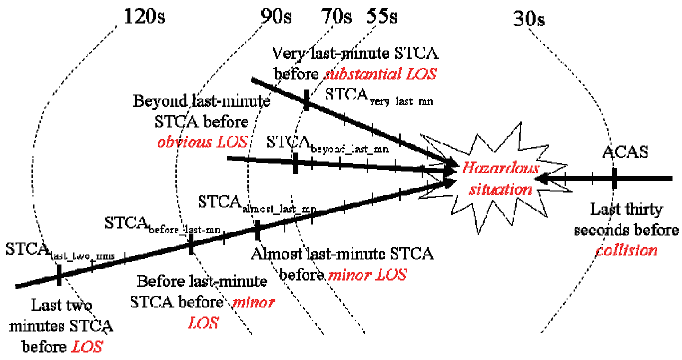

Figure 6: STCA configurations

Pilot response modeling has been derived from operational airborne recordings and has been built as a continuum of responses around ICAO standard response, i.e., 5s delay, 0.25g acceleration., 1500fpm Vertical Speed.

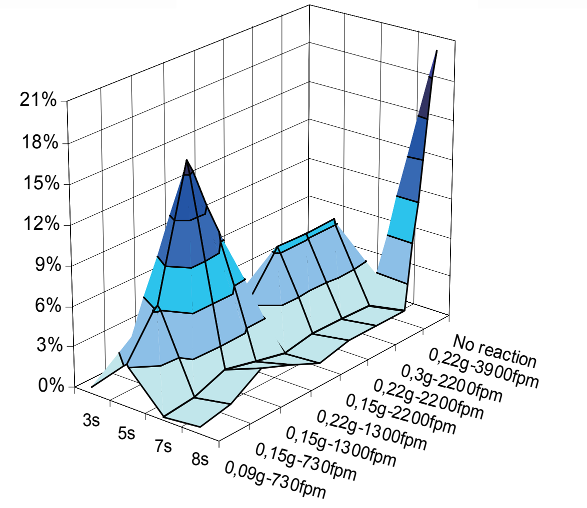

Figure 7: Modeling pilot responses to ACAS RA

The peak in the middle of the Figure 7 represents the most typical pilot response i.e., 5s delay, 0.15g acc., 1,300fpm vertical speed while the peak on the right indicates the percentage of non responding pilots.

4 SIMULATIONS & RESULTS

4.1 Framework of simulations

Using the inputs from monitoring actual events and the description of the European STCA environment conducted earlier in the project, a number of operational scenarios have been defined, that cover both TMA and en-route airspace. These operational scenarios cover a wide range of operationally realistic STCA implementations as observed in Europe. Several STCA families have notably been identified, which supply a greater or lesser frequency of time-critical alerts depending on the ANSP expectations regarding STCA, i.e. significant positive contribution to "collision avoidance" mainly or also to "separation protection". Specific scenarios were also defined to assess the influence of the CNS characteristics on the performance of STCA, as well as the influence of the human behaviour on the potential safety benefits that can be expected from STCA operation.

4.2 Key performance areas of STCA

In parallel with the setting up of this simulation framework, a set of metrics have been defined that allow the performance of STCA in any given scenario to be quantified. These metrics relate to the likelihood of STCA alerts, to their operational relevance, to their potential efficacy and to the level of interaction between STCA and ACAS (relative timing when the 2 SNET are triggered).

4.3 Results on the likelihood of STCA alerts

The subsequent fast-time simulations that have been performed show that the strategy followed by an ANSP when implementing and optimizing its STCA system has a direct effect on the likelihood of alerts.

All investigated STCA configurations show comparable alert rates for the most severe encounters

For less severe encounters, STCA configurations designed for collision avoidance only show an alert rate 100 less than STCA configurations designed for « separation protection » as well as « collision avoidance ».

All STCA configurations issue unnecessary alerts (no loss of separation). In addition, the quality of the surveillance data used by STCA also has a small effect on the STCA alert rate.

4.4 Results on the operational efficacy of STCA alerts

The efficacy of STCA alerts is mostly linked to the warning time afforded by the STCA to the controller for him/her to assess the situation and take action to ensure that separation will not be infringed or will be restored. STCA systems designed for "separation protection" as well as "collision avoidance" issue fewer time-critical alerts than those designed only for "collision avoidance". For a given STCA system, the use of optional features (use of CFL/SFL, additional filters, …) can provide additional warning time to the controller in a few specific circumstances.

The various STCA configurations provide fairly similar WARNING TIME performances. Optional features (turning prediction filter, use of CFL or SFL) improve the separation margins in the most time-critical alerts.

The safety benefits can be expressed by the Ratio of (separation infringements with the effect of STCA) / (Separation infringements without the effect of STCA).

The less conservative STCA families appear to be less effective than the other families to maintain or restore separation. However, all but one STCA family reduce the number of separation infringements for severe encounters by a factor of at least FIVE (Ratio <20%)

These general trends are of course susceptible to be influenced by the performance of human actors involved in the responses to STCA alerts, with prompter controller responses or the use of avoiding phraseology reducing the final number of separation infringements. However, STCA systems designed for "separation protection" as well as "collision avoidance" are less sensible to this influence of controller (and pilot) performances.

4.5 Results on the STCA and ACAS interaction

The simulations performed have also demonstrated that STCA families fundamentally designed for "collision avoidance" significantly increase the likelihood of interaction with ACAS, compared to those families designed for "separation protection" as well. For the former STCA families, avoiding instructions should be preferably given in the vertical dimension so as to reduce the likelihood of a subsequent ACAS RA (since horizontal instructions are less effective in increasing safety margins, and hence to prevent RA issuance). However, belated vertical avoiding instructions have a greater potential for being contrary to a subsequent RA if and when it happens.

5 CONCLUSION AND FUTURE WORK

The comprehensive range of simulations conducted within PASS have led to the recommendation of a set of performance metrics that can help quantify the qualitative requirements expressed in EUROCONTROL Specification of Short-Term Conflict Alert [STCA1]. Depending on the exact strategy adopted by an ANSP with regard to the role of its STCA system (i.e. focused on "collision avoidance" or on "separation protection"), appropriate thresholds for these metrics can be established so as to set up minimum performance requirements for this STCA system.

The project is now finalizing the study report which will be subject to a dissemination workshop on 23th of November 2010 (EUROCONTROL HQ Brussels).

The report will be consolidated and should be considered as a step further towards a consistent overall concept for ground-based and airborne safety nets in coordination with appropriate bodies.

Indeed, the SESAR Operational Project 4.8.1 (Evolution of Ground-Based Safety Nets) will use the report and the methodology to express Operational Requirements, Safety and Performance requirements in support of the development of an industrial prototype by the SESAR Technical Project 10.4.3 (Safety Nets adaptation to new modes of operation). The SESAR Operational Project 4.8.3 (ground-airborne safety nets compatibility) will in parallel, ensure that the requirements developed for Ground safety nets do not compromise ACAS performance in a detrimental way. These projects started in 2010 and will carry their work until 2016.

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