

## IAPA Project Final Report – Synthesis and guidelines

### Implications on ACAS Performances due to ASAS implementation

#### IAPA Project

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## RECORD OF CHANGES

Issue	Date	Detail of changes
0.1	25-04-2005	Outline complemented with material from IAPA Interim Report from Phase I
0.2	02-06-2005	Material added in sections 3, 4 and 5 based on the WP7 and WP8 final reports
0.3	01-07-2005	Revised report structure with new sections 2, 3,4 and 5 (with emphasis on the various IAPA study results from both Phase I and Phase II);  Material added in section 1 about the relationship between IAPA Phases and Work packages;  Material added in sections 2, 3, 4 and 5 based on the WP4 and WP6 final report and paper 106 (about initial WP10 study results)
0.4	09-09-2005	Minor modifications in all sections;  Material added in section 5 based on WP10 final report version 1.0, further development of section 6 based on all WP final reports;  New section 7 with draft conclusions and recommendations
1.0	30-09-2005	Revisions in sections 1, 2, 6 and 7 following the comments made at the 14 <sup>th</sup> Progress Meeting held in Toulouse;  Revised section 5 taking into account version 1.2 of WP10 final report, updated lists of definitions, references and acronyms;  Development of the executive summary
1.1	07-10-2005	Minor revisions in all sections following internal review
1.2	28-10-2005	Editorials in all sections;  Revised executive summary and section 7 taking into account the comments made following the IAPA seminar rehearsal held in Brussels

**IMPORTANT NOTE: ANY NEW VERSION SUPERSEDES THE PRECEDING VERSION, WHICH MUST BE DESTROYED OR CLEARLY MARKED ON THE FRONT PAGE WITH THE MENTION *OBSOLETE VERSION***

## EXECUTIVE SUMMARY

### **E.1. IAPA project overview**

#### **E.1.1. Background and context**

- E.1.1.1. The Airborne Collision Avoidance System II (ACAS) is an essential component in the current ATM system and should play the same role in future ATM operations.
- E.1.1.2. The operational use of the Airborne Separation Assistance System (ASAS) is seen as a promising option to improve the ATM system through a greater involvement of the flight crew in the separation provision.
- E.1.1.3. The interaction between ACAS and the operational use of ASAS is an open issue never thoroughly investigated, which needs to be addressed before any European ASAS implementation.
- E.1.1.4. The IAPA (Implications on ACAS Performances due to ASAS implementation) project addresses the issue, analyses its potential operational and safety implications and provides guidelines for the future development of ASAS applications in Europe. The study comes within the scope of the EUROCONTROL Mode S & ACAS Programme. It is of particular interest for several areas dealing with ASAS development.

#### **E.1.2. Scope and purpose**

- E.1.2.1. The IAPA project is focused on the potential interaction with ACAS of ATM operations both with and without the use of ASAS. It ascertains:
  - whether there are any significant implications for ACAS performance due to possible ASAS implementation in the ECAC (European Civil Aviation Conference) airspace; and
  - whether the benefits expected from ASAS could be compromised due to the operations of ACAS.
- E.1.2.2. The introduction of ASAS potentially raises some interaction issues with ACAS in terms of airborne system integration and operation by the pilot, but these issues are out of the scope of the project.
- E.1.2.3. The IAPA project identifies and assesses the operational issues (in terms of undesirable ACAS alerts) resulting from the potential interaction between the ACAS logic and ASAS procedures. It also performs a safety analysis of the ACAS / ASAS interaction, which evaluates the safety benefits (in terms of reduced risk of collision) that can be expected from ACAS during ASAS procedures.
- E.1.2.4. The project builds on the methodology that was established, and the tools that were developed in the ACASA (ACAS Analysis) project. Advantage is also taken of the recent improvements brought to some of these tools in the ACAS Safety Analysis post-RVSM Project (ASARP).

### E.1.3. Project breakdown

E.1.3.1. The project was conducted in three main phases:

- Phase I (November 2002 – October 2003) defined the scope and framework of the ACAS / ASAS interaction study;
- Phase II (November 2003 – December 2004) consisted in conducting a full set of simulations, based on different sources of data, for an in-depth operational and safety analysis of the interaction between ACAS and ASAS; and
- Phase III (January 2005 – November 2005) consolidated the results of the previous phases and drew the project conclusions and recommendations.

E.1.3.2. The IAPA project represented a total effort of more than 11 man-years.

### E.1.4. Phase I: Scope and framework

E.1.4.1. Phase I of the IAPA project first consisted of selecting and defining an ASAS application with the potential for studying a maximum of significant and realistic ACAS / ASAS interaction issues.

E.1.4.2. This selection was supported by a preliminary analysis of the ACAS / ASAS interaction issue for a set of ASAS applications proposed for early implementation in Europe. The focus was on ASAS applications with the potential for raising interaction issues with ACAS.

E.1.4.3. An Operational Environment Definition (OED) was developed for the purposes of the IAPA study, which describes the main assumptions about the selected ASAS application, i.e. the ASAS lateral crossing application, and its ATM/CNS environment. This OED took advantage of available Operational and Service Environment Definitions from various European projects. The applicable spacing (Option 1) / separation (Option 2) value during the ASAS procedures was established so as to be realistic yet demanding in terms of potential interaction with ACAS.

E.1.4.4. Phase I also established the framework required for an in-depth investigation of the ACAS / ASAS interaction issue. This framework supported the various simulations conducted in Phase II and includes:

- a common simulation framework defining three different ASAS scenarios for the use of the selected ASAS application, and defining a list of ACAS / ASAS interaction indicators;
- a simplified model of the selected ASAS application simulating its nominal effect on the aircraft trajectories assuming perfect ASAS performance; and
- an ATM encounter model describing conflict situations observed in current ATM operations in core Europe.

E.1.4.5. Within IAPA Phase II, an ASAS encounter model was derived from the ATM encounter model, which was assumed to model an airspace in which the selected ASAS application would be used in accordance with the operational principles defined in the OED.

#### **E.1.5. Phase II: Operational and safety analyses**

E.1.5.1. Phase II consisted of a comprehensive investigation of the operational and safety issues potentially raised by the introduction of ASAS in the European airspace. This investigation was focused on the ASAS application selected during Phase I, viz. the ASAS lateral crossing procedure.

E.1.5.2. The operational analysis of the potential ACAS / ASAS interaction issues was focused the two aircraft involved in the ASAS procedure. It was supported by a full set of simulations using different sources of data including:

- the ASAS encounter model;
- modified European radar data;
- CFMU flight plan simulation data; and
- data extracted from real-time simulation data.

E.1.5.3. Different sources of data were used to compensate for any individual limitations related to any one of them and to ensure that all relevant issues were identified. The use of the common simulation framework set-up during Phase I allowed the cross-validation of ACAS / ASAS interaction trends identified using each source of data, as well as the investigation of specific features depending on the source of data.

E.1.5.4. The safety analysis of the potential ACAS / ASAS interaction investigated and assessed the impact of ASAS operations on the safety benefit provided by ACAS. This analysis considered not only the two aircraft involved in the ASAS procedures, but also the possible presence of a third aircraft. It was supported of a set of methods and tools developed in previous studies of ACAS safety and supplemented by other ATM safety assessment methodologies.

#### **E.1.6. Phase III: Synthesis and guidelines**

E.1.6.1. Phase III concluded the project by consolidating the work performed during Phase I and Phase II, and delivering guidelines for the development of future ASAS applications.

### **E.2. Initial investigation of the ACAS / ASAS interaction**

#### **E.2.1. Scope and approach**

E.2.1.1. The preliminary investigation of the ACAS / ASAS interaction issue performed during Phase I was supported by a case-by-case analysis of relevant encounters featuring possible ASAS operations.

E.2.1.2. The range of ASAS applications of initial interest included the Package I of Airborne Surveillance applications proposed for early implementation in Europe. To cope with the IAPA study purposes, this set was extended to the ASAS applications presenting the potential for an extension into airborne separation applications (Package II).

E.2.1.3. A preliminary step consisted of identifying the encounter situations that have the potential to trigger an ACAS alert. This was determined on the basis of the ICAO guidance material associated with the ACAS Standards and Recommended Practices. In a second step, a set of specific and demanding encounters (in terms of potential interaction with ACAS) was built manually and ACAS simulations were performed.

E.2.1.4. Finally, a specific case study of the ASAS lateral crossing application was performed to further identify the encounter parameters that influence the interaction with ACAS.

#### E.2.2. Main achievements and results

E.2.2.1. Following this preliminary investigation of the ACAS / ASAS interaction issue, **no interaction with ACAS is anticipated for the following ASAS applications:**

- The in-trail phases of the ASPA-S&M: “Enhanced sequencing and merging” operations whatever the altitude layer, assuming the Wake Vortex separation minima are preserved; and
- The lateral passing situations resulting from ASPA-C&P: “Enhanced crossing and passing” operations whatever the altitude layer, since the lateral spacing values required to trigger an ACAS alert during slow convergence situations are of the order of the ACAS minimum protection distance parameter (DMOD), e.g. 1.3NM for a TA above FL200. It is unlikely that such lateral spacing values would not be operationally acceptable.

E.2.2.2. **Some interaction with ACAS potentially exists for the ASPA-S&M: “Enhanced sequencing and merging” operations, but only during merging situations close to the limit to what could be considered operationally acceptable.** In particular, some merging encounters with required spacing at the IAF close to the radar separation minimum in Terminal control Area, i.e. 3 NM, may trigger a TA. However, such spacing values between aircraft in sequence are unlikely to occur during typical merging situations.

E.2.2.3. Finally, the results of the preparatory analysis showed that **some interaction with ACAS potentially exists for the ASPA-C&P: ‘Enhanced crossing and passing operations’** during nominal operations. In particular, the following encounter situations were identified as likely to trigger TAs:

- Lateral crossing encounters with high closure rate and small horizontal separation between the aircraft at CPA, i.e. typically encounters with angles of convergence greater than 90 degrees and a Horizontal Miss Distance close to the applicable radar separation minima, i.e. 3 NM in TMA and 5 NM in en-route ECAC airspace; and
- Level-off encounters at the applicable vertical separation minima, i.e. 1,000 ft below FL415 in the ECAC airspace, with vertical rates operationally realistic for almost all aircraft types. In addition, 2,000 ft level-off encounters may trigger TAs in the altitude layer FL100-FL410 in case of significant, but realistic, relative altitude rates.

E.2.2.4. The 1,000 ft level-off encounters may even trigger ‘undesirable’ RAs below FL415 in the case of significant, but realistic, vertical rates. It should be noted that the ACAS interaction issue raised by such encounters already exists for current ATM operations. Therefore, it is not solely linked to the introduction of ASAS operations.

E.2.2.5. With regard to the lateral crossing encounters, the main factors influencing the interaction with ACAS include the angle of convergence, the aircraft speed and the type of ASAS manoeuvre (i.e. “pass in-front” or “pass behind”): the higher the resulting closing speed between the aircraft, the higher the likelihood of a TA.

E.2.2.6. In particular, by increasing the initial rate of convergence, the “pass behind” manoeuvres are more likely to trigger TAs than the “pass in-front” manoeuvres. However, this does not mean the latter are safer than the former.

### **E.3. Operational analysis of the ACAS / ASAS interaction**

#### **E.3.1. Scope and approach**

E.3.1.1. The various data-oriented studies performed during Phase II focused on the ASAS lateral crossing application. In order to assess the ACAS / ASAS interaction issue on the most demanding basis, the ASAS separation applied in most of the simulations was 4 NM (considered the minimum separation applicable assuming RNP-1 navigation performances and perfect surveillance and communication performances). Further, a specific sensitivity analysis of the ACAS / ASAS interaction, depending on that applicable separation minimum, was performed through the study based on flight plan data.

E.3.1.2. An investigation into ASAS operations with distinct assumptions was performed through the study based on real-time simulation data. This dealt with both “ASPA-Crossing & Passing” and “ASPA-Sequencing & Merging” procedures with ASAS spacing values close to current ATC practices. The analysis of the available real-time simulation data did not reveal any ACAS interaction issue.

E.3.1.3. The framework developed during Phase I successfully supported the full set of simulations conducted within Phase II. Further, specific methodologies, and associated sets of tools, were developed in support of the various data-oriented studies. The studies based on modified radar data, the ASAS encounter model and flight plan data provided comparable results highlighting a set of potential operational issues linked to the issuance of undesirable ACAS alerts during nominal ASAS operations.

E.3.1.4. The studies based on the ASAS encounter model and on modified radar data allowed a comparative analysis of the interaction with ACAS between current ATM operations and future operations following the introduction of ASAS procedures. Because of the forward looking nature of the IAPA study, this comparison was limited to the ASAS application selected for further investigation, i.e. the ASAS lateral crossing procedure.

#### **E.3.2. Potential impact of ACAS on ASAS performance**

E.3.2.1. The possible issuance of “undesirable” ACAS alerts during the execution of ASAS lateral crossing procedures (with a minimum separation value of 4 NM) is likely to **affect the performance of the ASAS procedures, and therefore, their expected benefits.**

E.3.2.2. Although all three IAPA studies provided different estimates of the ratio of ASAS procedures triggering at least one TA, a similar trend was observed whatever the source of data used in the simulations. It is estimated that a TA will occur in between 13% and 18% of the ASAS procedures regardless of whether or not a manoeuvre is required to ensure the ASAS separation. The likelihood of TAs increases to between 42% and 67% when considering ASAS encounters with a “pass behind” or “pass in-front” manoeuvre.

- E.3.2.3. With regard to the likelihood of RAs, all three studies provided comparable results: on average just under 1% of the ASAS procedures triggering at least one RA whatever the scenario. Nevertheless, this proportion noticeably varies depending on the ASAS encounters, and particularly whether or not a manoeuvre is required to ensure ASAS separation.
- E.3.2.4. In line with the initial results of the IAPA case study, all three studies resulted in a slightly increased likelihood of ACAS alerts for the “pass behind” manoeuvres compared to the “pass in-front” ones.
- E.3.3. Potential impact of the ACAS / ASAS interaction on pilot acceptance
- E.3.3.1. The **frequent, but non-systematic, issuance of Traffic Advisories** by the ACAS logic against the other aircraft involved in an ASAS lateral crossing procedure **is likely to be considered as disruptive from the pilot perspective, and therefore, a major ACAS / ASAS interaction issue**. Further, this is likely to affect the pilot's confidence in the ASAS procedure and system.
- E.3.3.2. The mean likelihood of undesirable TAs during ASAS operations has been estimated up to one time per ten flight hours, regardless of any other TAs that may occur independently of the ASAS lateral crossing procedure. This result is highly dependent on the frequency of the ASAS procedure, which has itself been estimated to be in between one to five times per ten flight hours in the study based on modified radar data.
- E.3.3.3. It should be noted that, in all three IAPA studies, the likelihood of TAs during the ASAS lateral crossing procedure appeared to be greater at high altitudes, i.e. within the sensitivity level 7 of the TCAS II logic version 7.0. Furthermore, a non-negligible proportion of repetitive TAs has been observed, i.e. in between 1% to 3%, depending on the source of data.
- E.3.4. Potential incompatibility between ACAS and ASAS operations
- E.3.4.1. **The possible occurrence of disruptive and undesirable Resolution Advisories by the ACAS logic during nominal ASAS operations is a major ACAS / ASAS interaction issue**. Indeed, such alerts would be considered as a lack of compatibility between the separation function provided by ASAS and the collision avoidance function devoted to ACAS. Further, this is likely to affect the operational applicability of the ASAS procedures.
- E.3.4.2. Assuming a nominal performance of the ACAS surveillance, the mean likelihood of undesirable RAs during nominal ASAS operations has been estimated up to one per sector every 6 days, regardless of any other RAs that may occur independently of the ASAS lateral crossing procedure. Once again, this result is highly dependent on the frequency of the ASAS procedure, which has been estimated to be at least one ASAS lateral crossing procedure every two hours per sector, and possibly up to three times per hour and per sector, for the European core area.
- E.3.4.3. The various simulation results show that the issuance of the RAs is quite sensitive to the quality of the aircraft trajectories used in the simulations. A specific analysis of the TCAS II logic version 7.0, conducted in the study based on flight plan simulation data, highlighted the effects of simulated trajectory variations on the ability of the “Miss Distance Filter” of the TCAS II logic to actually prevent the issuance of undesirable RAs.



- E.3.4.4. The ACAS / ASAS compatibility is likely to depend on the minimum separation value applicable during the ASAS operations. In this respect, **the demanding value of 4 NM appeared to cause compatibility issues when compared with current separation margins applied by ATC.**
- E.3.4.5. The sensitivity analysis (conducted in the study based on flight plan simulation data) indicated that a minimum separation value of 7 NM was necessary to prevent TAs from being triggered when an ASAS lateral crossing manoeuvre was required. Further, a minimum separation value of 5 NM was necessary to prevent the issuance of any RAs.
- E.3.5. Comparison between ASAS and ATM operations under nominal circumstances
- E.3.5.1. **Current ATC practices with the typical separation margins applied by ATC appears to be much more compatible with ACAS than the ASAS lateral crossing procedures with the demanding separation minimum of 4 NM** investigated within the IAPA study, except for the 1,000 ft level-off encounters.
- E.3.5.2. Depending on the source of data used for the ASAS simulations, the ratio of ASAS encounters triggering an RA compared to the original encounters with ATC increases by a factor of four with the ASAS encounter model and by a factor of forty with the modified radar data.
- E.3.5.3. It was thus not possible to draw precise conclusions on the extent to which the introduction of ASAS lateral crossing procedures would increase the issuance of undesirable ACAS alerts during ASAS operations since both IAPA studies provided distinct alert rates. However, both studies provided a similar trend with regard to the prevalence of RAs between ASAS and ATM encounters.

#### **E.4. Safety analysis of the ACAS / ASAS interaction**

- E.4.1. Scope and approach
- E.4.1.1. The safety analysis conducted during Phase II performed an initial evaluation of the level of safety that can be expected from the operation of ACAS when aircraft are engaged in ASAS procedures. This level of safety was assessed both qualitatively in terms of consequences and severity of hazards, and quantitatively in terms of the reduced risks of collision.
- E.4.1.2. Using the guidelines of the EUROCAE Operational Safety Assessment methodology and the EUROCONTROL Safety Assessment Methodology, the technique of Operational Hazard Analysis was employed to identify and assess the ways in which the use of ASAS and ACAS could result in a safety issue, and particularly a Near Mid-Air Collision (NMAC).
- E.4.1.3. The main findings of the ACAS / ASAS interaction OHA was used to adapt a contingency tree previously developed in the ACASA project, to the context of the IAPA study and to ensure the completeness of the set of events that it considered.
- E.4.1.4. This contingency tree combines ACAS logic risks with the probabilities of other external events (such as human factor events and visual acquisition events) to provide a full-system risk evaluation. By varying some of the scenario parameters of the ACAS simulations, many full-system risk estimates can be determined for distinct assumptions related to the ACAS equipage and operation by the flight crew.

- E.4.1.5. To allow for the computation of ACAS logic risks in an ASAS environment, and the comparison with the logic risks in the airspace prior to the introduction of ASAS, a ACAS/ASAS-applicable safety encounter model (related to the close encounters in which the ASAS procedure would be applicable) and a ACAS/ASAS safety encounter model (related to the close encounters following the use of the ASAS procedure) have been produced.
- E.4.1.6. All these methods and tools as a whole has proven useful in identifying the safety issues potentially raised by the ACAS / ASAS interaction, and assessing the safety benefits that can be expected from ACAS during ASAS operations.
- E.4.1.7. Because of the forward looking nature of the IAPA study, this evaluation was limited to the ASAS application selected for further investigation, i.e. the ASAS lateral crossing procedure.
- E.4.2. Operational hazards and IAPA contingency tree
- E.4.2.1. Two separate Operational Hazard Analyses were first conducted on the ASAS procedure and the ACAS procedure respectively, which were used as the basis for an analysis of the impact of the ASAS OHA on the ACAS OHA. This analysis revealed that **the interaction with ACAS is different depending on whether or not the ACAS intruder is the other aircraft involved in the ASAS procedure or a third aircraft.**
- E.4.2.2. Furthermore, the analysis highlighted that the **enhanced Airborne Traffic Situational Awareness of the flight crew that can be expected in an ASAS environment can be a safety-contributing factor** that either mitigates the consequences or reduces the likelihood of some operational hazards related to the ACAS procedure.
- E.4.2.3. These findings were taken into account in the development of the IAPA contingency tree. The two possibilities of the reference aircraft being on a close encounter course with the other aircraft in the ASAS procedure, or being on a close encounter course with a third aircraft, was handled by a high-level split of the contingency tree into an ‘ASAS intruder branch’ and a ‘third aircraft branch’. Many of the events on one branch were qualitatively duplicated on the other branch, but were assigned different probabilities that reflect the two contexts.
- E.4.3. Safety encounter models and underlying NMAC rates
- E.4.3.1. A crucial factor in evaluating the risk reduction provided by the operation of ACAS is the underlying NMAC rate of the considered airspace. The ACAS / ASAS-applicable safety encounter model and the ACAS/ASAS safety encounter model were thus used to determine the underlying NMAC rate (before and after the introduction of ASAS in the airspace) in those encounters in which the ASAS lateral crossing procedure would be applicable.
- E.4.3.2. For the ASAS-applicable close encounter set (when handled by conventional ATC), an NMAC rate of  $1.53 \times 10^{-7}$  per flight hour was estimated. For the ASAS close encounter set (when applying the ASAS lateral crossing procedure in the same encounters), an NMAC rate of  $1.85 \times 10^{-7}$  per flight hour was estimated.

E.4.3.3. Rather than indicating that there will be a rise in the underlying NMAC rate when ASAS procedures are introduced, these values should instead be viewed as evidence that **care will be needed to ensure that the introduction of ASAS procedures does not lead to an unacceptable rise in the underlying risk of collision.**

E.4.4. Risk ratio calculations

E.4.4.1. The ACAS logic risk ratios calculated using both the ACAS/ASAS-applicable safety encounter model and the ACAS/ASAS safety encounter model revealed that the safety performance of ACAS is similar in both environments. **The introduction of ASAS procedures into the airspace does not present any particular problems for the ACAS logic, which will continue to act as an effective safety net.**

E.4.4.2. The ACAS full-system risk ratios calculated using the ACAS/ASAS safety encounter model revealed that the deployment of ACAS in ASAS procedures could typically be expected to reduce the risk of collision to 4.6% of the risk in the absence of ACAS. The alerting aspects of ACAS (the prompting of contact with the controller and/or visual acquisition of the threat) are contributory factors in achieving this overall reduction, but the most important factor is the resolution advice (i.e. RAs) generated by the ACAS logic.

E.4.4.3. By operating ACAS and responding to RAs in the same typical manner as other pilots, the pilot engaged in an ASAS procedure can reduce the risk of collision to which he is exposed to 16.5% of the value applicable if he were not ACAS equipped. By improving his own response to RAs (whilst the response of other pilots remains typical), the risk of collision to which pilot engaged in an ASAS procedure is exposed can further reduced to 11.2% of the value applicable if he were not ACAS equipped.

E.4.4.4. By not responding to RAs, a pilot seriously compromises the safety benefit that can be afforded by ACAS equipage. Operating ACAS in RA mode, but ignoring the RA it generates, a pilot would expose himself (and the unwitting pilot of the other aircraft) to a risk of collision that is over four times greater than it can be if pilot typically respond to the RAs.

E.4.4.5. If, for some reason, an aircraft is unable to comply with RAs it is preferable that the system be placed in TA-only mode. In this circumstance the risk of collision is reduced, compared to the case of ignoring RAs, because ACAS in equipped threats is free to choose the most effective RA. Nevertheless, ACAS should not be routinely operated in TA-only mode. By operating ACAS in RA mode and following the RAs that are generated, the risk of collision to a pilot engaged in an ASAS procedure is less than half the risk to which he would be exposed if he operates ACAS in TA-only mode.

E.5. Conclusions

E.5.1. General

E.5.1.1. The IAPA project is a substantial European contribution to the understanding of the potential interaction between ACAS and ASAS procedures. Such a contribution was required given the envisaged evolution of the European ATM system, which may impact the forecasted performance of both ACAS and the new ATM system itself.

E.5.1.2. The IAPA study of the ACAS / ASAS interaction issue consisted of a comprehensive work programme supported by a set of sophisticated methods and tools. It has demonstrated that:

- ACAS remains effective as the last resort safety net and the demonstrated safety benefits underline the need to operate ACAS during ASAS operations;
- The ACAS constraints must be taken into account when developing ASAS procedures envisaged for implementation; and
- The existing ACAS system may need to evolve to improve compatibility with ASAS applications envisaged for implementation.

E.5.1.3. Any conclusions drawn from the IAPA study results should be considered taking due account of the various study assumptions and limitations. These assumptions may be challenged by a specific implementation of ASAS. If such, there will be a need to further assess the interaction between ACAS and ASAS taking into account the specific environment in which the operational use of ASAS would be envisaged.

E.5.1.4. With this perspective, the complete work programme carried out within the IAPA project is substantial body of work on which further work should build on.

#### E.5.2. ACAS safety net during ASAS operations

E.5.2.1. The safety analysis conducted within IAPA Phase II demonstrated that, if nominally operated, ACAS would continue to provide positive safety benefits during ASAS operations.

E.5.2.2. It confirms that operating ACAS in RA mode, but ignoring the RAs that it generates, is more dangerous than operating ACAS in TA-only mode. However, operating ACAS in TA-only mode during ASAS procedures entails a risk of collision that is more than twice what it would be if pilots engaged in ASAS procedures nominally operate ACAS.

E.5.2.3. The standard operational procedure should be that in ASAS procedures, as at all other times, ACAS should be operated in RA mode and the RAs that are generated should be followed, and followed promptly for best benefits.

#### E.5.3. Effect of ACAS on ASAS application development

E.5.3.1. The preliminary analysis made during IAPA Phase I has demonstrated that the interaction with ACAS highly depends on the nature of the ASAS application and its main assumptions with regard to the type of separation applied, i.e. lateral, longitudinal or vertical separation with applicable separation minima.

E.5.3.2. It also allowed identifying possible ACAS / ASAS interaction issues that may affect a set of Package I Airborne Surveillance applications during nominal operations. In particular, some interaction with ACAS potentially exists for:

- the ASPA-C&P: ‘Enhanced Crossing and Passing operations’, for lateral crossing situations in case of demanding applicable separation minima; and
- the ASPA-S&M: “Enhanced Sequencing and Merging operations” during the merging phases, but only during marginal situations.

E.5.3.3. The in-depth investigation of the ACAS / ASAS interaction issue performed during IAPA Phase II on the ASAS Lateral Crossing application confirmed the initial results achieved during Phase I. Furthermore, it demonstrated the influence of the separation minimum applicable during ASAS operations on the interaction with ACAS.

**E.5.4. Possible effect of ASAS applications on ACAS**

E.5.4.1. With regard to the ACAS / ASAS compatibility, the various simulations performed during IAPA Phase II have shown to what extent a demanding ASAS application can trigger undesirable ACAS alerts.

E.5.4.2. This is particularly the case for the possible issuance of frequent, but non-systematic, TAs against the other aircraft involved in the ASAS procedure. To avoid affecting the performance of demanding ASAS procedures, and therefore, their expected benefits, it may hence be required to revisit the current ACAS logic for TAs.

E.5.4.3. Further, it will be critical to ensure that the desirable role of the ‘Miss Distance Filter’ of the TCAS II logic version 7.0 (in preventing the issuance of undesirable RAs) is effective.

**E.5.5. Strength and relevance of the IAPA methodology**

E.5.5.1. The IAPA methodology has proven successful in assessing the ACAS / ASAS interaction issue and would equally benefit to any future investigation of the interaction between ACAS and ATM changes in the provision of separation.

E.5.5.2. The use of European radar data is key to operational relevance. It is particularly valuable in obtaining a precise understanding of the current ATC practices and allows a comparative analysis between current and future ATM operations.

E.5.5.3. The ATM encounter model developed within IAPA (based on real encounters extracted from radar data) is a powerful tool for evaluating ATM changes and their interaction with ACAS

E.5.5.4. Finally, the sophisticated methods and tools that supported the safety analysis of the ACAS / ASAS interaction allows identifying potential safety issues and assessing the ACAS safety benefits during ATM operations.

**E.6. Recommendations**

E.6.1. ACAS must be operated during ASAS procedures as in any ATM operations. Furthermore, the possible impact on the safety benefits provided by ACAS should be carefully assessed prior to any particular ASAS implementation.

E.6.2. The ACAS constraints must be taken into account when developing ASAS applications so as to achieve an appropriate ACAS / ASAS compatibility. In this regard, particular attention should be paid to the determination of the separation minima applicable during ASAS operations.

E.6.3. When implementing ASAS operations, appropriate consideration should be given to ACAS developments that would improve the compatibility with ASAS while preserving the independence of ACAS.

E.6.4. Any future investigation of ACAS / ASAS interaction issues should be supported by a comprehensive and robust methodological framework such as the one established during the IAPA project.

## LIST OF DEFINITIONS

<b>ACAS</b>	<p>Airborne Collision Avoidance System – A system standardised in the ICAO SARPs that uses transponder replies from other aircraft to warn the pilot of a risk of impending collision.</p> <p>In IAPA ACAS always refers to ACAS II – a system that generates traffic advisories (TAs) and also generates resolution advisories (RAs) in the vertical plane.</p>
<b>ACASA project</b>	<p>ACAS Analysis – a study commissioned by EUROCONTROL in support of the mandate for the carriage of ACAS II in Europe. Work Package 1 of ACASA investigated the safety of ACAS and developed a European safety encounter model, and a contingency tree.</p>
<b>ACASA safety encounter model</b>	<p>A safety encounter model developed in the ACASA project which characterised close encounters occurring in European airspace before the introduction of RVSM.</p>
<b>ACAS/ASAS-applicable safety encounter model</b>	<p>A safety encounter model characterising the close encounters expected to occur in the encounters in which the ASAS lateral crossing procedure would have been applicable.</p>
<b>ACAS/ASAS safety encounter model</b>	<p>A safety encounter model characterising the close encounters expected to occur during ASAS lateral crossing procedures.</p>
<b>ACAS / ASAS interaction</b>	<p>Any implications for ACAS performance due to possible ASAS implementation and/or any implication for ASAS applications due to the operation of ACAS.</p> <p>In the IAPA study, focus is on the operational and safety issues potentially raised by the interaction between ACAS and ASAS. The potential issues in terms of airborne system integration and operation by the pilot are out of the scope of the study.</p>
<b>Aircraft-centred risk ratio</b>	<p>The risk ratio (in a given procedure) experienced by an individual aircraft as a result of other aircraft equipping with ACAS.</p> <p>In the IAPA study, this is the ratio of the risk of collision to the reference aircraft in the ASAS lateral crossing procedure when other aircraft are equipped in accordance with the ACAS mandate, compared to the risk of collision when no aircraft are ACAS equipped. In the two scenarios the reference aircraft is assumed not to be operating ACAS.</p>
<b>ASARP project</b>	<p>ACAS Safety Analysis post-RVSM Project – an ongoing study commissioned by EUROCONTROL to investigate the safety of ACAS following the introduction of RVSM.</p> <p>Work Package 2 of ASARP has developed a safety encounter model characterising current European airspace including the RVSM levels. Work Package 4 of ASARP has refined the pilot response model developed in ACASA.</p>
<b>ASARP safety encounter model</b>	<p>A safety encounter model developed in the ASARP project, which characterises close encounters occurring in current European airspace.</p>

<b>ASAS</b>	Airborne Separation Assistance System – An aircraft system based on airborne surveillance that provides assistance to the flight crew supporting the separation of their aircraft from other aircraft.
<b>ASAS active intervention</b>	A horizontal manoeuvre by one aircraft (either behind or in-front of another aircraft) that preserves ASAS separation.
<b>ASAS encounter (or encounter with ASAS)</b>	An encounter, either resulting from the modelling of the behaviour of ASAS procedures or extracted from real-time experiments of ASAS operations.
<b>ASAS encounter model</b>	An encounter model characterising the encounters expected to occur in an airspace in which the selected ASAS application would be used in accordance with the IAPA operational environment definition.
<b>ASAS lateral crossing procedure</b>	<p>A new air traffic control procedure to allow one ASAS equipped aircraft to cross the flight path of a designated aircraft, while maintaining a separation of no less than the applicable spacing (Option 1) / separation (Option 2) minimum.</p> <p>The ASAS procedure was selected for detailed investigation of the ACAS / ASAS interaction issue in the IAPA study.</p>
<b>ASAS passive intervention</b>	Monitoring of aircraft separation without any required manoeuvre to preserve ASAS separation.
<b>ASAS procedure</b>	A component of an ASAS application (which is a set of operational procedures for controllers and flight crews that makes use of an Airborne Separation Assistance System to meet a defined operational goal). In IAPA the lateral crossing procedure was selected for detailed study.
<b>ASAS separation</b>	<p>Either horizontal or vertical separation (or both) above the applicable separation minima in an encounter where ASAS separation is applied.</p> <p>When studying the ASAS lateral crossing procedure in IAPA, the applicable horizontal separation minimum was set to 4 NM and the vertical separation minimum to 1,000 ft.</p>
<b>ATC encounter (or encounter with ATC)</b>	An encounter, either a generated encounter or a radar encounter, which potentially includes ATC intervention to preserve separation.
<b>ATC intervention</b>	<p>Either a horizontal or a vertical manoeuvre (or both), on at least one aircraft, that preserves ATC separation. Hence, distinction can be made between:</p> <ul style="list-style-type: none"><li>- single intervention on only one aircraft,</li><li>- double intervention on both aircraft,</li><li>- single horizontal or vertical manoeuvre and</li><li>- combined horizontal and vertical intervention.</li></ul> <p>Any ATC intervention through speed regulation is out of the scope of the IAPA study.</p>
<b>ATC separation</b>	<p>Either horizontal or vertical separation (or both) above the applicable separation minima in an encounter managed by ATC.</p> <p>In the IAPA study, the ATC horizontal separation minimum is 3 NM or 5 NM, respectively below and above FL135, and the vertical separation minimum is 1,000 ft in the RVSM airspace, i.e. below FL415, and 2,000 ft above.</p>

<b>ATM encounter model</b>	<p>An encounter model characterising the encounters expected to occur in the current ATM operations (prior to the introduction of ASAS procedures).</p> <p>The ATM encounter model developed within the IAPA study describes the characteristics of radar encounters extracted from European radar data recordings.</p>
<b>Back-end facility</b>	<p>Software that analyses a set of encounters (e.g. the encounters extracted from radar data by the “front-end” facility) and determines their properties, using these to populate the tables of an encounter model.</p>
<b>Clear of traffic</b>	<p>Time and/or location in an encounter when:</p> <ul style="list-style-type: none"><li>- either the aircraft are diverging laterally (time to modified CPA is negative) and the current distance between the aircraft is equal or superior to the value of the applicable lateral spacing (Option 1) / separation (Option 2) [by ASAS],</li><li>- or the aircraft are not converging vertically and the difference in altitude is equal or superior to the applicable vertical separation [by ATC].</li></ul>
<b>Close encounter course</b>	<p>A trajectory of an aircraft in an encounter in which the HMD is less than the NMAC horizontal threshold (500 ft) and in which, if ACAS tracks the other aircraft, there will be an RA. Close encounter courses are considered (even when sufficient vertical separation prevents it from being a collision course) because manoeuvres in the vertical plane, in response to an ACAS alert, can reduce the vertical separation and result in an induced collision.</p>
<b>Closest Point of Approach</b>	<p>Local minimum in the physical distance between two aircraft (slant range) involved in an encounter.</p> <p>The issuance of ACAS alerts and the type of alert depends on the predicted time to CPA, which is calculated by dividing the slant range by the closure rate.</p>
<b>Closest Point of Proximity</b>	<p>Local minimum in the “propinquity” distance between two aircraft involved in an encounter. The “propinquity” distance scales the horizontal and vertical distances between the aircraft according to the respective separation minima applicable by ATC.</p> <p>The closest point of proximity is used as the instant of closest approach in the IAPA encounter model.</p>
<b>Cockpit Display of Traffic Information</b>	<p>A plan-view display of traffic in the vicinity of own aircraft. Most ACAS installations include a traffic display, and it is assumed that ASAS will also provide a CDTI.</p> <p>The IAPA study assumed that all aircraft engaged in an ASAS procedure have a single traffic display with shared ACAS and ASAS information.</p>
<b>Collision course</b>	<p>A trajectory of an aircraft which, if not modified as the result of an ACAS alert (either by following an RA, or following controller advice prompted by contact from the pilot because of the ACAS alert, or due to visual acquisition prompted by the ACAS alert), results in a collision.</p>
<b>Conscientious pilot response</b>	<p>A response by the pilot to ACAS RAs in which he never ignores the RA and if he responds to it (i.e. does not prefer to act on controller advice or visual acquisition) he responds promptly.</p>
<b>Contingency tree</b>	<p>A branching structure which combines the probabilities of individual events to calculate the overall probability of a given compound-event.</p>
<b>Designated aircraft</b>	<p>The other aircraft involved, but not actively engaged, in an ASAS procedure.</p>



<b>Encounter</b>	A traffic situation involving two aircraft and selected using agreed capture criteria. Hence, distinction can be made between: <ul style="list-style-type: none"><li>- an actual encounter extracted from radar data,</li><li>- an artificial (or generated) encounter built either manually or automatically from an encounter model.</li></ul>
<b>Front-end facility</b>	Software that analyses radar data and captures encounters, according to certain criteria, that are of interest.
<b>Generated encounter</b>	An artificial, but operationally realistic, encounter generated from an encounter model. Unless otherwise specified, generated encounters refer hereafter to encounters generated from the ATM encounter model developed in the IAPA project.
<b>Heading phase</b>	In the context of an ASAS lateral crossing procedure that requires a manoeuvre to preserve the ASAS separation, the heading phase extends from when the aircraft first manoeuvres from its original track until the ‘Clear of Traffic’ indication, at which point the aircraft can manoeuvre back towards its original track.
<b>IAPA project</b>	Implications on ACAS Performances due to ASAS implementation – a study commissioned by EUROCONTROL to assess the effect that the introduction of ASAS procedures might have on ACAS operations.
<b>Intruder</b>	An aircraft that is tracked by ACAS.
<b>Logic risk</b>	The risk of collision that results from the operation of the ACAS collision avoidance algorithms, given a particular pilot response to the RAs that are generated.
<b>Modified encounter (or encounter without ATC)</b>	An encounter, either a generated encounter or a radar encounter, resulting from the removal of any ATC intervention (where ATC has acted to preserve separation).
<b>Near Mid-Air Collision</b>	An encounter in which the horizontal separation between two aircraft is less than 500 ft and simultaneously the vertical separation is less than 100 ft.
<b>Operational Environment Definition</b>	An OED describes how and in what context an application of a system is expected to operate. For the purposes of IAPA, an OED of the ASAS lateral crossing procedure was developed.
<b>Operational Hazard Assessment</b>	A systematic procedure which identifies the hazards associated with a system or procedure. The ways in which the procedure could go wrong are considered, as well as the consequences and their severity.
<b>Operational Safety Assessment</b>	A methodology designed to identify the safety requirements of a procedure or system. In IAPA, the guidelines of the OSA methodology have been used to perform an Operational Hazard Assessment (OHA) of the ACAS procedure and of the possible interaction between the ACAS and ASAS procedures.
<b>Option 1</b>	First option of the ASAS lateral crossing application (in the context of the IAPA study) as an Airborne Spacing application, where separation minima are unchanged (i.e. applicable radar separation minima in the IAPA environment) and spacing minima depend on aircraft capabilities.
<b>Option 2</b>	Second option of the ASAS lateral crossing application (in the context of the IAPA study) as an Airborne Separation application, where the separation tasks are transferred to the flight crew for the duration of the ASAS lateral crossing procedure and airborne separation standards are defined. These include airborne separation minima applicable by the flight crew.

<b>Procedure-centred risk ratio</b>	<p>The risk ratio (in a given procedure) that results when all the appropriate aircraft in the airspace equip with ACAS.</p> <p>In the IAPA study, this is the ratio of the risk of collision (in the ASAS lateral crossing procedure) when all aircraft covered by the mandated are equipped and operate ACAS, compared to the risk of collision (in the ASAS lateral crossing procedure) when no aircraft operate ACAS.</p>
<b>Progressional risk ratio</b>	<p>The risk ratio (in a given procedure) experienced by an individual aircraft who equips with ACAS, the equipage of other aircraft remaining the same.</p> <p>In the IAPA study, this is the ratio of the risk of collision to the reference aircraft in the ASAS lateral crossing procedure when it operates ACAS, compared to the risk of collision when the same aircraft disables ACAS. In the two scenarios the equipage of intruders remains the same (i.e. carriage of ACAS by mandated aircraft).</p>
<b>Prompt pilot response</b>	<p>A response by the pilot to RAs that is close to the standard response assumed in the ACAS logic.</p>
<b>Radar encounter</b>	<p>An encounter extracted from radar data according to agreed capture criteria. Hereafter, radar encounters refer to encounters extracted from radar data recordings (using the “front-end” facility) within the IAPA study based on radar data. The IAPA capture criteria allow for the selection of encounters that correspond to a possible conflict for ATC.</p>
<b>Reference aircraft</b>	<p>The aircraft that has been instructed to conduct an ASAS procedure with respect to another designated aircraft.</p>
<b>Resolution advisory</b>	<p>A resolution advisory (RA) is an ACAS alert instructing the pilot how to modify or regulate his vertical speed so as to avoid the risk of collision diagnosed by the system. It is normally preceded by a traffic advisory.</p>
<b>Resume phase</b>	<p>In the context of an ASAS lateral crossing procedure that requires a manoeuvre to preserve the ASAS separation, the resume phase extends from the ‘Clear of Traffic’ indication until the aircraft is back on its original track</p>
<b>Risk ratio</b>	<p>The ratio of the risk of collision after some change in conditions to the risk of collision that existed before the change in conditions.</p> <p>In the IAPA study, the change in conditions is the carriage and operation of ACAS by certain aircraft. A risk ratio of 0% would indicate a perfect system that eliminated the risk of collision; a risk ratio of 100% would indicate an ineffective system that made no change to the risk of collision.</p>
<b>Safety encounter model</b>	<p>An encounter model that generates encounters in which the two aircraft are on a close encounter course.</p>
<b>See-and-avoid</b>	<p>The principal by which pilots are expected to visually acquire collision threats and make suitable avoidance manoeuvres to resolve the risk of collision.</p>
<b>Slow pilot response</b>	<p>A response by the pilot to RAs that is not as strong as the standard response assumed in the ACAS logic.</p>
<b>Standard pilot response</b>	<p>The response by the pilot to RAs that is assumed in the ACAS logic.</p>

<b>Third aircraft</b>	<p>i) In the context of ASAS, an aircraft other than the two aircraft (reference aircraft and designated aircraft) engaged in the ASAS procedure.</p> <p>ii) In the context of an ACAS alert, an aircraft other than own aircraft and the threat aircraft.</p>
<b>Threat aircraft</b>	The aircraft that is the subject of an ACAS alert.
<b>Traffic advisory</b>	A traffic advisory (TA) is an ACAS alert warning the pilot of the proximity of other traffic that might become the subject of a resolution advisory.
<b>Undesirable ACAS alert</b>	<p>An ACAS alert that occurs whereas the applicable separation minima are not infringed during the encounter without ACAS contribution.</p> <p>The same horizontal and vertical margins of error are used, i.e. <math>\Delta H = 0</math> NM and <math>\Delta V = 130</math> ft respectively, for the determination of undesirable ACAS alerts during ATC and ASAS encounters.</p>
<b>Wobulation</b>	A mathematical process that introduces realistic variations in to smoothed aircraft trajectories by incorporating both a random component (“wobble”) and a systematic component (“modulation”).

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## 1. Introduction

### 1.1. *Objective and scope*

- 1.1.1. The interaction between the Airborne Collision Avoidance System II (ACAS) and the operational use of the Airborne Separation Assistance System (ASAS) is an open issue never previously thoroughly investigated, which needs to be addressed before any European ASAS implementation. The IAPA project addresses the issue, analyses its potential operational and safety implications, and provides guidelines for the development of future ASAS applications in Europe.
- 1.1.2. **IAPA** stands for **Implications on ACAS Performances due to ASAS** implementation.
- 1.1.3. The focus is on the potential interaction with ACAS of Air Traffic Management (ATM) operations in the European Civil Aviation Conference (ECAC) area both with and without the use of ASAS. Hence, the IAPA project:
  - ascertains whether there are any significant implications for ACAS performance due to possible ECAC ASAS implementation;
  - ascertains whether the benefits expected from ASAS could be compromised due to the operation of ACAS;
  - identifies and assesses potential operational issues (in terms of undesirable ACAS alerts) resulting from the potential interaction between the ACAS logic and ASAS procedures; and
  - evaluates the safety benefits (in terms of reduced risk of collision) that can be expected from ACAS during ASAS procedures.
- 1.1.4. The introduction of ASAS potentially raises some interaction issues with ACAS in terms of airborne system integration and operation by the pilot, but these issues are out of the scope of the IAPA project.
- 1.1.5. The IAPA project builds on the methodology which was established, and the tools which were developed, for the Full System Safety Study [ACA1a], [ACA1b] and the ACAS / RVSM (Reduced Vertical Separation Minimum) interaction study [ACA3a] completed within the framework of the ACAS Analysis (ACASA) project. Advantage is also taken of the recent improvements brought to some of these tools in the ACAS Safety Analysis post-RVSM Project [ASARP].
- 1.1.6. The IAPA study comes within the scope of the EUROCONTROL Mode S & ACAS Programme. It is of particular interest for several areas dealing with ASAS development, e.g. the joint FAA/EUROCONTROL Requirement Focus Group (RFG) and the EUROCONTROL CASCADE (Co-operative ATS through Surveillance and Communication Applications Deployed in ECAC) Programme. The project is based on a two-year-and-a-half schedule and started in November 2002. The technical work was conducted by a consortium of four organisations (DSNA, EEC, QinetiQ and Sofréavia) and the project was managed by Sofréavia (ATM division).

## **1.2. Background and context**

### **1.2.1. The Role of ACAS in the ATM System**

- 1.2.1.1. The Airborne Collision Avoidance System II has been introduced in order to reduce the risk of mid-air collisions. It serves as a last resort safety net irrespective of any separation standards.
- 1.2.1.2. 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).
- 1.2.1.3. From 1<sup>st</sup> January 2005, the carriage and operation of ACAS compliant equipment (i.e. the Traffic alert and Collision Avoidance System (TCAS) II version 7.0) is mandatory in the ECAC area for all aeroplanes of a maximum takeoff mass exceeding 5,700 kg or authorised to carry more than 19 passengers.
- 1.2.1.4. ACAS is thus an essential component in the current ATM system and it should play the same role in future ATM operations.

### **1.2.2. Airborne Surveillance Applications based on ADS-B**

- 1.2.2.1. EUROCONTROL has defined a Roadmap of Operational Improvements (OI) to be implemented as part of the overall ATM system out to 2020. A significant proportion of the defined OIs are enabled by Automatic Dependent Surveillance - Broadcast (ADS-B) applications. The envisaged ADS-B related applications have, for implementation feasibility reasons, been organised into three packages. Each package includes both Ground Surveillance applications and Airborne Surveillance (AS) applications supported by ADS-B.
- 1.2.2.2. The EUROCONTROL CASCADE programme is in charge of planning and co-ordinating the implementation of a first package (Package I) of ADS-B applications, together with more Controller-Pilot Data-Link Communications services and some other data link services, in ECAC in the timeframe between now and 2010.
- 1.2.2.3. The determination of coordinated requirements for Package I applications is being carried out at the international level by the RFG following the ED78A/DO-264 guidelines. The RFG membership includes the EUROCONTROL CASCADE Programme, FAA, EUROCAE, RTCA, Airservices Australia, Japan, and industry. The main objective of the RFG work is to provide the Safety and Performance Requirements, as well as Interoperability requirements for surveillance applications supported by ADS-B (and possibly TIS-B). These requirements are based on definitions of the relevant applications and the environments in which they are operating.
- 1.2.2.4. At the ICAO level, the Surveillance and Conflict Resolution Systems Panel (SCRSP) has developed a Circular on ASAS [ICAO-ASAS], which addresses the whole range of ASAS applications included in Packages I, II and III of Airborne Surveillance applications. Although no commitment yet exists to internationally implement ASAS, the operational use of ASAS is seen as a promising option to provide an increase in capacity and flight efficiency while enhancing flight safety in conformity with the vision for the potential evolution of ATM described by ICAO [ICAO-OCD].

### 1.2.3. Relationship between ACAS and ASAS applications

- 1.2.3.1. Along the way towards a mature ASAS environment, compatibility must be assured between current and future systems and procedures. Before ASAS can be realistically implemented, questions remain to be answered in several areas. In particular, the issue of ACAS and ASAS interaction has to be addressed.
- 1.2.3.2. The purpose of ACAS is to prevent mid-air collision. Airborne collision avoidance is a last resort function, which requires immediate action. In normal circumstances, when separation (ATC or airborne) is provided, airborne collision avoidance should not be necessary.
- 1.2.3.3. It is thus essential to pay particular attention to compatibility with ACAS when designing ASAS applications. Furthermore, it must be ensured that ACAS will still act as an effective safety net under non-nominal circumstances.

## 1.3. **Project overview**

### 1.3.1. General

- 1.3.1.1. The IAPA project [WP00/002] was conducted in three main phases:
  - Phase I (November 2002 – October 2003) defined the scope and framework of the ACAS / ASAS interaction study;
  - Phase II (November 2003 – December 2004) consisted of the performance of the required simulations for an in-depth operational analysis of the interaction between ACAS and ASAS. It also assessed the impact of ASAS operations on the safety benefit provided by ACAS; and
  - Phase III (January 2005 – November 2005) consolidated the results of the previous phases and drew the project conclusions and recommendations.
- 1.3.1.2. The main achievements and results of Phase I were presented in an interim project report [WP00/032]. Phases II and III capitalised upon the methodology and framework which had been developed, and the preliminary analysis which had been undertaken, during Phase I.
- 1.3.1.3. The IAPA project represented a total effort of more than 11 man-years, including effort related to the project management, and spanned about three years from November 2002 until November 2005.

### 1.3.2. Phase I: Scope and framework

- 1.3.2.1. Phase I of the IAPA project consisted of selecting an ASAS application with the potential for ACAS interaction, performing a preliminary analysis of the potential ACAS / ASAS interaction issues, and establishing the framework required for an in-depth investigation of the identified issues, and possibly others, within Phase II.
- 1.3.2.2. It was composed of the following Work Packages (WP):
  - *WP01*: ASAS application selection and definition. Based on agreed criteria, including the results of WP04, the work consisted of selecting and defining an ASAS application of interest for the IAPA study;

- *WP02*: Performance indicator definition. The work consisted of defining a common simulation framework for IAPA, which consists of a set of scenarios and indicators to assess the ACAS / ASAS interaction;
- *WP03*: Simplified modelling of the ASAS application. The work consisted of developing a tool simulating the nominal effects of the selected ASAS application on the aircraft trajectories; and
- *WP04*: Case study. This work consisted of a preparatory analysis of the potential interaction with ACAS for some ASAS applications of potential interest for IAPA and a specific analysis of the ASAS application selected for further investigation within IAPA.
- *WP05*: ASAS encounter model development. This work started within Phase I with the specification of an ATM encounter model, and proceeded within Phase II with its derivation into an ASAS encounter model.

1.3.2.3. It should be noted that WP01 and WP04 were conducted in parallel and interacted between each other. The other work areas started following the completion of WP01.

### 1.3.3. Phase II: Operational and safety analyses

1.3.3.1. Phase II consisted of various studies based on different sources of data, i.e. encounter modelling, modified radar data, flight plan simulation data and real-time simulation data. The rationale for using different sources of data was to compensate any limitations related to each source of data, and to cope with a larger set of issues. It also consisted of a safety analysis of the potential ACAS and ASAS interaction.

1.3.3.2. It was composed of WP05 and of the first tasks of WP06 to WP10 defined as follow:

- *WP05*: (ATM and) ASAS encounter model development;
- *WP06*: Study based on the ASAS encounter model;
- *WP07*: Study based on modified radar data;
- *WP08*: Study based on flight plan simulation data;
- *WP09*: Study based on real-time simulation data; and
- *WP10*: Safety analysis based on the ED78A Operational Safety Assessment (OSA) methodology.

1.3.4. The various studies conducted within Phase II were stand-alone yet complementary studies. Nevertheless, certain relationships existed between some work packages, which are further described in section 1.5.

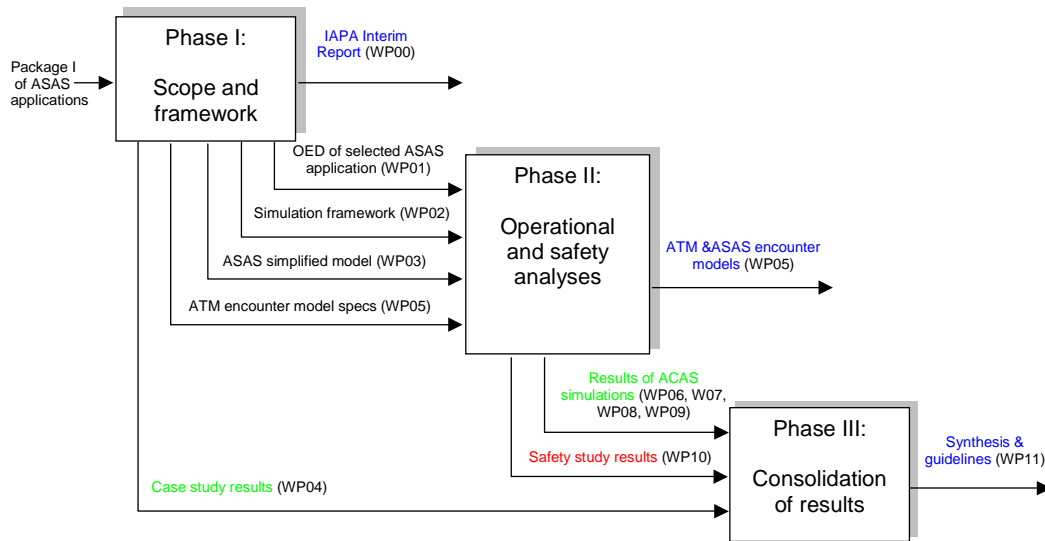
### 1.3.5. Phase III: Synthesis and guidelines

1.3.5.1. Phase III concluded the IAPA project by summarising the work performed during Phase I and Phase II and delivering guidelines for the development of future ASAS applications. It was composed of the report development tasks of WP06 to WP10 and of the final work package:

- *WP11*: Synthesis and guidelines.

## 1.4. Relationship between the IAPA Phases

1.4.1. The following figure provides an overview of the overall IAPA project structure and the relationship that existed between the various project phases. In particular, the main inputs and outputs of each phase are identified.



**Figure 1: Links between the phases of the IAPA project**

1.4.2. Phase I of the project set up the scope and framework of the ACAS / ASAS interaction study through the WP01, WP02, WP03 and WP05 work areas. It also provided initial results about the potential ACAS / ASAS interaction issues for a set of Package I AS applications with the WP04 case study.

1.4.3. Phase II was focused on the ASAS application selected for further investigation during Phase I. It further investigated both:

- the operational issues that may result from an interaction between nominal ASAS operations and ACAS, using different sources of data. This was the purpose of the simulations conducted within the WP06, WP07, WP08 and WP09 work areas, and
- the safety issues raised by a potentially reduced effectiveness of ACAS during non-nominal ASAS operations, through the safety analysis performed as part of the WP10 work area.

1.4.4. The framework set up during Phase I supported the various simulations conducted during Phase II and defined their common bases.

1.4.5. Finally, Phase III consolidated the results of the various studies performed during Phase II, first separately, then in combination including the initial results obtained during Phase I as part of the WP04 work area. It also concluded on the methodological framework set up by the IAPA project for studying the ACAS / ASAS interaction issue.

## 1.5. Relationship between the various Phase II studies

### 1.5.1. Relationship between the WP05, WP06 and WP07 studies

- 1.5.1.1. The links between the study based on modified radar data (WP07) and the development of the ASAS encounter model (WP05) were identified from the start of the IAPA project. Following coordination between the two work packages, both studies applied the same general principles to simulate ASAS operations in lieu of current ATC operations [WP05/091], [WP07/078].
- 1.5.1.2. As illustrated in the following figure, the numerical inputs of the ATM encounter model (from which the ASAS encounter model is derived [WP05/071]) were obtained from the same initial set of radar encounters captured using agreed capture criteria as part of the WP07 work area.

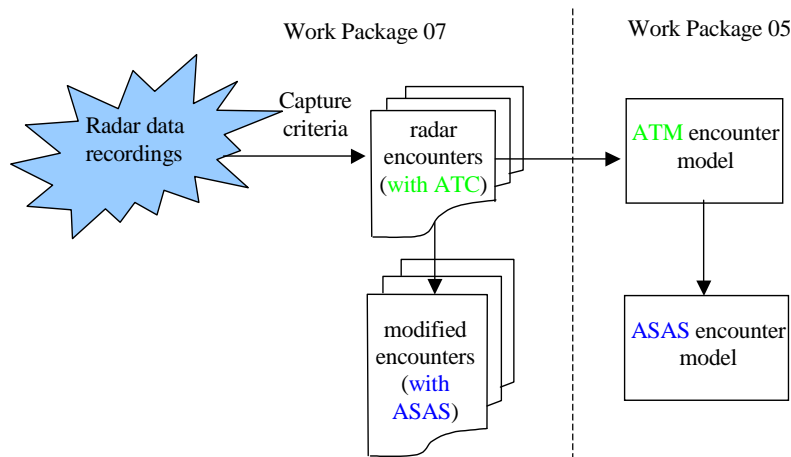
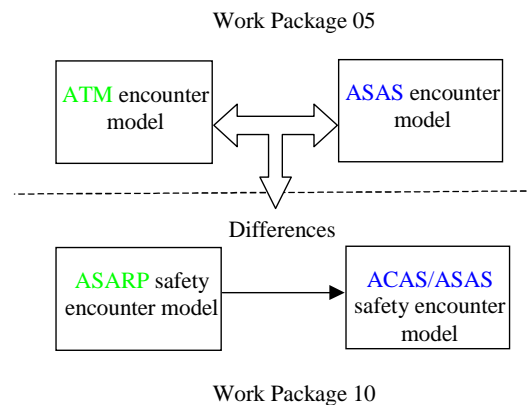


Figure 2: Links between the WP05 and WP07 studies of IAPA

- 1.5.1.3. The IAPA capture criteria are based largely on those used in the ACASA study [ACA1a], but the tests and parameters have been enhanced to allow the selection of encounters that correspond to a possible conflict for ATC, i.e. encounters involving two aircraft with a predicted loss of separation likely to be resolved with the manoeuvring of one or both aircraft [WP05/045].
- 1.5.1.4. Furthermore, the study based on modified radar data (WP07) and the study based on the ASAS encounter model (WP06) raised similar issues with regard to the derivation of ASAS encounters. Indeed, in both cases, the ASAS application would replace, when appropriate, the ATC actions to provide separation between aircraft. Although the working method was sometimes different, the main principles were coordinated between the two work packages.
- 1.5.1.5. Hence, both studies used the same preliminary criteria (i.e. separation and crossing status of the encounters) to identify those encounters of potential interest for the study of the selected ASAS application. In addition, the identification and removal of ATC intervention were addressed similarly within both work packages. Finally, the two studies used the simplified model of the ASAS application to simulate the effect of the ASAS application (cf. section 2.4 for further details).

### 1.5.2. Relationship between the WP05 and WP10 studies

- 1.5.2.1. The IAPA safety study of the ACAS / ASAS interaction (WP10) included, among other things, the development of a safety encounter model for assessing the benefits of ACAS during ASAS operations (focused on the selected ASAS application), i.e. the ACAS/ASAS safety encounter model.
- 1.5.2.2. As illustrated in the following figure, the ACAS/ASAS safety encounter model was derived from an existing safety encounter model describing close encounters observed in current ATM operations in core Europe, viz. the ASARP safety encounter model<sup>1</sup>. This derivation consisted of applying the observed differences between the ATM encounter model and the ASAS encounter model developed as part of the IAPA project (WP05). These differences between the two models are ostensibly due only to the introduction of the ASAS procedure into the airspace.



**Figure 3: Links between the WP05 and WP10 studies of IAPA**

- 1.5.2.3. More precisely, an intermediate step consisted of splitting the ASARP safety encounter model into two separate complementary models depending on whether the ASAS procedure was applicable or not. The ACAS/ASAS safety encounter model was then derived from the safety encounter model restricted to the encounters where the ASAS procedure would be applicable (cf. section 5.4 for further details).

## 1.6. Document overview

### 1.6.1. Organisation of the document

- 1.6.1.1. The document is organised into seven chapters, including this **Chapter 1** on the objectives and purpose of the IAPA project.

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<sup>1</sup> A European safety encounter model describing close encounters observed with conventional ATC had initially been developed in the ACASA project [ACA1a], [ACA1b]. This safety encounter model has recently been updated in the ASARP project [ASARP] to address post-RVSM operations in Europe.

- 1.6.1.2. **Chapter 2** defines the precise scope of the IAPA study including the selection of an ASAS application with the potential for raising some interaction issues with ACAS. It also describes the framework set in place during Phase I to support further investigation of the ACAS / ASAS interaction on the basis of the selected ASAS application.
- 1.6.1.3. **Chapter 3** presents the main results of the initial investigation performed during Phase I on a set of Package I ASAS applications, i.e. the WP04 case study of the potential ACAS / ASAS interaction issues.
- 1.6.1.4. **Chapter 4** deals with the operational investigation of the interaction between ACAS and the selected ASAS application performed during Phase II. The results of the various simulations conducted using various sources of data, i.e. the WP06, WP07, WP08 and WP09 studies, are presented and compared whenever possible.
- 1.6.1.5. **Chapter 5** is dedicated to the results of the safety analysis conducted as part of WP10 work area during IAPA Phase II. The tools and methods that supported the assessment of the safety benefits of ACAS during ASAS operations are first presented. Then the main findings of the operational hazard assessment and risk evaluation performed are described.
- 1.6.1.6. **Chapter 6** consolidates the main results of both the operational and safety analyses and provides a synthesis of the main ACAS / ASAS interaction issues identified. It also provides an overview the methodological framework that supported the various IAPA studies.
- 1.6.1.7. Finally, **Chapter 7** concludes on the approach and main results of the IAPA project and draws some recommendations for the future development of ASAS applications that take into account the potential implications raised by the ACAS / ASAS interaction features identified during the project.
- 1.6.2. Note to the reader
  - 1.6.2.1. Depending on their interests, the readers are encouraged to concentrate on specific chapters and overview the remaining ones.
  - 1.6.2.2. The readers who are interested in an overview of the potential interaction issues between the ACAS logic and a specific ASAS application (possibly distinct from the ASAS application selected for further investigation within IAPA) are invited to concentrate on **Chapter 3**.
  - 1.6.2.3. The readers who are interested in the assessment of the potential operational issues for the European airspace may prefer to concentrate on **Chapter 4**, whereas those who are more interested in the safety aspects of the ACAS / ASAS interaction are invited to concentrate on **Chapter 5**.
  - 1.6.2.4. Finally, the readers who are not particularly interested in the technical work of the IAPA project are invited to proceed directly to **Chapters 6 and 7** after a brief review of **Chapter 2** (i.e. mainly sections 2.1 and 2.2).



## **2. Scope and framework of the IAPA study**

### **2.1. General**

- 2.1.1. Phase I of the IAPA project first consisted of selecting and defining an ASAS application with the potential for studying a maximum of significant and realistic ACAS / ASAS interaction issues (WP01). The range of ASAS applications of initial interest included the Package I of Airborne Surveillance applications proposed for early implementation in Europe [PACKI].
- 2.1.2. Based on agreed selection criteria, including the results of an initial investigation of the potential ACAS / ASAS interaction issues (WP04), the ASAS lateral crossing procedure was selected for further investigation within the IAPA project (cf. Chapter 3).
- 2.1.3. An Operational Environment Definition (OED) was developed for the purposes of the study, which describes the main assumptions about the selected ASAS application and its ATM/CNS environment. These assumptions were as realistic as possible and built on available Operational and Service Environment Definitions (OSED) dealing with the ASAS lateral crossing application.
- 2.1.4. Finally, Phase I established the framework required for an in-depth investigation of the potential ACAS / ASAS interaction issues. Hence:
  - a simulation framework was proposed involving three different scenarios with full ASAS / ADS-B equipage (WP02);
  - a simplified model of the selected ASAS application, i.e. both the ASAS “pass behind” and “pass in-front” procedures, was developed (WP03); and
  - an ATM encounter model was specified, with the objective of supporting the development of an ASAS encounter model (WP05).
- 2.1.5. Within Phase II, this framework was further developed (with the ASAS encounter model), and supported the operational analysis of the ACAS / ASAS interaction issues using various sources of data (cf. Chapter 4) as well as the safety analysis of the ACAS / ASAS interaction (cf. Chapter 5).
- 2.1.6. The remainder of this chapter describes the selection process of an ASAS application with the potential for interaction, as well as the IAPA operational environment and simulation framework developed in support to the investigation of the ACAS / ASAS interaction issue.

### **2.2. *Selecting an ASAS application with the potential for ACAS interaction***

#### **2.2.1. Selection criteria and scope**

- 2.2.1.1. The ASAS application of most interest for studying the potential ACAS / ASAS interaction issues was selected from a set of Package I Airborne Surveillance applications as follows:

- Package I/ASPA-S&M Enhanced sequencing and merging operations;
- Package I/ASPA-C&P: Enhanced crossing and passing operations;
- Possible extension of the previous Airborne Spacing applications into Airborne Separation applications (Package II).

2.2.1.2. Further, the following criteria were considered during the selection process:

- **Demanding application**: an application with the potential for studying a **maximum of significant and realistic issues from an ACAS safety and operational performance perspective**;
- **Scope and applicability**: the larger the scope, the more interesting the ASAS application since it potentially addresses a wider range of operations;
- **Maturity**: Airborne Surveillance applications proposed for early implementation within Europe (Package I) were of particular interest, as well as extensions of these applications into airborne separation applications (Package II).

2.2.1.3. Finally, available documentation related to the candidate ASAS applications was reviewed in order to determine the most relevant set of encounters to be investigated within the IAPA study.

## 2.2.2. Preparatory analysis of candidate ASAS applications

2.2.2.1. To support the selection of the most relevant ASAS application, a preparatory analysis of the potential interaction with ACAS was performed, which dealt with a set of artificial encounters.

2.2.2.2. These encounters were built so as to simulate the possible aircraft trajectories resulting from various ASAS operations as described in the literature:

- **Package I/ASPA-S&M Enhanced sequencing and merging operations:**
  - NUP II Cluster D Arlanda OSED [NUPII-ITS],
  - NUP II Cluster D Frankfurt OSED [NUPII-FRA], and
  - NUP II Cluster E Co-operative ATS OSED [NUPII-COOPATS].
- **Package I/ASPA-C&P: Enhanced crossing and passing operations:**
  - MA-AFAS lateral crossing and passing [MA-AFAS], and
  - MFF A4 operational procedures (defined as airborne separation ones) [MFF-A4].

2.2.2.3. For each ASAS application, an initial analysis of a set of qualitative encounters was performed based on the ICAO guidance material associated with the ACAS Standards and Recommended Practices (SARPS). The objective was to identify the set of encounter parameters (e.g. encounter geometry, flight parameters, spacing values at the closest point of approach) that have the potential to trigger an ACAS alert.

2.2.2.4. In a second step, artificial encounters with specific aircraft trajectories were built, and simulations of the TCAS II logic version 7.0 were performed. These ACAS simulations were focused on the worst-case scenarios identified in the initial analysis.

2.2.2.5. The main assumptions and results of the preparatory analysis of the ACAS / ASAS interaction issue are further described in Chapter 3.

### 2.2.3. Final selection of a demanding ASAS application

2.2.3.1. In summary, Package I/ASPA-S&M, Package I/ASPA-C&P and Package II separation showed comparable results in the achievement of the agreed selection criteria with:

- an advantage to Package I/ASPA-S&M for the availability of real time simulation data, an Operational Service and Environment Definition, radar data and maturity of the application;
- an advantage to Package I/ASPA-C&P and Package II separation as demanding applications in terms of potential interaction with ACAS.

2.2.3.2. Package I/ASPA-S&M may be implemented earlier but is less demanding in terms of ACAS interaction.

2.2.3.3. The ASAS Lateral Crossing application can be seen as an excellent bridge between Package I and Package II, and it was agreed that a Package I application with the potential to become a Package II application constitutes the best compromise for the IAPA study.

2.2.3.4. An additional interest of the ASAS Lateral Crossing application is that it also allows the potential issues related to the merging phase of the Package I/ASPA-S&M application to be addressed.

2.2.3.5. Based on the agreed selection criteria, including the results of the preparatory ACAS / ASAS interaction analysis, the ASAS lateral crossing application was therefore selected for further investigation.

## 2.3. ***Selected application: ASAS Lateral Crossing application***

### 2.3.1. General

2.3.1.1. The IAPA Operational Environment Definition defined the main assumptions within the study with regard to the ASAS Lateral Crossing application and the airspace in which it would be used [WP01/024].

2.3.1.2. It built on the available OSEDs dealing with the ASAS Lateral Crossing application. Care was taken to make assumptions as realistic as possible, while addressing the study objectives. These assumptions are briefly presented hereafter.

### 2.3.2. Operational purpose

2.3.2.1. The purpose of the ASAS lateral crossing application is to provide a new air traffic control procedure, allowing one ASAS equipped aircraft to cross a designated aircraft. Within the IAPA study, it is assumed to apply in radar controlled airspace between FL60 and FL410<sup>2</sup>.

2.3.2.2. To allow for investigation of a wider range of operations, the IAPA operational environment envisaged the ASAS Lateral Crossing application within the scope of the following options:

- **Option 1: Airborne spacing application**, where separation minima are unchanged (i.e. applicable radar separation minima in the IAPA environment) and spacing minima depend on aircraft capabilities;
- **Option 2: Airborne separation application**, where the separation tasks are transferred to the flight crew for the duration of the ASAS application and airborne separation standards are defined. These include airborne separation minima applicable by the flight crew.

2.3.2.3. Furthermore, the applicable spacing (Option 1) / separation (Option 2) value was established so as to be realistic yet demanding in terms of potential interaction with ACAS.

### 2.3.3. Operational procedure and conditions of use

2.3.3.1. The air traffic controller can instruct a flight under his control to perform an ASAS lateral crossing procedure against a designated aircraft, if some general conditions are met which ensure the compatibility of the ASAS application with the provision of separation by ATC.

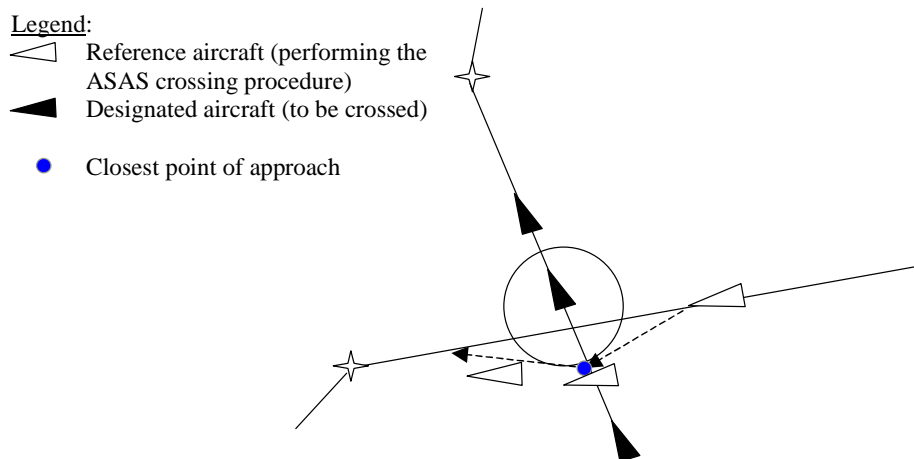
2.3.3.2. The ASAS lateral crossing procedure can be accepted by the flight crew of a controlled flight if some general conditions are met, which allow for the safe and efficient execution of the procedure.

2.3.3.3. Two different procedures (i.e. “pass behind” and “pass in-front” procedures) are distinguished, each of which results in a heading alteration by the aircraft performing the ASAS lateral crossing procedure.

2.3.3.4. At the ‘Clear of Traffic’ indication, which corresponds to the time/location when the risk of infringement of applicable separation is over, the aircraft performing the ASAS lateral crossing procedure can resume its navigation direct to track.

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<sup>2</sup> The lower limit of FL60 was taken to avoid restrictions related to noise abatement constraints that alter the nominal climb rates. The upper limit of FL410 corresponds to the upper boundary of the RVSM airspace.



**Figure 4: Example of a “Pass Behind” instruction**

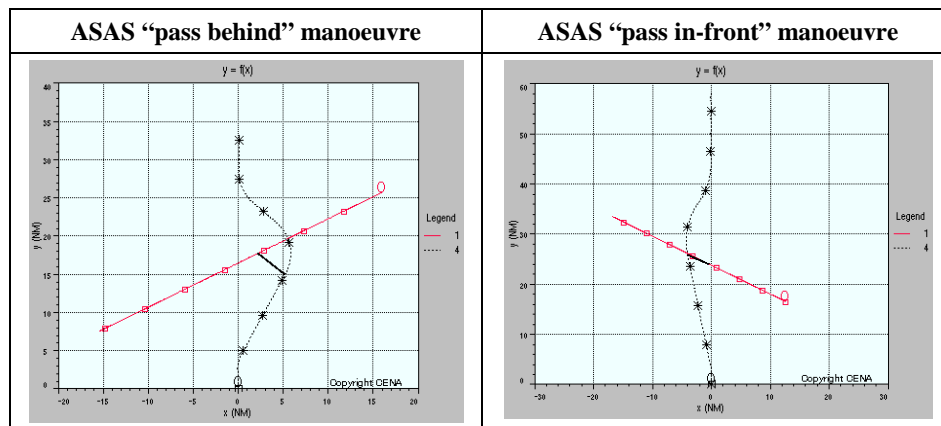
- 2.3.3.5. To cope with the IAPA study purposes, **the minimum applicable spacing (Option 1) / separation (Option 2) during the ASAS lateral crossing procedure was set to 4 NM**. This value is derived from the integrity requirement for positioning accuracy of 99.999% at 2×RNP established within the [RNP-MASPS] assuming RNP-1 aircraft navigation performances. It is considered to be the minimum applicable between two RNP-1 compliant aircraft, assuming perfect surveillance and communication performances.
- 2.3.3.6. It is recognised that under certain circumstances the value of 4 NM would be lower than the Wake Vortex radar separation minimum applicable by ATC. Depending on the actual airborne surveillance performances of the future ASAS equipment, additional margins will probably have to be taken into account, but this is beyond the scope of the IAPA study.

## **2.4. Simplified model of the selected ASAS application**

### **2.4.1. Main principles and characteristics**

- 2.4.1.1. The simplified model developed during Phase I allowed the simulation of the effects of the selected ASAS application, i.e. the ASAS lateral crossing procedure, on the aircraft trajectories. The development of this simplified model was guided by the following general approach:
- **the simulation of the nominal effect of the ASAS procedure** (i.e. assuming perfect ASAS performance) on the aircraft trajectories of an encounter involving two conflicting aircraft (without any ATC intervention); and
  - **the off-line trajectory modification of the aircraft performing the ASAS procedure**, rather than the execution of an airborne algorithm that would support the performance of the ASAS application in real-time, but potentially with limited performances due to the simulated airborne surveillance and separation processing functions.

2.4.1.2. The figures below are examples of aircraft trajectories resulting from the use of the simplified model of the ASAS lateral crossing procedure. In the left-hand figure, the northbound aircraft was initially crossing the other aircraft trajectory with almost no horizontal separation at the Closest Point of Approach (CPA). In the right-hand figure, the aircraft northbound was the first aircraft at the track crossing point, with a Horizontal Miss Distance of less than 2 NM. In both modified encounters, the aircraft manoeuvre resulted in a horizontal separation of 4 NM at CPA



**Figure 5: Illustrations of the simplified modelling of ASAS lateral crossing procedures**

Note: In both figures, an '0' symbol shows the start of the horizontal trajectory of each aircraft and a solid line is drawn between both aircraft positions at CPA. The trajectory of the ASAS manoeuvring aircraft is depicted in black, whereas that of the crossed aircraft is depicted in red.

## 2.4.2. Use of the simplified model of the ASAS application

2.4.2.1. Within Phase II of the IAPA project, the simplified model of the ASAS application was used within:

- the study based on the ASAS encounter model (WP06), to derive a set of ASAS encounters from a set of encounters generated from the ATM encounter model;
- the study based on modified radar data (WP07), to generate a set of ASAS encounters from a set of encounters extracted from radar data recordings and modified to remove ATC intervention, when appropriate; and
- the study based on data extracted from fast-time simulations (WP08), to generate a set of ASAS encounters from encounters issued from fast-time simulations based on European flight plan data.

2.4.2.2. When using the simplified model of the ASAS application to simulate the effect on the aircraft trajectory starting from an actual encounter with ATC, there was a need to first **identify and remove any manoeuvre resulting from an ATC intervention**.

2.4.2.3. This was actually the case during the development of the ASAS encounter model (WP05) and the study based on modified radar data (WP07). Indeed, in both cases, the effects of ASAS application should replace, when appropriate, the ATC actions to provide separation between aircraft.

#### 2.4.3. Addressing ATC intervention in actual encounters

2.4.3.1. To allow for comparison between the various simulation results, the same principles were applied within both studies for addressing ATC intervention. It was thus agreed to:

- **identify an ATC intervention when the separation is reduced (and not necessarily lost) within the modified encounter (with the ATC intervention removed)** when compared to the original encounter (with ATC). In many cases the ATC intervention results in large separation, i.e. greater than the applicable ATC separation minima, and so the removal of ATC intervention does not necessarily result in a loss of separation.
- **consider as candidate ASAS encounters, only those encounters with an ATC intervention that preserves ATC separation.** In particular, to allow for a fair comparison between ATC and ASAS, the encounters with loss of ATC separation were discarded from the set of encounters of interest<sup>3</sup>. Further, although the ASAS lateral crossing procedure could in principle be applied by ATC even when there was no ATC intervention in the original encounter, this simplification is considered acceptable within the scope of the IAPA study<sup>4</sup>.
- **include in the ASAS encounters all the candidate encounters in which ASAS proved to be applicable**, with either an ASAS active or passive intervention, i.e. with or without a “pass behind/in-front” manoeuvre required to ensure ASAS separation. Indeed, as far as ATC did intervene to maintain aircraft separation, the use of ASAS instead of ATC is considered relevant. The fact that the use of ASAS has no impact on the trajectory should be considered as a positive side-effect in terms of flight efficiency.

2.4.3.2. Almost the same types of ATC intervention have been addressed within both IAPA work areas including the tactical turns, the tactical level-offs of an aircraft in vertical evolution and the tactical flight level change on an aircraft in level flight.

2.4.3.3. Other potential ATC interventions to preserve separation, which are not taken into account in the IAPA study, include speed regulations or expedite descent/climb instructions. Indeed, these actions were difficult to determine based only on the aircraft trajectories without any further knowledge of the actual aircraft performances or flight plans<sup>5</sup>.

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<sup>3</sup> Because of the perfect modelling of the ASAS application, the simplified model does not result in any loss of ASAS separation.

<sup>4</sup> The encounters without an ATC intervention are unlikely to be modified by the simplified model of the ASAS procedure, and so would not be of interest for a comparative assessment of the compatibility with ACAS between ATC and ASAS.

<sup>5</sup> No direct correlation was possible between the encounters extracted from the radar data (which were missing the call-sign information) and the flight plan recordings collected within the study.

- 2.4.3.4. The horizontal and vertical manoeuvres were addressed independently. Further, for some encounters, more than one ATC intervention could be identified. The common strategy applied when removing the manoeuvres identified as possible ATC interventions is summarised in the following table:

Type of ATC intervention	Modified encounter
<b>Single intervention</b> (on only one aircraft)	Removal of the horizontal (respectively, vertical) manoeuvre on <u>the manoeuvred aircraft</u> , only if it reduces horizontal (respectively, vertical) separation at closest approach
<b>Double intervention</b> (at least one manoeuvre on both aircraft)	Removal of the horizontal (respectively, vertical) manoeuvre preferably on <u>both manoeuvred aircraft</u> if it reduces horizontal (respectively, vertical) separation at closest approach  Otherwise, removal preferably of the <u>latest</u> horizontal (respectively, vertical) manoeuvre, or the first one otherwise, if it reduces horizontal (respectively, vertical) separation at closest approach

**Table 1: Removal of ATC intervention within actual encounter**

- 2.4.3.5. The vertical manoeuvres were similarly removed by assuming that the aircraft continues at the same vertical rate (i.e. a climbing/descending aircraft that originally reverses its rate or levels-off shall continue to climb/descent at the same vertical rate; an aircraft that originally leaves level flight shall stay in level flight), whereas the removal of horizontal manoeuvres slightly differed between the two work packages [WP5/091], [WP07/078].
- 2.4.3.6. The minor discrepancies that existed between the WP05 and WP07 studies were linked to their respective assumptions and limitations and notably the distinct encounter time windows addressed within the two studies. For instance, the encounters generated by the ATM encounter model are constrained to a maximum of two turns in each aircraft trajectory, whereas more turns can be observed in the trajectories of aircraft in radar encounters.

## **2.5. The ATM and ASAS encounter models**

### **2.5.1. Scope**

- 2.5.1.1. Within IAPA Phase I, initial work consisted of developing the specification of an ATM encounter model for the airspace associated with the selected ASAS application. This work builds on the specification of an ATM encounter model in the ACAS SARPs and the specification of the European safety encounter model in the ACASA project.
- 2.5.1.2. Within IAPA Phase II, an ASAS encounter model was derived from the ATM encounter model [WP05/071], which was assumed to model an airspace in which the selected ASAS application is used by ATC according to the conditions of applicability and operational use defined in the defined IAPA operational environment.



2.5.1.3. Both the ASAS and ATM encounter models have the same structure, but differ in terms of likelihood of specific encounters. Their common structure is further described hereafter, whereas their development process and main encounter characteristics are further described in section 4.3.

## 2.5.2. General features

2.5.2.1. The advantage of an encounter model is that it can be used to generate an arbitrarily large set of artificial encounters whose properties are characteristic of a given airspace.

2.5.2.2. These encounter properties are specified by appropriate parameters, whose values can be different in each encounter and are determined by being selected stochastically from a distribution of probabilities representative of the considered airspace. Many of these distributions are in the form of histograms. Hence, the encounter model includes a set of tables defining the probabilities of each of the encounter parameters.

2.5.2.3. The encounter model parameters define the characteristics of individual trajectories and their relationship to one another when combined into an encounter.

## 2.5.3. Encounter properties

2.5.3.1. Each encounter takes the form of a sequence of three-dimensional positions at regular intervals. The time window of each encounter is 8 minutes and is centred upon the instant of “**closest approach**”.

2.5.3.2. Closest approach is defined here as the minimum in a measure of closeness referred to as “**propinquity**”. Propinquity considers the horizontal and vertical components of separation separately and scales them according to the appropriate separation minimum before combining them in a normal manner using Pythagoras’ theorem.

2.5.3.3. This definition of closest approach, which differs from the one used when studying the efficacy of ACAS, is used because horizontal separation standards are much larger than vertical separation standards and facilitates the capture of the operational characteristics of encounters in which safety is not necessarily compromised (even if there is an infringement of separation standards).

2.5.3.4. The altitude at which each encounter occurs is a dominant feature of the model. The airspace is divided into a number of **altitude layers** whose boundaries have been chosen to reflect the differing characteristics of air traffic and ATC procedures at different altitudes. Most of the distributions within the encounter model have a dependency on the particular layer to which an encounter has been assigned.

Layer <sup>6</sup>	2	3	4	5
from	5000ft	FL135	FL215	FL295
to	FL135	FL215	FL295	FL415

**Table 2: Altitude layers in the IAPA encounter models**

2.5.3.5. The model includes eight **aircraft performance classes** based on engine type and airframe size. These are broad classes intended to reproduce the typical performance limitations of groupings of aircraft rather than reproduce the precise performance of any particular types. Limitations on altitude, speed and vertical rate are taken into account when the distributions within the model are sampled.

2.5.3.6. The **vertical and horizontal profiles** of each aircraft are specified by the timing and magnitude of accelerations defining aircraft manoeuvres:

- The vertical profile consists of three segments of flight at constant vertical rate between which there are two potential vertical manoeuvres in which the vertical rate may change. Where the vertical profiles of the aircraft need to be correlated, this is achieved by selecting the profile types from a joint distribution.

In each segment, the aircraft may be in a climb (“C”), in a descent (“D”) or flying level (“L”). Each vertical profile is also assigned an overall vertical trend, which can be “climbing”, “descending”, “level” or “mixed”.

- The horizontal profile consists of three segments of flight on given headings between which there are two potential turns. The probability of each aircraft executing a turn in each portion of the encounter window is determined independently. Further, the probability of a turn depends on the general trend of the vertical profile, and whether or not the horizontal profiles of the aircraft need to be correlated.

The turns themselves are specified by the time at which they start, the change in heading (or track, since for the sake of simplicity the effects of wind are ignored in the model), and the bank angle used to achieve the specified change in heading.

- In addition, the speed of the aircraft may vary in an encounter. The probability of a change in speed and its nature is determined by the general trend of the vertical profile.

The speed profiles of the two aircraft are determined independently. However, the relative speeds of the two aircraft, in encounters that are not vertically separated, are considered when deciding which aircraft passes in-front the other should the ground-tracks of the aircraft cross. Hence, there is a tendency for the faster aircraft to pass behind the slower aircraft in the model.

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<sup>6</sup> The first layer considered within IAPA is named Layer 2, and its lower boundary was set to 5000 ft, for compatibility with encounter models used in other ACAS studies, which include a Layer 1 that corresponds to the altitude band from 1,000 ft to 5,000 ft.

2.5.3.7. Aircraft are frequently in level flight in which case they fly close to (nominally at) standard cruising levels. These standard cruising levels are separated by the vertical separation minimum (viz. 1,000 ft in the airspace and range of altitudes considered within the IAPA encounter model). There are consequently many instances when, in an encounter, the two aircraft are flying level at closest approach separated by a multiple of 1,000 ft. For this reason, the encounter model distinguishes between:

- ‘**level-level**’ encounters (i.e. both aircraft flying level close to (nominally at) standard cruising levels); or
- ‘**non level-level**’ encounters (i.e. at least one aircraft not flying level at closest approach).

2.5.3.8. An essential feature of the encounter model is the **separation at closest approach, i.e. at the Closest Point of Proximity (CPP)**. This is composed of a horizontal component (‘Horizontal Miss Distance’) and a vertical component (‘Vertical Miss Distance’).

2.5.3.9. In those encounters in which it is judged that separation is being provided in a given dimension (i.e. horizontal or vertical) at closest approach, the aircraft profiles of the two aircraft in the other dimension are independent – in those encounters in which it is judged that separation is not being provided in a given dimension the aircraft profiles in the other dimension are correlated.

2.5.3.10. Hence, separate Vertical Miss Distance (VMD) and Horizontal Miss Distance (HMD) distributions are used for the ‘non level-level’ and ‘level-level’ encounters, to reflect the tendency of aircraft in level-level encounters to be separated by a multiple of the vertical separation standard.

#### 2.5.4. Encounter generation

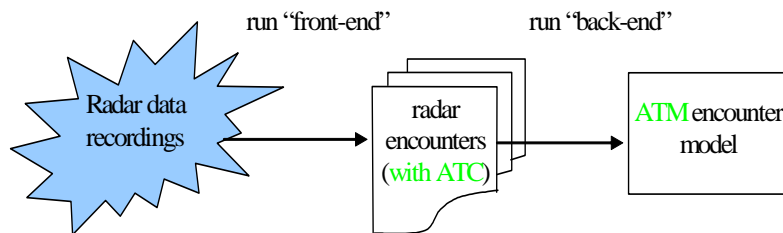
2.5.4.1. Once the positions and velocities of the two aircraft at closest approach and the accelerations and timings defining the manoeuvres have been determined, it is possible to construct the aircraft trajectories throughout the encounter window.

2.5.4.2. In some respects the encounters generated by the process described above can be too smooth, lacking the variations around general trends found in real aircraft trajectories. This shortcoming is overcome by introducing realistic variations in the aircraft trajectories. This process incorporates both a random component (“wobble”) and a systematic component (“modulation”) – hence it has come to be known by the portmanteau word “wobulation”.

2.5.4.3. Wobulation is applied independently to both the horizontal and vertical positions of each trajectory. For the IAPA model, the wobulation parameters have been chosen so that the variations in horizontal position are compatible with the aircraft having navigation of RNP-1 capability, and the variations in vertical position are compatible with the aircraft having altimetry and navigation performance that is RVSM MASPS compliant.

### 2.5.5. “Front-end” and “back-end” processing

- 2.5.5.1. The tables of the encounter model are populated by analysing very many encounters that represent the airspace to be modelled and simply counting the number of instances of an encounter with given properties.
- 2.5.5.2. When the source of encounters is real events observed in radar data then some pre-processing to identify relevant encounters is needed. This is achieved using a tool called the “front-end” which implements the agreed IAPA encounter capture criteria. When the encounters are produced by an encounter model, and then modified in some way (i.e. to model an evolution of the initial encounter model), the encounters can be used directly.
- 2.5.5.3. Once the appropriate set of encounters has been assembled, they can be analysed to determine their characteristics and populate the tables of the encounter model under construction. This is done using another tool called the “back-end”.



**Figure 6: Tools supporting the derivation of the ATM encounter model**

### 2.5.6. Validation of the ATM encounter model

- 2.5.6.1. The specification of the structure of the ATM encounter model was developed before the radar data and the tools to analyse the radar data were available. Therefore, a number of assumptions were made concerning the distribution of certain parameters and their possible interdependence with other parameters.
- 2.5.6.2. A validation exercise was undertaken to determine the validity of a number of key assumptions sustaining the specification of the ATM encounter model. The validation exercise included a statistical analysis of some of the key assumptions using the log of parameters generated when encounters were processed by the back-end facility, as well as an operational analysis, by an experienced former air traffic controller, of a sample of more than one hundred encounters generated by the model.
- 2.5.6.3. Although pointing out areas of improvement in the encounter model, the statistical analysis has demonstrated the relevance of key assumptions of the model [WP05/107]. This is particularly the case for the distinction made between ‘level-level’ encounters and ‘non level-level’ encounters. Further, the statistical analysis revealed that:
- a uniform distribution of the encounter altitude within each layer might not be appropriate. A significant example was the layer 5 (FL295 to FL415) for which there was a definite tendency for encounters to occur more toward the middle of the layer (close to FL350) than at the extremes of the altitude layer.

- a more natural altitude layers for ‘level-level’ encounters would have divisions at FL275 and FL315. With the current altitude layers there is a tendency to have too few level-level encounters in the altitude range FL275–FL295 and too many level-level encounters in the altitude range FL295–FL315.
- there are at least four distinct distributions of the approach angle in each altitude layer (instead of the two currently specified in the encounter model) depending on the separation mode (i.e. horizontal and/or vertical) of the encounter.

2.5.6.4. The operational analysis assessed the realism of the encounters from an operational perspective using expert judgement [WP05/117]. It revealed that generally the ATM encounter model produced encounters representative of those that might be expected in reality. However a number of unrealistic features were observed including improbable ground speeds (i.e. high speeds at low altitude and low speeds at high altitudes), inconsistent vertical rates and ground speeds.

2.5.6.5. These features appeared to result from an oversight in the implementation of the model, which failed to correlate the speed tables with the altitude layers. This deficiency might have had some effect on the subsequent ACAS and ASAS simulations, but is not expected to affect the results significantly.

2.5.6.6. Further, the number of unresolved conflicts (with significant or small infringements of the applicable separation minima) was judged to be slightly too high. This feature was confirmed by the rates of ACAS alerts that were computed from the ATM encounter model, which were greater than the figures observed in real-life (see section 4.7).

## **2.6. IAPA simulation framework definition**

### **2.6.1. Scope and purpose**

2.6.1.1. To support the in-depth investigation of the ACAS / ASAS interaction within IAPA Phase II, a common simulation framework was defined, which consists of:

- a set of scenarios “**with and without ASAS**”, which supports the assessment of ASAS lateral crossing operations in comparison with conventional ATM operations before the use of ASAS; and
- a comprehensive set of “**ACAS / ASAS interaction indicators**”, which supports the assessment of the potential improvements or drawbacks for both ACAS and ASAS operations.

2.6.1.2. These scenarios were defined taking into account the airspace and ASAS application characteristics defined in the IAPA operational environment. All scenarios (with and without ASAS) include the ACAS component as a constraint. Indeed, ACAS is an essential element of the ATM system, and it is not envisaged that its role should be put in question as a result of the introduction of ASAS operations.

## 2.6.2. ASAS scenarios

2.6.2.1. Three different scenarios related to ASAS operations were defined for further investigation:

- Scenario “**Mix of pass behind/in-front**”: Both “pass in-front” and “pass behind” procedures were applied to ASAS equipped aircraft, in accordance with their respective conditions of use. Further, preference was given to the “pass behind” procedure, as far as the procedure is applicable in accordance with its conditions of use;
- Scenario “**Pass behind**”: Only “pass behind” procedures were applied to ASAS equipped aircraft, in accordance with their conditions of use; and
- Scenario “**Pass in-front**”: Only “pass in-front” procedures were applied to ASAS equipped aircraft, in accordance with their conditions of use.

2.6.2.2. Scenario elements of particular interest included the following:

- ASAS application characteristics (e.g. minimum horizontal spacing (Option 1)/separation (Option 2) value at CPA) and conditions of use;
- Characteristics of pilot behaviour during an ASAS application, as well as in response to any ACAS alert;
- Level of aircraft equipage (e.g. ACAS, ASAS/ADS-B equipage); and
- Level of aircraft navigation capabilities (e.g. RNP-1, RVSM).

2.6.2.3. Unless otherwise required to perform a sensitivity study, and in order to investigate ACAS / ASAS interaction on the most demanding basis, the default value for the targeted horizontal spacing (Option 1)/separation (Option 2) value at closest point of approach during an ASAS lateral crossing procedure was set as 4 NM (cf. paragraph 2.3.3.5 for further details).

## 2.6.3. ACAS equipage and pilot behaviour

2.6.3.1. In accordance with the mandatory carriage of ACAS applicable by 1st January 2005 in ECAC, all aircraft with a maximum takeoff mass exceeding 5,700 kg or authorised to carry more than 19 passengers have been assumed TCAS II version 7.0 equipped.

2.6.3.2. Unless otherwise specified (in particular within the IAPA safety analysis), a standard pilot reaction model, as defined in [ICAO-ACAS], was applied for all ACAS equipped aircraft in response to the Resolution Advisories triggered by the ACAS logic.

Note: A recent ACAS safety study [ASARP] has identified various actual pilot reactions to ACAS alerts. However, it is not known if the pilot behaviour observed in the current European airspace will be unaffected by the introduction of ASAS operations. Therefore, it was decided not to vary the pilot reaction model to an ACAS alert or to vary the rate of pilot compliance with an alert during the IAPA operational analysis.

2.6.3.3. In addition, the following assumptions were used with regard to aircraft equipage:

- All aircraft are equipped with a Mode S transponder and report their altitude in 25-ft increments<sup>7</sup>;
- All ACAS equipped aircraft supply their ACAS logic with the most fine own altitude quantization (i.e. one foot); and
- A perfect TCAS II surveillance is assumed, i.e. no surveillance errors have been introduced in the ACAS simulations.

#### 2.6.4. ACAS / ASAS interaction indicators

2.6.4.1. To allow for the assessment of the potential ACAS / ASAS interaction from different perspectives, four distinct sets of ACAS / ASAS interaction indicators were defined which highlight potential improvements or drawbacks respectively in terms of:

- **ACAS safety performance:** From an ACAS perspective, priority is given to the assessment of the safety benefits provided by ACAS with and without ASAS. The aim would be to answer the question: “what is acceptable from an ACAS standpoint?”. The ACAS safety indicators are typically related to the effectiveness of RAs during non-nominal operations.
- **ASAS performance:** From an ASAS perspective, the purpose is to assess the potential impact of ACAS on the expected benefits from the ASAS application. More precisely, the focus is on assessing the impact of ACAS on the applicability of the ASAS lateral crossing procedure through the likelihood of ACAS alerts during ASAS operations.
- **Pilot acceptance:** The objective is to assess from a pilot’s perspective the acceptability of ACAS during ATM operations with and without ASAS, through:
  - the issuance of appropriate ACAS alerts (typically, RAs) during non-nominal operations; and
  - the extent to which undesirable ACAS alerts (both TAs and RAs) occur during nominal operations.
- **ACAS / ASAS compatibility:** The objective is to assess the impact of ASAS on ACAS, and vice-versa, from an overall ATM perspective, i.e. the compatibility of ACAS with ATM operations with and without ASAS, including the extent to which disruptive ACAS alerts (typically, undesirable RAs), and deviations from clearance resulting from compliance with RAs, occur during operations.

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<sup>7</sup> Although not all aircraft are currently able to report their altitude in 25-ft increments, this assumption is considered operationally realistic at the 2,010 timeframe considered within the IAPA study. In addition, introducing a small proportion of aircraft reporting altitude in 100-ft quanta is not expected to modify the simulation results.

## **2.7. ACAS simulation tools**

- 2.7.1. The execution and analysis of the ACAS simulations have been performed by the various organisations involved in the IAPA project using their own simulation facilities. These ACAS simulation tools include:
- The EUROCONTROL ‘Interactive Collision Avoidance Simulator’, i.e. the [InCAS] tool, version 2.4;
  - The French DNSA ‘Off-line Simulator for Collision Avoidance Resolution’, i.e. the [OSCAR] test bench, version 5.0; and
  - The QinetiQ in-house ACAS simulator, i.e. STC20.
- 2.7.2. All three simulators include an implementation of the TCAS II logic version 7.0 conforming to the TCAS Minimum Operation Performance Standards [TCAS-MOPS] incorporating the changes specified in Technical Standard Order C119B [TSO-C119B]. For the two last tools, the simulated TCAS logic also incorporates the modification to the TSO recommended by RTCA SC-147’s Requirements Working Group in 1999 [TSO-C119B-RWG], i.e. approved changes 1 to 92 and 98.



### 3. Initial investigation of the ACAS / ASAS interaction

#### 3.1. General

- 3.1.1. Within IAPA Phase I, an initial ACAS / ASAS interaction study (WP04) was performed to support the selection of a demanding ASAS application to be further investigated during Phase II.
- 3.1.2. A preliminary analysis consisted of studying the ACAS and ASAS interaction through the use of a qualitative set of artificial encounters, representative of Airborne Surveillance applications proposed for early implementation in the CARE-ASAS Package I [PACKI].
- 3.1.3. This preparatory analysis highlighted the potential interaction that exists between ACAS and the ASAS lateral crossing procedure. Further, a specific case study of this ASAS application was performed at the end of IAPA Phase I, which confirmed its final selection as a demanding application from an ACAS / ASAS interaction perspective.
- 3.1.4. The remainder of this chapter describes the main study assumptions and results of the preparatory analysis of a set of Package I AS applications, as well as the specific case study of the ASAS application selected for further investigation within IAPA (cf. [WP04/029] for further details).

#### 3.2. Preparatory analysis of a set of Package I AS applications

##### 3.2.1. Scope and approach

- 3.2.1.1. The scope of the preparatory analysis of the potential ACAS / ASAS interaction issues was as follows:
  - **Package I/ASPA-S&M Enhanced sequencing and merging operations:** Two encounter types corresponding to the merging and the in-trail phases of the ASPA-S&M application were selected for further analysis. In addition, the encounter type dealing with the in-trail phase was proposed to include aircraft turns.
  - **Package I/ASPA-C&P: Enhanced crossing and passing operations:** Three encounter types corresponding to the lateral crossing, the vertical crossing and the lateral passing procedures were selected for further analysis.
- 3.2.1.2. For each encounter type, a preliminary step consisted of identifying the set of encounter parameters (e.g. encounter geometry, flight parameters, separation values at closest approach) that have the potential to trigger an ACAS alert. This was determined on the basis of the guidance material associated with the ACAS minimum requirements defined in ICAO Annex 10, Volume IV [ICAO-ACAS], and in particular the protected volume defined by means of the range test and altitude test (cf. Appendix B for further details).

3.2.1.3. In a second step, specific and demanding encounters were generated using an in-house aircraft simulator [BASILE] and ACAS simulations were performed using the OSCAR test bench [OSCAR], which includes an implementation of the TCAS II logic version 7.0. These simulations were conducted assuming ACAS equipage, altitude reporting in 25-ft increments and standard pilot reaction to ACAS resolution advisories for all aircraft.

3.2.1.4. It should be noted that both the analysis based on ACAS SARPS and the ACAS logic simulations were performed assuming perfect CNS performances.

### 3.2.2. Characteristics of the simulated ASAS encounters

3.2.2.1. In support to these ACAS simulations, a set of qualitative encounters was built for each ASAS application of interest, which involved two aircraft with various performances. Aircraft trajectories were generated according to aircraft performances defined in the EUROCONTROL BADA tables [BADA] for each of the following representative aircraft types:

A/c type	ATR 42/72	SAAB 2000	A320	B767-300	A340	B747-400
Propulsion Type	Turbo	Turbo	Jet	Jet	Jet	Jet
Approach Category	B	B	C	C	D	D
WV Category	Medium	Medium	Medium	Heavy	Heavy	Heavy

**Figure 7: Aircraft types investigated during the IAPA preparatory analysis**

3.2.2.2. Encounters resulting from all possible combination of aircraft types were analysed since they correspond to different situations in terms of aircraft performance mix. In addition to the aircraft type, other encounter parameters of interest included the relative positioning of aircraft trajectories, as well as the aircraft relative velocities, at closest approach.

3.2.2.3. The simulated trajectories were ideal trajectories with neither any wind effect nor any trajectory blunders or overshoots due to navigation errors. This was considered an acceptable assumption for a preliminary analysis.

3.2.2.4. It should also be noted that the ratios of TAs and RAs depend highly on the aircraft performance mix included in the set of simulated encounters, which was not intended at this stage to be representative of the European fleet of aircraft.

## 3.3. ***Preparatory analysis of the ASPA-S&M merging phase***

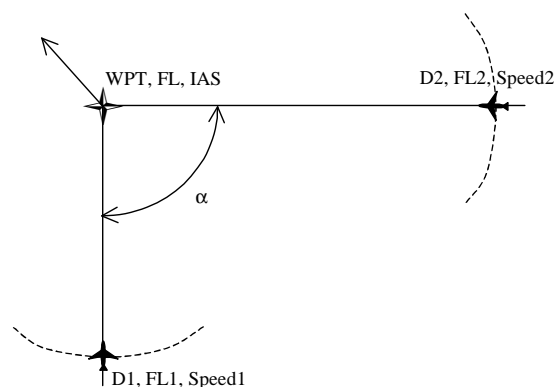
### 3.3.1. Scope of the analysis

3.3.1.1. The investigation of the merging phase of ASPA-Sequencing & Merging encounters dealt with encounters where two aircraft are converging in-descent towards the same merging point (WPT) at the same FL, and then follow the same track after WPT, which is either part of a STAR, or of an approach procedure.

3.3.1.2. Further, it was assumed that a speed constraint applies at the merging point, e.g. maximum IAS of 280 kt below FL200, 250 kt at or below FL120, and 220 kt at or below FL60, respectively.

3.3.1.3. The encounter parameters of particular interest included the following:

- the required spacing at WPT, either in time or distance, which depends on the flight level. To be operationally acceptable, this spacing should not be lower than the radar separation minimum (typically, 5 NM in Extended-TMA and 3 NM in TMA) nor the wake turbulence separation minimum which depends on both aircraft types (as described in Appendix A);
- the angle of convergence at WPT (maximum value of 90 degrees in STARs and up to 180 degrees in approach procedures<sup>8</sup> – typically below FL60); and
- the relative initial speed of aircraft 1 (leading aircraft) and aircraft 2 (trailing aircraft), which depend on both aircraft types and initial altitudes FL1 and FL2;

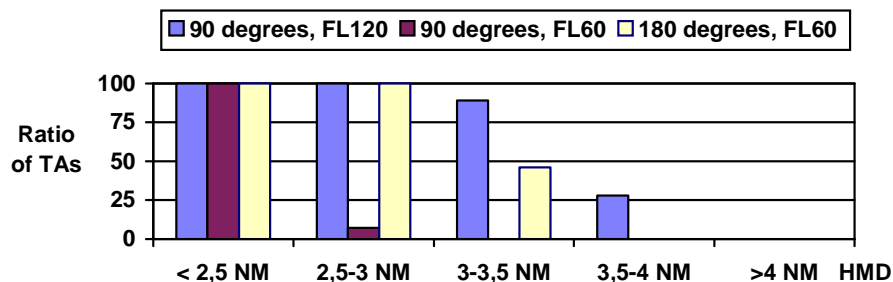


**Figure 8: Horizontal trajectories of an ASPA-S&M encounter - merging phase**

### 3.3.2. Main results of the preliminary analysis

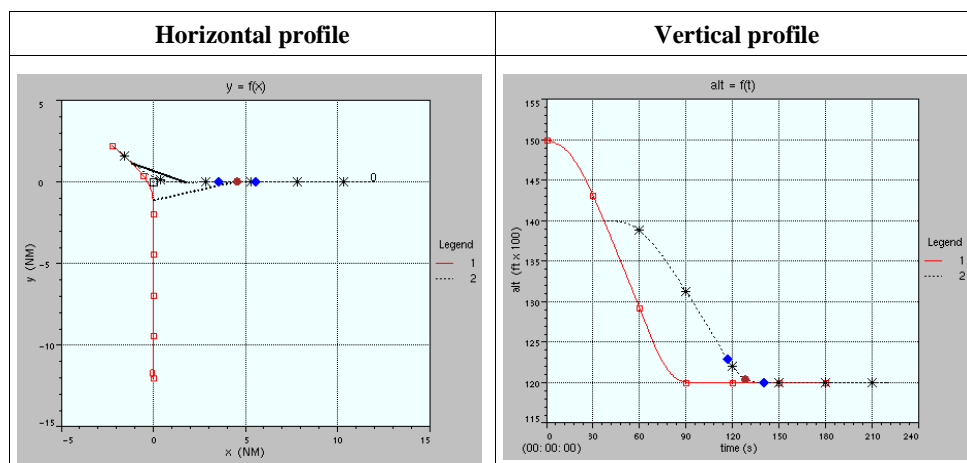
- 3.3.2.1. The preliminary analysis based on the ACAS guidance material indicated that some marginal merging situations, with a required spacing value at the merging point close to 3 NM, may trigger a TA under certain circumstances.
- 3.3.2.2. This was confirmed by the ACAS logic simulations performed on various sets of (216) merging encounters at given altitudes and with given angles of convergence. The following table presents the ratio of TAs generated in these sets depending on the horizontal miss distance between both aircraft:

<sup>8</sup> Approach procedures with converging tracks from opposite directions do not apply everywhere, but are operationally realistic. Furthermore, they correspond to the most demanding situations in terms of ACAS / ASAS interaction.



**Figure 9: Ratio of TAs for ASPA-S&M merging encounters against horizontal separation at WPT**

- 3.3.2.3. As shown, no occurrence of TAs is triggered with distance spacing at the merging waypoint greater than the en-route radar separation minima, i.e. 5 NM, which corresponds to a time separation of 60 seconds at FL120 with the given IAS of 250 kt.
- 3.3.2.4. For distance spacing values between 3 NM and 4 NM, the ratio of TAs generated per aircraft with TCAS II logic version 7.0 depends on the targeted flight level at the merging waypoint. It rises up to about 50% for the encounters with aircraft converging at 90 degrees towards FL120, and is about 23% for the encounters with aircraft converging at 180 degrees towards FL60.
- 3.3.2.5. An illustration of a TA triggered during a merging encounter at 90 degrees towards FL120 and involving two distinct aircraft types, i.e. an Airbus A320 and a Boeing 747-400, is provided in the following figures:



**Figure 10: Traffic Advisory during the merging phase of an ASPA-S&M encounter (at 90 degrees)**

Note: In the left figure, the solid line is drawn between both aircraft positions at CPA, whereas the dotted line is drawn between the aircraft positions at the time the TA is first issued. The evolution of the intruder status (on board aircraft 1) is also represented along the aircraft trajectory using the usual TCAS II symbols.

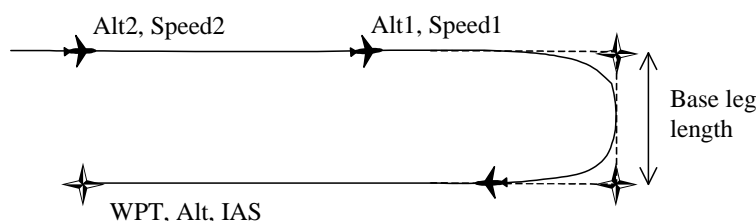
3.3.2.6. However, it should be noted that such aircraft spacing (so close to the radar separation minima in TMA) is unlikely to occur during typical merging situations.

### 3.4. Preparatory analysis of the ASPA-S&M in-trail phase

#### 3.4.1. Scope of the analysis

3.4.1.1. The investigation of the in-trail phase of ASPA-Sequencing & Merging encounters dealt with encounters defined as follows:

- Both aircraft fly along the same trajectory, either a published trajectory in ‘NAV Trail’ mode, or the vectored trajectory flown by the leading aircraft in ‘Target Trail’ mode.
- Both aircraft are in descent towards same altitude (Alt) at final WPT, where a speed constraint is defined, e.g. IAS set to 170 kt at 4,000 ft.
- The trailing aircraft (aircraft 2) is not allowed to select its own turn point in order to maintain the required spacing by flying a different track distance than the leading aircraft (aircraft 1).



**Figure 11: Horizontal trajectories of an ASPA-S&M encounter - in-trail phase**

3.4.1.2. The encounter parameters of particular interest included the following:

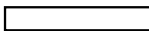

- the required spacing at WPT, either time or distance, which should not be lower than the radar separation minimum (typically 3 NM, possibly reduced to 2.5 NM, in TMA) nor the applicable wake turbulence separation minimum; and
- the relative initial altitude and spacing between the two aircraft. The initial spacing between both aircraft at the start of the encounter is set so as to obtain the maximum throughput at WPT, while still preserving the applicable separation minimum.

#### 3.4.2. Main results of the preliminary analysis

3.4.2.1. The preliminary analysis based on the ACAS guidance material indicated that all the in-trail situations that may trigger a TA would not be operationally acceptable:

- when flying along the same transition leg, since aircraft are flying with similar speeds, the maximum miss distance triggering an ACAS alert is defined by the DMOD parameter (cf. Appendix B for further details), whose value is far below the applicable Wake Vortex (WV) radar separation minima;





Altitude	2350ft-FL50	FL50-FL100	FL100-FL200
DMOD (NM) for TA	0,33	0,48	0,75
DMOD (NM) for RA	0,20	0,35	0,55

**Legend:** In-trail spacing greater than the WV radar separation minima   
In-trail spacing lower than the WV radar separation minima 

**Table 3: Potential ACAS alerts during an ASPA-S&M - in-trail phase along same transition leg**

- when flying on one side and the other of the base leg, the configurations that may trigger a TA would correspond to a base length lower than the radar separation minimum in TMA, i.e. 3 NM, or lower than the minimum base length required for the aircraft to turn (at maximum bank angle of 25 degrees).

TAS Turn	Minimum Base Leg Length	Maximum miss distance (in NM) for TA		
(Kts)	Turn at 25 degrees	2350ft-FL50	FL50-FL100	FL100-FL200
180,00	2,0	1,6	2,1	2,5
190,00	2,3	1,7	2,2	2,6
200,00	2,5	1,7	2,3	2,7
210,00	2,8	1,8	2,5	2,8
220,00	3,0	1,9	2,6	2,9
230,00	3,3	2,0	2,7	3,0
240,00	3,6	2,1	2,8	3,2
250,00	3,9	2,1	2,9	3,3
260,00	4,2	2,2	3,0	3,4
270,00	4,6	2,3	3,1	3,5
280,00	4,9	2,4	3,2	3,6
290,00	5,3	2,5	3,3	3,8
300,00	5,6			3,9
310,00	6,0			4,0
320,00	6,4			4,1
330,00	6,8			4,2
340,00	7,2			4,4
350,00	7,7			4,5

**Legend:** In-trail spacing greater than both the minimum base leg length and the horizontal separation minima   
In-trail spacing lower than the minimum base leg length   
In-trail spacing lower than the horizontal separation minima   
In-trail spacing lower than both the minimum base leg length and the horizontal separation minima 

**Table 4: Potential Traffic Advisories during an ASPA-S&M - in-trail phase along opposite transition legs**

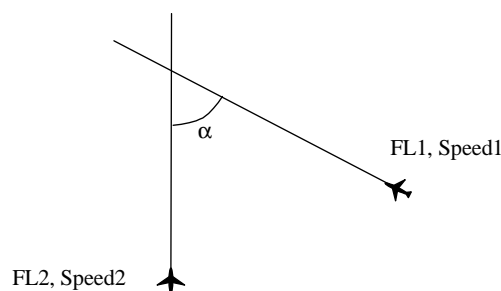
3.4.2.2. In view of the previous results, which show the improbable occurrence of ACAS alert during in-trail encounters, no ACAS logic simulations have been performed for the in-trail phase of ASPA-Sequencing & Merging application.

### 3.5. *Preparatory analysis of the ASPA-C&P lateral crossing*

#### 3.5.1. Scope of the analysis

3.5.1.1. When investigating lateral crossing encounters likely to result from ASPA-Crossing & Passing operations, the encounter parameters of particular interest included the following:

- the required spacing at the track crossing point, either in time or distance, between the first (aircraft 1) and second (aircraft 2) aircraft at the crossing point. To be operationally acceptable, this spacing should not be lower than both the radar separation minimum (typically, 5 NM in en-route and 3 NM in TMA) and the applicable Wake turbulence separation minimum.
- the angle of convergence at the track crossing point (value between 30 degrees and 150 degrees); and
- the relative speed between both aircraft during the crossing, which depends on the angle of convergence and the speed of both aircraft (which may be distinct if aircraft types are distinct).



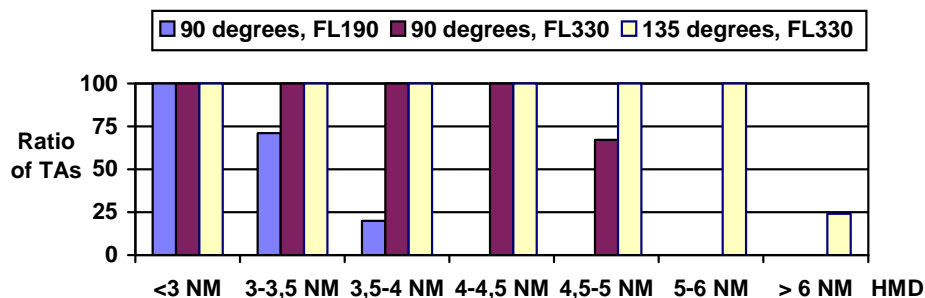
**Figure 12: Horizontal trajectories of an ASPA-C&P encounter with lateral crossing**

3.5.1.2. It should be noted that, depending on the angle of convergence between aircraft tracks and the relative speed between both aircraft, the resulting CPA occurs either before or after the first aircraft passes the track crossing point.

#### 3.5.2. Main results of the preliminary analysis

3.5.2.1. The preliminary analysis based on the ACAS guidance material indicated that some crossing situations with a tight, but operationally acceptable, spacing values at the track crossing point may trigger a TA under certain circumstances, in particular at high altitudes with great converging speeds.

3.5.2.2. This was confirmed by the ACAS logic simulations performed on various sets of crossing encounters at given altitudes and with given angles of convergence. The following table presents the ratio of TAs generated on these encounter sets depending on the horizontal separation at CPA:



**Figure 13: Ratio of TAs for ASPA-C&P lateral crossing encounters against horizontal separation at CPA**

3.5.2.3. As shown, at high altitude (i.e. FL330), for HMD values close to the en-route separation minimum, i.e. between 4.5 NM and 5 NM, the ratio of TAs is about 67% for the crossing encounters at 90 degrees and raises up to 100% in case of converging tracks at 135 degrees.

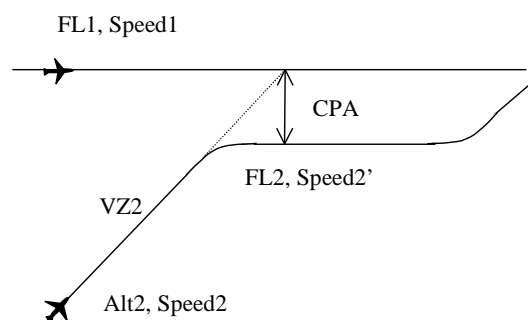
3.5.2.4. No RA was triggered over the whole set of simulated encounters thanks to the ‘Miss Distance Filter’ (MDF) of TCAS II logic version 7.0. However, the preliminary analysis based on the ACAS guidance material indicated that when circumstances prevent the MDF from being fully effective some crossing situations with probable aircraft speeds could trigger an RA.

### 3.6. Preparatory analysis of the ASPA-C&P vertical crossing

#### 3.6.1. Scope of the analysis

3.6.1.1. The investigation of vertical crossing encounters likely to result from ASPA-Crossing & Passing operations dealt with encounters defined as follows:

- Both aircraft are assumed to be flying along tracks that cross and are not necessarily horizontally separated at the track crossing point.
- One aircraft is assumed to be in level flight and the other, with a changing vertical rate, is levelling-off below the other aircraft just before the track crossing point, and resumes its climb only when some required lateral spacing is restored between both aircraft.



**Figure 14: Vertical trajectories of an ASPA-C&P encounter with vertical crossing**



3.6.1.2. The encounter parameters of particular interest included the following:

- the horizontal separation at CPA between both aircraft, which varied from 0 NM to the applicable horizontal separation minima (typically, 3 NM in TMA and 5 NM in en-route airspace);
- the required vertical separation between both aircraft when level flight, which minimum value is the minimum vertical separation (typically, 1,000 ft up to FL410, and 2,000 ft above, in the ECAC airspace); and
- the relative vertical and horizontal speed between both aircraft, which depend on both aircraft type and their targeted altitudes.

### 3.6.2. Main results of the preliminary analysis

3.6.2.1. The preliminary analysis based on the ACAS guidance material focused on level-off encounters with projected co-altitude at CPA and for which the range test of the ACAS logic is satisfied (cf. Appendix B for further details).

3.6.2.2. Assuming only one aircraft levelling-off below (respectively, above) another level aircraft at the applicable vertical separation minimum, the analysis indicated that such level-off encounters (with projected co-altitude at CPA) would trigger a TA, as far as the aircraft vertical rate was:

- greater than 1,500 fpm below FL410, or
- greater than 3,000 fpm above.

3.6.2.3. Although the second alternative is unlikely to occur with typical aircraft types, the first one is operationally realistic for almost all aircraft types.

3.6.2.4. In addition, the analysis indicated that, in the altitude layer FL100-FL410, a vertical rate greater than 3,000 fpm would even trigger a TA when considering an aircraft levelling-off 2,000 ft above or below another level aircraft.

3.6.2.5. Finally, the analysis indicated that single level-off encounters could even trigger an RA, as far as the aircraft vertical rate was:

- greater than 3,800 fpm below FL100, or
- greater than 2,800 fpm between FL100 and FL200, or
- greater than 2,200 fpm between FL200 and FL420.

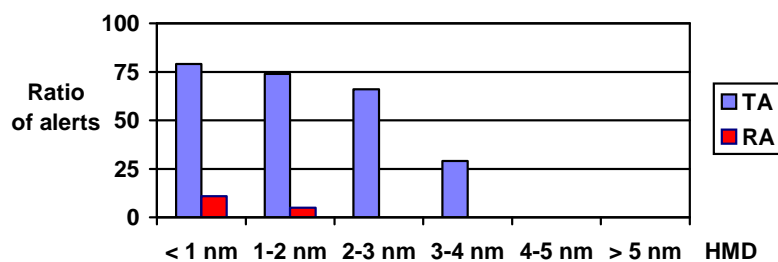
3.6.2.6. These vertical rates are operationally realistic either in climb or descent, in particular for low aircraft weights which allow higher rates of climb for a given aircraft type.

3.6.2.7. Following the previous analysis, ACAS logic simulations were performed on a set of (468) artificial encounters with the following assumptions:

- both aircraft are flying along converging tracks at 90 degrees;
- one aircraft is flying level at FL190; and
- the other one levelling-off 1,000 ft below at the track crossing point.

3.6.2.8. In order to assess the ACAS / ASAS interaction on a broad range of situations, the time separation between both aircraft at the track crossing point ranged from 0 seconds up to  $\pm 60$  seconds (with 10 seconds increments).

3.6.2.9. Both Traffic Advisories and Resolution Advisories were generated by the TCAS II logic version 7.0. The following figure presents the ratios of TAs and RAs generated per aircraft for the overall set of encounters depending on the horizontal separation at CPA:

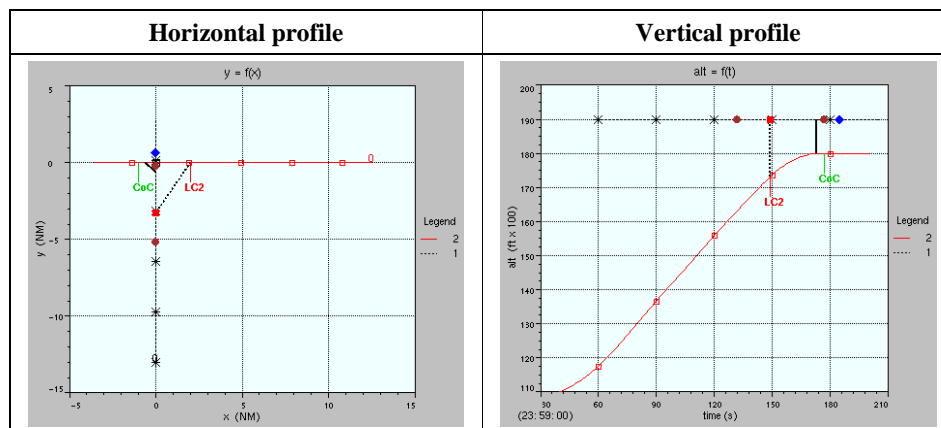


**Figure 15: Ratio of ACAS alerts during (single) level-off ASPA-C&P encounters (at 90 degrees) at FL190 against horizontal separation at CPA**

3.6.2.10. As expected, the ratio of ACAS alerts generated per aircraft decreases when HMD increases since the range test and the altitude test of the ACAS logic (cf. Appendix B for further details) are less likely to be satisfied at the same time:

- For HMD values lower than 2 NM, the ratio of TAs generated per aircraft is quite substantial (75%). This ratio is still significant (66%) for HMD values between 2 NM and 3 NM. Finally, no TA was generated for those encounters with an HMD value greater than 4 NM.
- For HMD values lower than 2 NM, some RAs were generated on board the aircraft levelling-off, whereas no RA was generated for those encounters with an HMD value greater than 2 NM.

3.6.2.11. An illustration of such an encounter (with small HMD) triggering an RA with TCAS II logic version 7.0 is provided in the following figure. The encounter involves a Boeing 747-400 levelling-off 1,000 ft below an Airbus A340 flying steady at FL190.



**Figure 16: Resolution Advisory during a single level-off ASPA-C&P encounter (1,000 ft below a steady aircraft)**

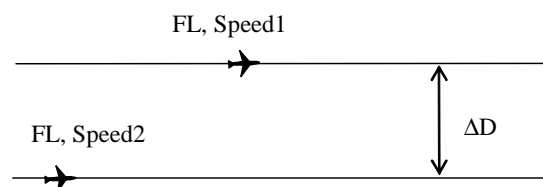
Note: In the figure, the solid line is drawn between both aircraft position at CPA, whereas the dotted line is drawn between the aircraft position at the time the TA is first issued. The evolution of the intruder status (on board aircraft 1) is also represented along the aircraft trajectory using the usual TCAS II symbols. Further, the RA issued by the ACAS logic (on board aircraft 1) are represented along own aircraft trajectory.

- 3.6.2.12. It should be noted that in this specific encounter, and thanks to the improved behaviour of TCAS II logic version 7.0 in such level-off geometries, an RA was only triggered on board the climbing aircraft whereas the level aircraft only experienced a TA.

### **3.7. Preparatory analysis of the ASPA-C&P lateral passing**

#### **3.7.1. Scope of the analysis**

- 3.7.1.1. The investigation of lateral passing encounters likely to result from ASPA-Crossing & Passing operations dealt with encounters involving two aircraft flying level on parallel tracks and distinct speeds. Therefore, the faster aircraft is overtaking the slower aircraft.



**Figure 17: Horizontal trajectories of an ASPA-C&P encounter with lateral passing**

- 3.7.1.2. The encounter parameters of particular interest included the following:

- the track spacing, whose minimum value is the minimum radar separation (typically, 3 NM in TMA and 5 NM en-route);
- the relative speed between the slower aircraft (aircraft 1) and the faster (aircraft 2), which depends on both aircraft types and the altitude of the encounter.

#### **3.7.2. Main results of the preliminary analysis**

- 3.7.2.1. The preliminary analysis based on the ACAS guidance material concluded that, since both aircraft are in slow convergence, the lateral spacing values that may trigger an ACAS alert are of the order of the DMOD parameter, i.e. far below the applicable horizontal separation minima, and would therefore not be operationally acceptable.
- 3.7.2.2. In view of the previous results, no ACAS logic simulations have been performed for lateral passing encounters resulting from ASPA-Crossing & Passing operations.

### **3.8. Main preparatory results on the ACAS / ASAS interaction issue**

- 3.8.1. In summary, according to the results of this preparatory analysis of the potential ACAS / ASAS interaction issue, **no interaction with ACAS is anticipated for the following ASAS applications:**
- The in-trail phases of the ASPA-S&M: Enhanced sequencing and merging operations whatever the altitude layer, and as far as the Wake Vortex separation minima are preserved; and
  - The lateral passing situations resulting from ASPA-C&P: Enhanced crossing and passing operations whatever the altitude layer, since the lateral spacing values required to trigger an ACAS alert during slow convergence situations are of the order of the DMOD parameter, e.g. 1.3 NM for a TA above FL200. Such lateral spacing values would not be operationally acceptable.
- 3.8.2. **Some interaction with ACAS potentially exists for the ASPA-S&M: ‘Enhanced sequencing and merging operations’** for the merging phases, but only **during situations close to the limit to what could be considered operationally acceptable**. In particular, some merging encounters with required spacing at WPT close to the radar separation minimum in TMA, i.e. 3 NM, may trigger a TA. However, such spacing values between aircraft in sequence are unlikely to occur during typical merging situations.
- 3.8.3. Finally, the results of the preparatory analysis show that **some interaction with ACAS potentially exists for the ASPA-C&P: ‘Enhanced crossing and passing operations’**. In particular, the following encounters are likely to trigger TAs:
- Lateral crossing encounters, typically with angles of convergence greater than 90 degrees and a horizontal separation at CPA close to the applicable radar separation minima, i.e. 3 NM in TMA and 5 NM in en-route ECAC airspace; and
  - Level-off encounters at the applicable vertical separation minima, i.e. 1,000 ft below FL415, and 2,000 ft above, in the ECAC airspace, with operationally realistic vertical rates. Such encounters are common events, in particular between arrivals and departures in TMA.
- 3.8.4. Such 1,000 ft level-off encounters may even trigger “undesirable” RAs when significant, but realistic, relative altitude rates occur close to the cleared flight levels. This issue has already been identified for current ATM operations, and is not specifically linked to the introduction of ASAS operations.
- 3.8.5. Therefore, in view of these overall results, the preparatory analysis concluded that the lateral crossing encounters resulting from ASPA-Crossing & Passing operations were of particular interest for the IAPA study of the ACAS / ASAS interaction issue.

### **3.9. Specific case study of the ASAS lateral crossing procedure**

#### **3.9.1. Scope and purpose**

- 3.9.1.1. To complement the preparatory ACAS logic simulations already performed on ASAS lateral crossing operations, a specific case study was performed to identify those scenarios (i.e. encounter geometry, type of ASAS manoeuvre and aircraft type) that have the potential for triggering ACAS alerts.
- 3.9.1.2. During this specific ACAS / ASAS interaction analysis of the ASAS crossing procedure, TCAS II logic simulations were performed on a set of qualitative encounters involving two aircraft, one of which was performing an ASAS “**pass behind**” or “**pass in-front**” manoeuvre as defined in section 2.3. These ASAS manoeuvres were simulated using the ASAS simplified model developed within IAPA (cf. section 2.4).
- 3.9.1.3. Looking into the parameters of the ACAS logic enabled an understanding of the influence of various encounter parameters on TA and RA characteristics. Encounter parameters of interest included:
  - the angle of convergence between both aircraft (between 30 degrees and 150 degrees);
  - the aircraft performances (i.e. turboprop or jet aircraft);
  - the encounter flight level (i.e. FL80, FL140, FL240 or FL330);
  - the applicable spacing (Option 1) / separation (Option 2) value at CPA (around the default value of 4 NM);
  - the vertical profiles of both aircraft, and the resulting vertical separation at CPA. Three vertical profiles were simulated:
    - both aircraft flying level at same FL;
    - one aircraft flying level and the other climbing through the FL of the level aircraft; and
    - one aircraft flying level and the other descending through the FL of the level aircraft.
- 3.9.1.4. For all the encounters, the simulated trajectories were ideal trajectories with neither any wind effects, nor any trajectory blunders nor track deviations due to navigation errors or uncertainties.

#### **3.9.2. Main outcomes of the specific case study**

- 3.9.2.1. At the end of IAPA Phase I, the results of the IAPA case study (WP04) confirmed that the ASAS lateral crossing application was indeed a demanding application in terms of possible interaction with ACAS.
- 3.9.2.2. With regard to TAs, the main ACAS / ASAS features underlined during the case study of the ASAS lateral crossing application include the following:
  - The issuance of a TA is strongly dependent on the angle of convergence and the aircraft speed, which itself depends on the flight level and the aircraft type. The higher the resulting closing speed, the higher the likelihood of a TA;

- No TAs were generated during encounters occurring at FL80 (low flight level) and for encounters involving aircraft with an initial angle of convergence of 30 degrees (low angle of convergence);
- The “pass behind” manoeuvre is more likely to trigger a TA because it increases the initial rate of convergence, while the “pass in-front” decreases it. However, this result does not mean that the “pass in-front” manoeuvre is safer than the “pass behind” one.

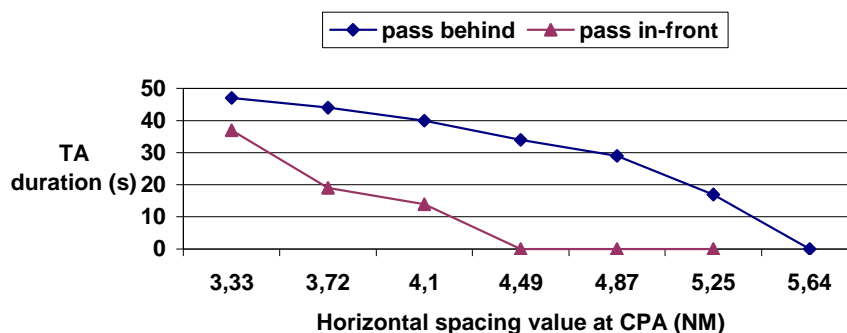
This feature is illustrated in the table below, which shows the effect of both types of manoeuvre on the angle of convergence, the closing speed and the likelihood of ACAS alerts, depending on the initial relative track angle simulated in a crossing encounter involving two jet aircraft at FL330:

Initial convergence angle	“pass behind” manoeuvres			“pass in-front” manoeuvres		
	Modified convergence angle	Closing speed	ACAS alert	Modified convergence angle	Closing speed	ACAS alert
150°	160°	973 kt	TA	140°	928 kt	TA
120°	130°	895 kt	TA	106°	789 kt	TA
90°	102°	768 kt	TA	76°	608 kt	TA
60°	70°	567 kt	TA	–	500 kt	None
30°	–	259 kt	None	–	259 kt	None

**Table 5: ACAS alerts within ASAS lateral crossing encounters between two jets at FL330 for several angles of convergence**

- For both the “pass behind” and “pass in-front” manoeuvres, the greater the horizontal separation at CPA, the less likely that a TA would occur, especially in the case of a “pass in-front” manoeuvre. In addition, when a TA is triggered, its duration decreases with the horizontal separation at CPA;

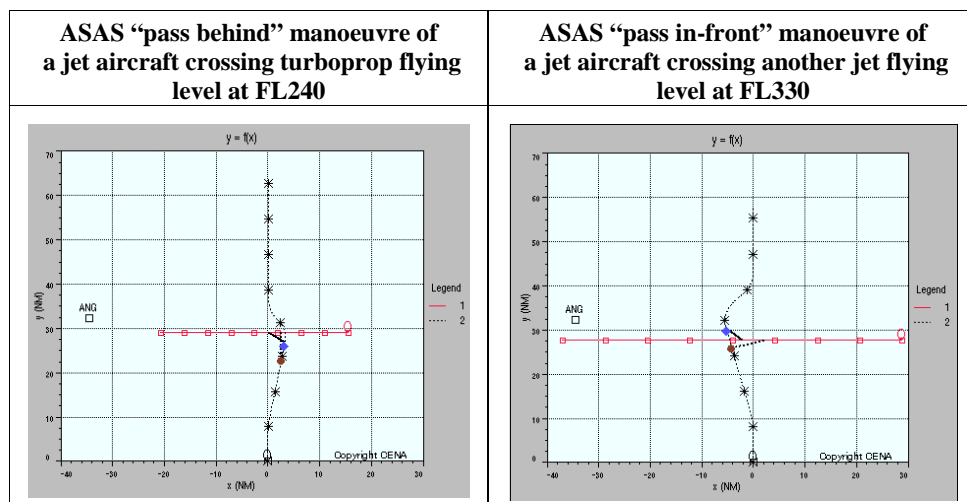
This feature is illustrated in the figure below, which shows the TA duration, depending on the HMD achieved in a crossing encounter at 90 degrees involving two jet aircraft at FL330 with either a pass behind or in-front manoeuvre:



**Figure 18: TA duration within ASAS lateral crossing encounters at 90 degrees between two jets at FL330**

- TAs only occurred during the first phase of the ASAS lateral crossing manoeuvre, i.e. before the “resume track” phase, despite the selected heading of 45 degrees when flying direct to track.

This feature is illustrated in the figures below. The left-hand figure shows an encounter between a jet and a turboprop aircraft both flying level at FL240 with initial tracks converging at an angle of 90 degrees. A Traffic Advisory is triggered during the first phase of the “pass behind” manoeuvre. The right-hand figure shows an encounter between two jets both flying level at FL330 with initial tracks converging at an angle of 90 degrees. A Traffic Advisory is triggered during the first phase of the “pass in-front” manoeuvre.



**Figure 19: Traffic Advisory during an ASAS lateral crossing encounter (at 90 degrees) at FL240**

Note: In the figures, an ‘0’ symbol shows the origin of the horizontal trajectory of each aircraft. The solid line is drawn between both aircraft positions at CPA, whereas the dotted line is drawn between the aircraft positions at the time the TA is first issued. The evolution of the intruder status (on board aircraft 1) is also represented along the aircraft trajectory using the usual TCAS II symbols.

- 3.9.2.3. Assuming perfect aircraft navigation (i.e. with neither blunders nor track deviations) as well as perfect ACAS surveillance, the case study has demonstrated that RAs are not expected to occur during an ASAS lateral crossing procedure, due to the ‘Miss Distance Filtering’ feature of TCAS II logic version 7.0.
- 3.9.2.4. Nevertheless, initial investigation of the sensitivity of the MDF to cross-track deviations has shown that this feature might not be effective in cases where the ACAS logic detects an intruder manoeuvre, even if this detection only results from the aircraft navigation performance, e.g. cross-track deviations.
- 3.9.2.5. The extent to which undesirable Resolutions Advisories are likely to occur during ASAS lateral crossing operations was further assessed through the various ACAS simulations performed during IAPA Phase II.

## **4. Operational analysis of the ACAS / ASAS interaction**

### **4.1. General**

#### **4.1.1. Scope**

4.1.1.1. Within IAPA Phase II, the operational investigation of the ACAS / ASAS interaction issues was performed through various studies based on different sources of data:

- a study based on artificial encounters from the ASAS encounter model (WP06);
- a study based on modified radar encounters derived from European radar data (WP07);
- a study based on artificial encounters derived from European flight plan data (WP08); and
- a study based on encounters extracted from real-time simulation data (WP09).

4.1.1.2. The various studies dealt with the ASAS application selected for further investigation during Phase I, i.e. the ASAS lateral crossing procedure [WP01/024]. Further, in order to investigate ACAS / ASAS interaction on the most demanding basis, the minimum applicable separation used in most of the ASAS simulations was 4 NM.

4.1.1.3. Not all these different data-oriented studies were necessarily able to fully comply with the IAPA simulation framework. This particularly applies to the study based on real-time simulations (WP09). Since this study involved the use of ASAS by human operators, it was not possible to always achieve the specific conditions of use defined for IAPA.

#### **4.1.2. Rationale and background**

4.1.2.1. The rationale for conducting simulations on different sources of data was to compensate for the limitations related to any one of them, and to identify a larger set of issues. In addition, the use of the common simulation framework [WP02/025] developed within IAPA Phase I helped to validate the ACAS / ASAS interaction trends identified with each source of data.

4.1.2.2. Similar methodology based on various data-oriented studies had already been followed during the ACAS / RVSM interaction study [ACA3a] completed within the ACASA project. Hence, the IAPA study built upon the experience gained, and the tools developed, during this former EUROCONTROL ACAS Analysis project.

#### **4.1.3. Study of the ACAS / ASAS interaction using the ASAS simplified model**

4.1.3.1. The ASAS simulations conducted within the three first studies, i.e. those based on the ASAS encounter model (WP06), on modified radar data (WP07) and on flight plan data (WP08), were enabled by the simplified model of the ASAS application [WP03/020] developed during IAPA Phase I. Consequently, these studies provided comparable results despite their specific features, which were as follows:



- Both the WP06 and WP07 studies dealt with ASAS encounters with or without a required manoeuvre to preserve ASAS separation (i.e. active or passive ASAS interventions), whereas the WP08 study focused on ASAS encounters including either a “pass behind” or “pass in-front” lateral manoeuvre.
  - All three studies investigated the demanding ASAS separation minimum of 4 NM. Further, the WP08 study performed a specific sensitivity analysis of the ACAS / ASAS interaction depending on that separation minimum.
  - Both the WP06 and WP08 studies used the wobulation process developed within IAPA to introduce RNP-1 and RVSM realistic variations in the aircraft trajectories. Further, the WP08 study made a specific analysis of the ACAS / ASAS interaction with and without wobulations.
  - Finally, the WP06 and WP07 studies performed a comparative analysis of the interaction with ACAS between ASAS and ATM. This had not been possible within the WP08 study based on flight plan data, due to the lack of ATC modelling within the simulations.
- 4.1.3.2. All three studies investigated nominal ASAS operations. Indeed, the “perfect” modelling of the ASAS application implemented within the WP03 simplified model, and the resulting large HMD values at the closest point of approach, did not allow the direct assessment of ACAS safety performance.
- 4.1.4. The specific case of the study based on real-time simulation data
- 4.1.4.1. The study based on real-time simulation data (WP09) provided a complementary insight into the potential ACAS / ASAS interaction issues during nominal ASAS operations. Unlike the previous studies, it has not been possible to specifically address the ASAS application selected for further investigation within IAPA. Instead, the study dealt with various types of ASAS operations for which real-time simulation data were available.
- 4.1.4.2. The main advantage expected from real-time simulations was the ability to take into account the behaviour of air traffic controllers. Of course, due to the training issues related to each new improvement like ASAS, the real time simulations would not necessarily reflect the precise actual controllers’ behaviour in future ASAS operations.
- 4.1.4.3. An anticipated limitation of real-time simulations was that they represent only a few hours of ATC, and specific ATC sectors, due to the expensive cost of such simulations. Furthermore, due to the simplified flight trajectories used in simulations, the introduction of trajectory deviations was required in order to obtain more realistic aircraft trajectories for the ACAS simulations. This was done using the same wobulation process used in the WP06 and WP08 studies.
- 4.1.5. The remainder of this chapter first introduces the three IAPA studies that used the common IAPA framework, i.e. those based on modified radar data (WP07), on the ASAS encounter model (WP06) and on flight plan data (WP08). Then, their consolidated results are presented and compared whenever possible. Finally, the specific study based on real-time simulation data (WP09) is described.
- 4.1.6. Further details on each of these data-oriented studies can be found in [WP07/103], [WP06/108], [WP08/104] and [WP09/072] respectively.

## 4.2. Study based on modified radar data

### 4.2.1. Scope and approach

4.2.1.1. The ACAS / ASAS interaction study performed in Work Package 7 of the IAPA project was based on European radar data. The approach consisted of replacing, where appropriate, the ATC intervention observed in the radar data by the expected effects of the selected ASAS application, i.e. the ASAS lateral crossing procedure.

4.2.1.2. The overall process used to derive ASAS encounters from a set of (real) encounters extracted from radar data recordings is summarised in the following figure:

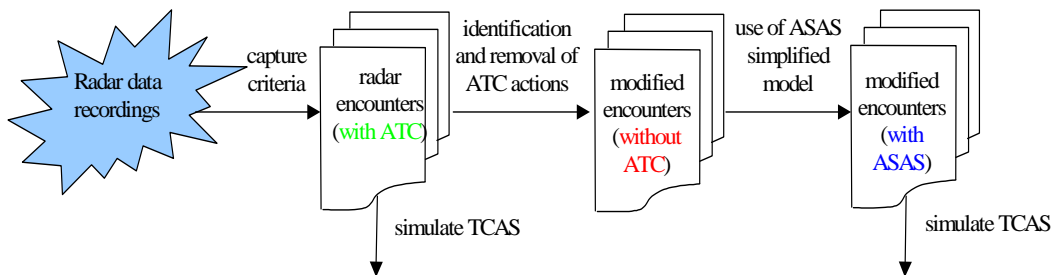


Figure 20: Main steps for the derivation of ASAS encounters from radar data

4.2.1.3. More precisely, the derivation of ASAS encounters from modified radar data consisted of:

- the extraction of **(real) encounters from radar data recordings according to agreed capture criteria**, and the identification of radar encounters that involve aircraft with RNP-1 and RVSM MASPS compliant trajectories;
- the selection of relevant radar encounters based on the type of separation provided by ATC and the crossing status of the encounters. In the context of an in-depth investigation of the ASAS lateral crossing procedure, this step was focused on the selection of **appropriate horizontal crossing encounters with an ATC intervention** that ensures aircraft separation;
- the identification and removal of **horizontal and vertical manoeuvres likely to result from an ATC intervention** [WP07/078] (cf. section 2.4.3 for further details). The types of ATC intervention taken into account include: the tactical turn (with one or two heading alterations), the tactical level-off of an aircraft in vertical evolution, the tactical flight level change on an aircraft in level flight, and the delayed descent/climb<sup>9</sup> for an aircraft in level flight.

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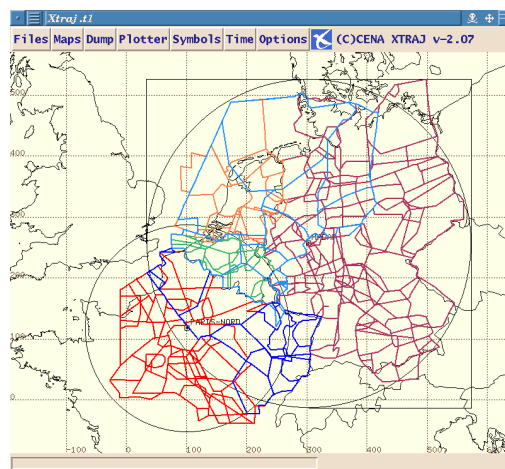
<sup>9</sup> This specific type of ATC intervention (only dealt with within the WP07 study) has been arbitrarily removed by translating the delayed descent/climb earlier in time depending on the altitude. It represented about 17% of the horizontal crossing encounters with an ATC intervention extracted from the radar data.

- the simulation of the **nominal effect of the ASAS lateral crossing application**, either a “pass behind” or a “pass in-front” procedure, using the simplified model of the ASAS application [WP03/020] developed during the Phase I of the IAPA project; and
- executing and analysing **ACAS simulations** performed on the ASAS encounters derived from the radar data, as well as the original horizontal crossing encounters with an ATC intervention, for comparison purposes. This step was supported by the [OSCAR] test bench, as well as the set of ACAS / ASAS interaction indicators identified within the IAPA simulation framework defined during Phase I.

4.2.1.4. It should be noted that no specific removal of observable pilot reaction to actual ACAS alerts was performed. However, this might have indirectly been the case when removing ATC intervention (e.g. the removal of a level-off manoeuvre implies the removal of any ACAS responses during this manoeuvre). This limitation is considered acceptable within the scope of the WP07 study since the ACAS responses observable in the radar encounters do not normally prevent the issuance of ACAS alerts in the simulations, although this may lead to an underestimation of these alerts during ATM encounters.

#### 4.2.2. Description of the original radar encounter set

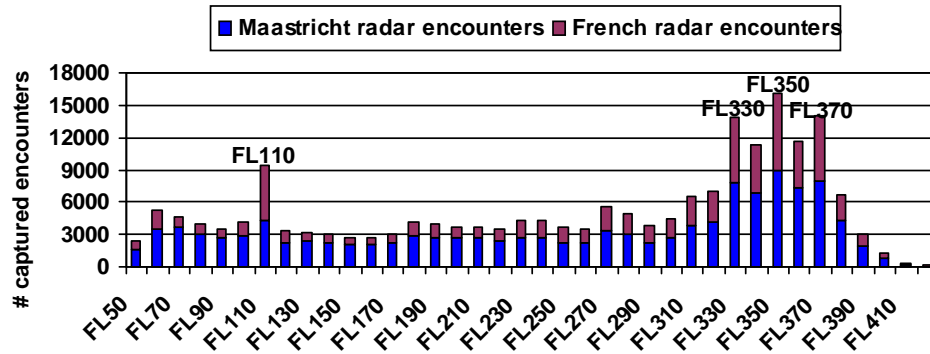
4.2.2.1. A total amount of **ten days of European radar data recordings** representing 67,713 flight-hours was collected and processed from two distinct sources of radar data, i.e. Maastricht multi-radar data and French mono-radar data. Hence, the overall radar data coverage encompassed the control area of various ATC units in the European core area and the amount of radar data was estimated to represent about 11,236 sector-hours.



**Figure 21: Overview of ATC sectors in the European radar data coverage**

4.2.2.2. The processing of the European radar data captured encounters that correspond to tactical conflicts from an ATC perspective. It resulted in the extraction of 196,412 radar encounters, i.e. on average about three encounters captured per flight hour which seems operationally realistic.

4.2.2.3. As illustrated in the following figure, a majority of encounters occur at high altitude:



**Figure 22: Altitude distribution of the encounters captured from European radar data**

Note: In the figure, the altitude of an encounter corresponds to that of the higher aircraft at CPA.

4.2.2.4. The peak of captured encounters at FL110 can be explained by the well known “hot-spots” linked to arrival and departure conflicts in TMAs. Other peaks of captured encounters occur within the most frequently used FL within the European RVSM airspace<sup>10</sup> observable within the European radar data.

4.2.2.5. These radar encounters included not only horizontal crossing encounters (i.e. with relative tracks between 30 and 150 degrees), but also head-on encounters (about 25%) and some slow convergence encounters (about 20%). Further, a small proportion of the encounters corresponded to unresolved conflicts with loss of ATC separation.

#### 4.2.3. Description of the modified radar encounter sets

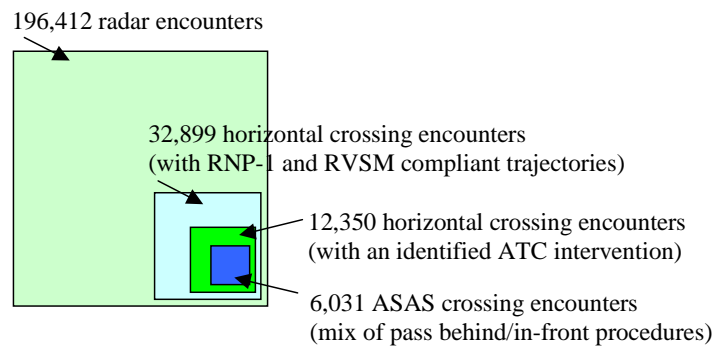
4.2.3.1. In accordance with the IAPA common simulation framework, three distinct sets of ASAS encounters were derived from the radar data, which correspond to all three ASAS scenarios under investigation:

- 6,031 ASAS encounters with a mix of “**pass behind/in-front**” procedures,
- 5,805 ASAS encounters with only “**pass behind**” procedures,
- 5,678 ASAS encounters with only “**pass in-front**” procedures.

4.2.3.2. These ASAS encounters resulted from the modification of the horizontal crossing encounters extracted from the European radar data, which initially included at least one manoeuvre identified as an ATC intervention to preserve aircraft separation.

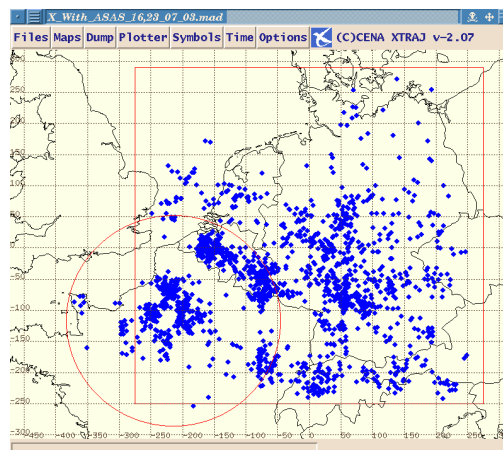
<sup>10</sup> The unexpected peaks of encounters at odd flight levels have been checked against the Requested FLs (RFL) recorded in CFMU data for the period corresponding to the European radar data. Only the peak of encounters at FL370 could not be correlated to a peak of flight plans with that RFL.

- 4.2.3.3. As shown in the following figure, the amount of ASAS encounters was far lower than the amount of encounters initially captured from the European radar data:



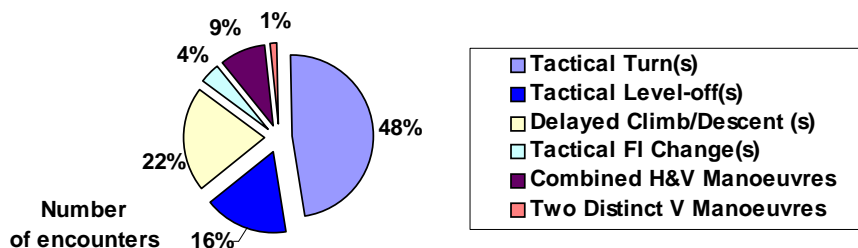
**Figure 23: Amount of ASAS encounters derived from the European radar data**

- 4.2.3.4. This is linked to the study assumption to limit the investigation to the horizontal crossing encounters with an ATC intervention, as well as the limitations set up for the use of the simplified model of the ASAS application developed within IAPA. Further, the amount of radar encounters initially captured was itself highly dependent on the look-head time of the capture criteria used for the extraction of real encounters from the radar data.
- 4.2.3.5. As a consequence, the mean likelihood of ASAS lateral crossing encounters derived from the radar data processing should be treated with care. This mean likelihood was roughly estimated for the European core area to be **at least one ASAS lateral crossing procedure every two hours per sector, and possibly up to three times per hour and per sector, and between one to five times per ten flight hours.**
- 4.2.3.6. As shown in the following figure, the ASAS encounters derived from the radar data are located at crossing points between major traffic flows in the Europe core area. This is particularly the case for the busy corridor between London and Frankfurt, via Belgium and Luxembourg, as well as over the Paris TMA.



**Figure 24 : Geographical distribution of ASAS encounters derived from the European radar data**

- 4.2.3.7. Further, **a great majority of the ASAS encounters are located at high altitudes** (i.e. about 67% above FL295 and about 22% between FL215 and FL295) whatever the ASAS scenario.
- 4.2.3.8. The following figure provides the distribution of ATC intervention identified in the radar encounters corresponding to the ASAS encounters with the “Mix of pass behind/in-front” lateral crossing procedure. Similar distribution also applies to the other ASAS scenarios, i.e. the “Pass behind” and the “Pass in-front” scenarios.



**Figure 25: Distribution of the ATC interventions in the unmodified radar encounters (Mix of “Pass behind/in-front” ASAS scenario)**

Note: Readers are reminded that only encounters with an ATC intervention have been considered as candidate ASAS encounters.

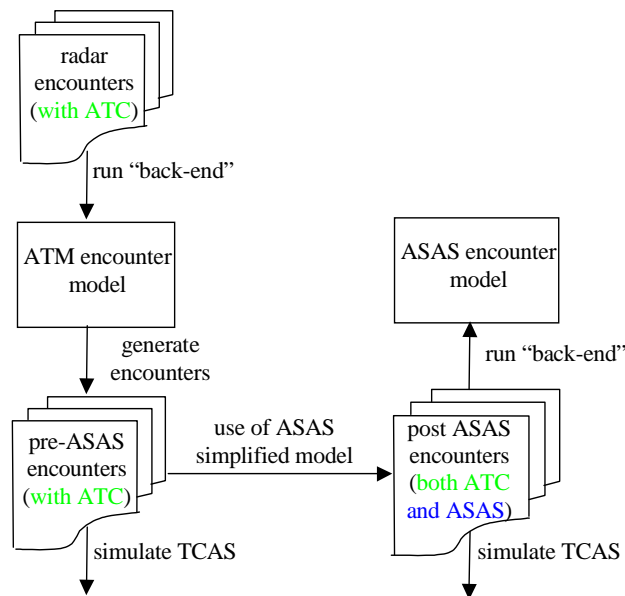
- 4.2.3.9. As shown, a majority of the ASAS encounters (52%) derive from radar encounters with at least one vertical manoeuvre identified as an ATC tactical intervention to ensure aircraft separation. Another large proportion (48%) of the ASAS encounters derive from radar encounters with one or two tactical turns issued by ATC.
- 4.2.3.10. Further, it should be noted that the great majority of the ASAS encounters (between 80% and 85% depending on the scenario) correspond to an ASAS passive intervention, i.e. encounters without any required manoeuvre to preserve ASAS separation.

### **4.3. Study based on ASAS encounter model**

#### **4.3.1. Scope and approach**

- 4.3.1.1. The ACAS / ASAS interaction study performed in Work Package 6 of the IAPA project was based on the ASAS encounter model developed for the IAPA purposes (cf. section 2.5). The encounter model approach allows an arbitrarily large set of encounters to be generated, which are representative of the airspace environment dealt with by the model.
- 4.3.1.2. The development of the ASAS encounter model built upon that of the ATM encounter model, which describes the current ATM operations (prior to the introduction of ASAS procedures). In line with the project scope and objectives, the ASAS encounter model corresponds to a future ATM environment in which the selected ASAS application, i.e. the ASAS lateral crossing procedure, is used where appropriate.

4.3.1.3. The overall process aiming at developing both the ATM and ASAS encounter models is shown in following figure:



**Figure 26: Main steps for the derivation the ASAS encounter model**

4.3.1.4. More precisely, the various stages in their development were as follows:

- the set of real encounters (with possible ATC intervention included) extracted from the European radar data as part of the WP07 study was processed by the back-end to produce **the tables of the ATM encounter model**;
- the ATM encounter model was used to generate a large set of artificial encounters with modelled ATC interventions (the **pre-ASAS ATM encounters**);
- where appropriate, the ASAS procedure was applied to the pre-ASAS encounters to produce a large set of encounters (the **post ASAS ATM encounters**), consisting of encounters with either ASAS intervention or modelled ATC interventions depending on whether or not the ASAS procedure was applicable;
- then, the post ASAS ATM encounters were processed by the back-end to produce **tables of the post ASAS ATM encounter model, i.e. the ASAS encounter model**;
- the set of pre-ASAS ATM encounters was used in ACAS simulations to determine the performance of ACAS in the current ATM environment, and the set of post ASAS ATM encounters was used in ACAS simulations to determine the performance of ACAS in an ATM environment that incorporates ASAS procedures.

4.3.1.5. The production of the post ASAS encounters from the pre-ASAS encounters followed the same approach as that adopted in the study based on modified radar data (WP07) including:

- the selection of horizontal crossing encounters with modelled ATC intervention providing ATC separation;
- the identification and removal of **horizontal and vertical manoeuvres modelling an ATC intervention** [WP05/091] (cf. section 2.4.3 for further details). The types of ATC intervention taken into account include: the tactical turn (with two heading alterations<sup>11</sup>), the tactical level-off of an aircraft in vertical evolution, the tactical flight level change on an aircraft in level flight, and the rate reversing manoeuvres<sup>12</sup> of aircraft in vertical evolution;
- the simulation of ASAS lateral crossing procedures using the **simplified model of the ASAS application** [WP03/020] developed during IAPA Phase I. Both active and passive ASAS interventions were included in the post ASAS encounters.
- finally, the ASAS encounter trajectories were wobbled, i.e. RNP-1 and RVSM MASPS compliant wobbulations were added, to be more representative of real aircraft trajectories.

4.3.1.6. To speed up the work while dealing with a larger set of encounters, this overall process had been conducted in parallel by two partners of the IAPA project. In both cases, the production of the pre-ASAS and post ASAS encounters was performed using the same set of tools developed by for the IAPA purposes. The ACAS simulations were performed by each organisation using its own simulation facility, i.e. InCas at the EUROCONTROL Experimental Centre and the . Finally, the analysis of the ACAS simulation results was supported by the set of ACAS / ASAS interaction indicators identified within the IAPA simulation framework defined during Phase I.

4.3.1.7. Where directly comparable simulations have been carried out, the ACAS simulation results obtained by the two IAPA partners were in agreement. Hence, the results from both sets of simulations have been combined (where appropriate) and scaled (where necessary).

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<sup>11</sup> Due to the encounter model characteristics which include no more than two turns in each aircraft trajectory, the modelling of horizontal manoeuvres was limited. Further, the only options for removing such manoeuvres were to extend either forward the first segment, or backward the last segment, observed in the generated encounters with two turns.

<sup>12</sup> These types of vertical manoeuvres represented less than 1% of the encounters generated from the ATM encounter model.



#### 4.3.2. Description of the encounter data sets

- 4.3.2.1. Two sets of approximately 400,000 pre-ASAS encounters, equivalent to  $1.8 \times 10^5$  flight-hours each, were then generated respectively by each IAPA partner. Each set was passed through the process described earlier to generate post ASAS encounters. One partner processing focussed on the “mix of pass behind/in-front” scenario, whereas the other partner addressed all three ASAS scenarios defined in the IAPA simulation framework.
- 4.3.2.2. The former simulations resulted in 10,377 ASAS encounters with a mix of “**pass behind/in-front**” procedures simulated when necessary to comply with the separation minimum of 4 NM and other encounters left unchanged (with any manoeuvre preserving ATC separation having been removed) to simulate passive ASAS interventions;
- 4.3.2.3. Hence, the ASAS lateral crossing procedure proved to be applicable in only about 3% of the encounters generated from the ATM encounter model. This set of ASAS encounters, together with the remaining (97%) unmodified encounters for which the ASAS procedure was not applicable, constitute the post-ASAS encounter set used to build the ASAS encounter model:

Post-ASAS ATM encounter set		Proportion of the pre-ASAS ATM encounters	
<b>Unmodified ATM encounters</b>	Inappropriate horizontal and separation status (i.e. losses of ATC separation and/or non-crossing encounters)	62%	97%
	Appropriate horizontal crossings, but without an identified ATC intervention	34%	
	Appropriate horizontal crossings with an identified ATC intervention, but ASAS procedure not applicable	1%	
<b>Actual ASAS encounters</b>	With a “pass behind/in-front” manoeuvre	1%	3%
	No manoeuvre simulated	2%	

**Table 6: Post-ASAS encounter set used to build the ASAS encounter model**

- 4.3.2.4. The latter simulations (which explored the three ASAS scenarios defined within the IAPA simulation framework) resulted in:
- 10,783 ASAS encounters with a mix of “**pass behind/in-front**” procedures simulated when necessary to comply with the separation minimum of 4 NM and other encounters left unchanged (with any manoeuvre preserving ATC separation being removed) to simulate passive ASAS interventions;
  - 10,583 ASAS encounters with only “**pass behind**” procedures simulated when necessary and passive ASAS intervention being kept otherwise,
  - 10,190 ASAS encounters with only “**pass in-front**” procedures simulated when necessary and passive ASAS intervention being kept otherwise.

4.3.2.5. The first of these three sub-set of ASAS encounters complemented the initial sub-set of ASAS encounters dealing with the “**mix of pass behind/in-front**” scenario, which was hence the scenario most represented in terms of encounters.

#### 4.3.3. Main characteristics of the ATM and ASAS encounter models

4.3.3.1. The ATM encounter model describes the encounter characteristics as observed in a set of real (147,250<sup>13</sup>) encounters collected in European airspace and representing 67,713 flight-hours (cf. section 4.2.2 for further details).

4.3.3.2. The proportion of encounters, by altitude layer, for both the ATM and the ASAS encounter models (the distribution is the same) is shown in the final column of the following table:

Layer	Boundaries	ASAS-applicable encounters	All encounters
2	5000 ft - FL135	14.7%	12.6%
3	FL135 - FL215	19.9%	14.0%
4	FL215 - FL295	21.4%	16.6%
5	FL295 - FL415	44.0%	56.8%
		100%	100%

**Table 7: Proportion of altitude layers in the ATM and ASAS encounter models**

4.3.3.3. As previously mentioned, the ATM encounter model and the ASAS encounter model reproduce the characteristics of all encounters in an airspace where a small proportion (about 3%) of them involve, or potentially involve, an ASAS lateral crossing procedure. Focussing on that small proportion of encounters gives the distribution shown in the first column of data in Table 7.

4.3.3.4. Since only a small proportion of encounters in the ATM model are affected by the ASAS procedure the tables for the full ATM encounter model and ASAS encounter model are very similar. However, again focussing on the small proportion of encounters in which the ASAS procedure is applicable in the ATM encounter model and in which the ACAS procedure is deployed in the ASAS encounter model we can see differences in the characteristics of the encounters.

4.3.3.5. The most notable difference is the proportion of level-level and non level-level encounters which is shown in the following table:

<sup>13</sup> When processing the whole set of 196,412 radar encounters extracted within the WP07 study, 147,250 encounters (75.0%) were suitable for populating the ATM encounter model tables. The other encounters were rejected as being comprised of two inappropriate aircraft trajectories, or because the aircraft separation at closest approach was outside the range specified within the encounter model (i.e. 10 NM in the horizontal plane and 2,000 ft in the vertical dimension).

	ASAS encounters		ASAS-applicable encounters	
	level-level	non level-level	level-level	non level-level
Layer 2	0.056	0.944	0.107	0.893
Layer 3	0.061	0.939	0.088	0.912
Layer 4	0.102	0.898	0.127	0.873
Layer 5	0.329	0.671	0.194	0.806
all layers	0.185	0.815	0.146	0.854

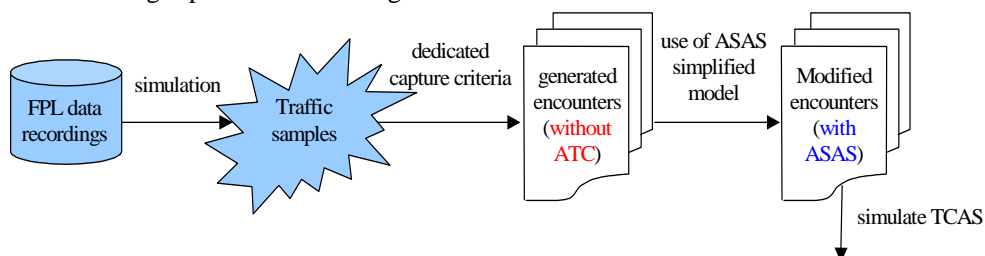
**Table 8: Proportion of level-level and non level-level encounters in the ASAS encounters and the original ATM encounters**

- 4.3.3.6. At low altitude, the proportion of level-level encounters decreases when the ASAS procedure is used – this corresponds to encounters in which ATC preserved separation using a level-off; in the ASAS encounter model, this ATC intervention has been removed (i.e. the aircraft continue climbing or descending) and instead separation is provided by the ASAS procedure.
- 4.3.3.7. At high altitude, the proportion of level-level encounters increases when the ASAS procedure is used – this corresponds to encounters in which ATC preserved separation by using a level-change; in the ASAS encounter model, this ATC intervention has been removed (i.e. the aircraft continues level) and instead separation is provided by the ASAS procedure.

#### 4.4. Study based on flight-plan simulation data

##### 4.4.1. Scope and approach

- 4.4.1.1. The ACAS / ASAS interaction study performed in Work Package 8 of the IAPA project was based on European flight plan data. The following figure summarises the main steps performed to generate ASAS encounters from a set of encounters derived from flight plan data recordings.



**Figure 27: Main steps for the derivation of ASAS encounters from flight plan data**

- 4.4.1.2. More precisely, the WP08 study based on flight plan data consisted of:

- the **generation of traffic samples**, using a fast-time simulator working on flight plan data, and the capture of potential encounters suitable for an ASAS lateral crossing procedure as defined within the IAPA OED [WP01/024];

- the simulation of the **nominal effects of the ASAS lateral crossing application**, either a “pass behind” or a “pass in-front” procedure, using the simplified model of the ASAS application [WP03/020] developed during the Phase I of the IAPA project; and
- the execution and analysis of **ACAS simulations** performed on the ASAS encounters derived from the fast-time data, as well as the study of the influence of the applicable ASAS separation minimum on the interaction with ACAS. The study has also been an opportunity to gain some insight into the behaviour of the TCAS II logic version 7.0 on ASAS encounters in which no wobbulations had been introduced.

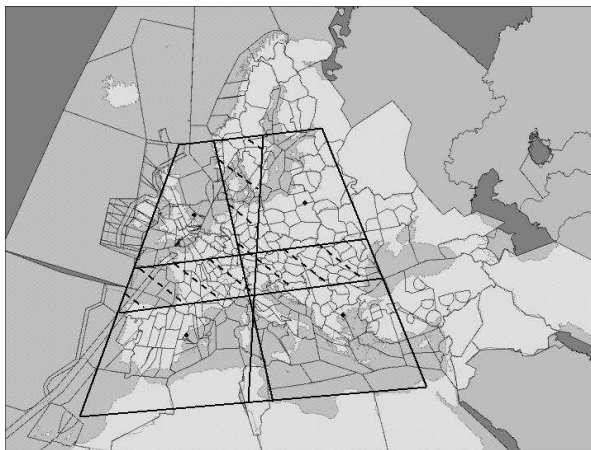
This step was supported by the [OSCAR] test bench, as well as the set of ACAS / ASAS interaction indicators identified within the IAPA simulation framework defined during Phase I [WP02/025].

4.4.1.3. It should be noted that no ATC intervention was simulated in the traffic samples , thus preventing the study of ACAS / ASAS interaction in a full ATM environment within the study. This was justified since the actual ATC interventions, and the comparison with ASAS operations, were investigated within the study based on modified radar data (WP07).

#### 4.4.2. Description of the ASAS encounters derived from flight plan data

4.4.2.1. A total amount of **11 days of European flight plans from the CFMU** (Central Flow Management Unit) were collected and processed. The (292,549) flight plans thus simulated are related to the whole ECAC area, therefore encompassing the control area of various ATC units, notably in the European core area but not restricted to that area.

4.4.2.2. Due to simulation constraints, each day of flight plans was simulated in four steps, using a different projection centre and encounter detection zone each time. The following figure provides an overview of the resulting ECAC area coverage (i.e. the four quadrants) obtained in the study:



**Figure 28: Overview of encounter detection zones in the study based on flight plan data**

Note: Due to projection constraints, there is some overlap between the four quadrants (shown in diagonal dash lines on the above figure). For those encounters that were consequently captured twice, only one occurrence was used in the study.

4.4.2.3. In accordance with the IAPA simulation framework, **three distinct sets of ASAS encounters were derived from the fast-time data**, which correspond to all three ASAS scenarios under investigation:

- 8,247 ASAS encounters with a mix of “**pass behind/in-front**” procedures,
- 6,393 ASAS encounters with only “**pass behind**” procedures, and
- 5,551 ASAS encounters with only “**pass in-front**” procedures.

4.4.2.4. These ASAS encounters resulted from the capture of horizontal crossing encounters extracted from European flight plan data, which met a set of capture criteria based on approach angle, and both horizontal and vertical separation.

4.4.2.5. Further, to support a sensitivity analysis of the interaction with ACAS depending on the applicable separation minimum during ASAS operations, additional ASAS encounter sets have been produced using different ASAS separation minima.

4.4.2.6. The following figure presents the layer distribution of the ASAS encounters among the different scenarios. As shown, the proportion of encounters for a given layer is fairly constant, which suggests that the applicability for an ASAS lateral crossing procedure does not depend strongly on the scenario parameters.

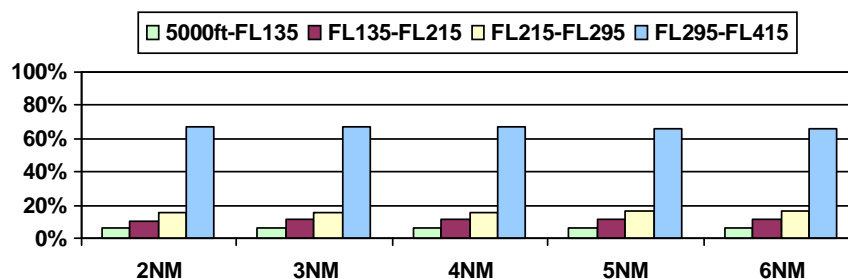


Figure 29: Altitude distribution of the ASAS encounters derived from flight plan data (“Mix of pass behind/in-front” scenarios)

## 4.5. Main ACAS simulation results for the common ASAS scenarios

### 4.5.1. General

4.5.1.1. The results of the ACAS simulations performed in all three investigated ASAS scenarios within the WP06, WP07 and WP08 studies confirmed the **potential interaction that may exist between ACAS and ASAS within the demanding assumptions taken within IAPA** (i.e. a minimum horizontal separation value of 4 NM).

4.5.1.2. The following table summarises the various ACAS / ASAS interaction areas investigated within the all three studies, as well as the amount of scenarios simulated. As shown, all the areas were investigated on the basis of the three ASAS scenarios defined within the IAPA simulation framework [WP02/025] in at least one study.

Number of scenarios per study objectives	Study based on ASAS encounter model	Study based on modified radar data	Study based on flight plan data
Effect on ASAS performance	3	3	3
Effect on pilot acceptance	3	3	3
ACAS / ASAS compatibility	3	3	3
Influence of wobbulations	N/A	N/A	3
Influence of the separation minimum	N/A	N/A	5×3
Comparison between ASAS and ATM	3	3	N/A

**Table 9: ACAS / ASAS interaction areas investigated in the WP06, WP07 and WP08 studies**

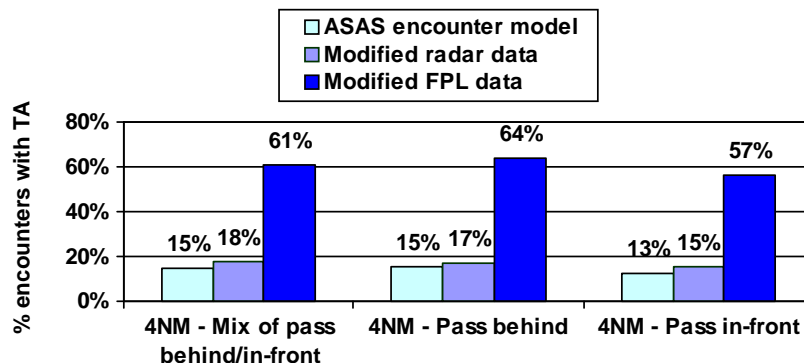
4.5.1.3. The results obtained through each study are presented hereafter. Whenever possible, result comparison is made to highlight the main trends identified in terms of potential ACAS / ASAS interaction.

#### 4.5.2. ACAS / ASAS interaction effect on ASAS performance

4.5.2.1. On one hand, the studies based on the ASAS encounter model (WP06) and on modified radar data (WP07) provide similar results with a ratio of ASAS procedures triggering at least one TA varying between 13% and 18%, depending on the scenario and the source of data. It should be noted that both studies are characterized by a great amount of ASAS encounters (about 90% in the former and about 80% in the latter) without any manoeuvre required to preserve the 4 NM separation minimum.

4.5.2.2. On the other hand, the study based on flight plan data (WP08), which focused on ASAS encounters requiring a manoeuvre to ensure ASAS separation, resulted in a much more significant likelihood of TAs, i.e. between 57% and 64% depending on the ASAS scenario.

4.5.2.3. The previous results are illustrated in the following figure, which presents the likelihood of ACAS traffic advisories during ASAS lateral crossing procedures observed within the various studies:



**Figure 30: Likelihood of undesirable TAs in the ASAS encounters**

- 4.5.2.4. In fact, when looking at the reduced set of ASAS encounters which include a “pass behind” or “pass in-front” manoeuvre in the WP06 and WP07 studies, a TA is received in just under or over half of them depending on the source of data (i.e. between 42% and 67%, depending on the ASAS scenario), which confirms the trend identified within the WP08 study.
- 4.5.2.5. Further, when comparing the last two scenarios with a single type of ASAS manoeuvre, all three studies resulted in a slightly increased likelihood of alerts for the “pass behind” manoeuvres compared to the “pass in-front” manoeuvres as already demonstrated in the IAPA case study (cf. section 3.9).

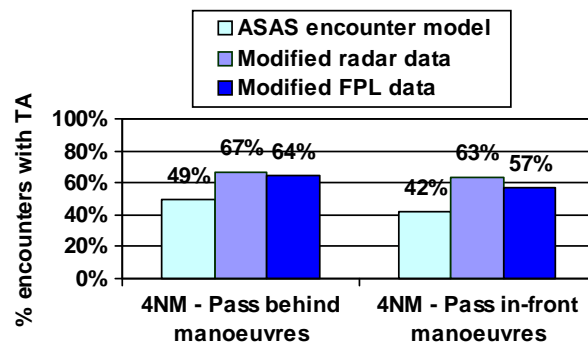


Figure 31: Likelihood of undesirable TAs during ASAS “pass behind/in-front” manoeuvres

- 4.5.2.6. With regard to the likelihood of ACAS resolution advisories, all three studies provided comparable results with on average **just under 1% of the ASAS procedures triggering at least one RA**, whatever the scenario. Nevertheless, this proportion varies noticeably depending on the ASAS encounters, and particularly whether or not an ASAS manoeuvre is required to ensure the minimum separation value of 4 NM at CPA.

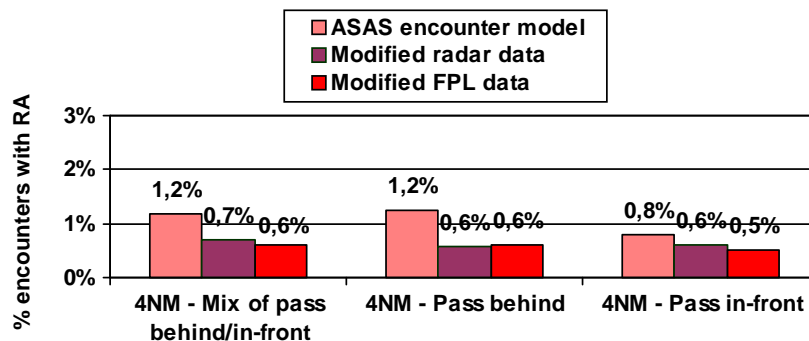


Figure 32: Likelihood of undesirable RAs in the ASAS encounters

- 4.5.2.7. As expected from the use of a “perfect” modelling of the ASAS application, **all the ACAS alerts triggered during the simulations correspond to “undesirable” alerts**, i.e. alerts triggered even though the applicable ASAS separation (i.e. 4 NM horizontally and 1,000 ft vertically) is not infringed.

4.5.2.8. The issuance of such undesirable ACAS alerts during nominal ASAS operations is likely to affect the performance of the ASAS procedures, and therefore, their expected benefits.

#### 4.5.3. ACAS / ASAS interaction effect on pilot acceptance

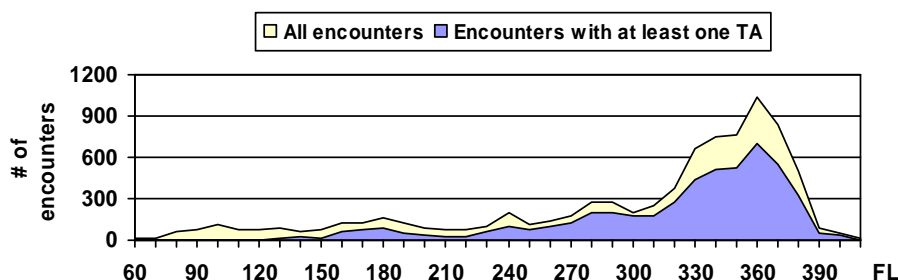
4.5.3.1. From a pilot's point of view, the issuance of ACAS traffic advisories during an ASAS lateral crossing procedure is likely to be considered as disruptive, particularly for the flight crew who is instructed to provide ASAS separation (regardless of whether or not a manoeuvre is required to achieve that separation).

4.5.3.2. Taking into account the frequency of the ASAS lateral crossing procedure estimated within the WP07 study based on modified radar data, **the mean likelihood of undesirable TAs during ASAS operations was estimated as up to one per ten flight hours**, regardless of any other TAs that may occur independently of the ASAS lateral crossing procedure.

4.5.3.3. Further, **the likelihood of TAs during the ASAS lateral crossing procedure appeared to be greater at high altitudes**, i.e. within sensitivity level 7 of the TCAS II logic version 7.0. As an example, about 96% of the ASAS encounters derived from the radar data which triggered at least one TA occur above FL200, whereas the ASAS encounters above that altitude correspond to about 92% of all encounters derived from the radar data. A similar trend was observed whatever the source of data used for the simulations.

4.5.3.4. As an illustration, the following figure presents the altitude distribution of ASAS encounters derived from flight plan data (with the wobbulations added) together with that of encounters which triggered at least one TA. As shown, the greater the altitude, the greater the proportion of encounters triggering a ACAS traffic advisory.

Note: In the figure, the altitude of the encounter is defined as the altitude of the higher aircraft at the Closest Point of Approach.



**Figure 33: Altitude distribution of ASAS encounters derived from flight plan data with and without TA (“Mix of pass behind/in-front” scenario)**

4.5.3.5. Whatever the source of data used for the simulations, the great majority of the TAs were triggered within ASAS encounters where an ASAS manoeuvre was required to achieve the applicable separation minimum. The particular interaction between the demanding separation minimum of 4 NM and the ACAS logic is illustrated in the following figure which presents the likelihood of TAs depending on the horizontal separation achieved at CPA within the ASAS encounters derived from radar data.



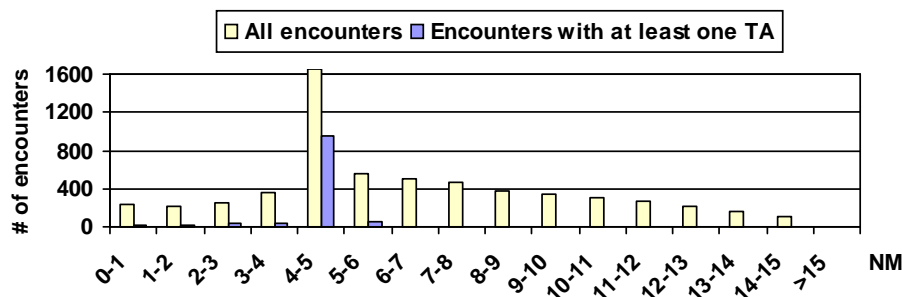


Figure 34: HMD distribution of ASAS encounters derived from radar data with and without TA (“Mix of pass behind/in-front” scenario)

- 4.5.3.6. In all cases where an ASAS lateral crossing procedure did trigger a ACAS traffic advisory, the TA was received in the “heading phase” of the manoeuvre and not in the “resume phase”.
- 4.5.3.7. Finally, depending on the source of data and the ASAS scenario, **from 1% to 3% of the ACAS traffic advisories observed in the simulations were repetitive alerts.** Under these circumstances the “traffic, traffic” enunciation would be given more than once on the flight deck against the same intruder: the other aircraft involved in the ASAS procedure.
- 4.5.3.8. These results are very dependent on the quality of the trajectories used in simulation. For instance, alerts were almost nonexistent on the ASAS encounters derived from the flight plan data (before adding the wobbulations). Consequently, although such situations could be expected to be very infrequent with perfect CNS performance, they are likely to occur during actual ASAS operations with real equipment.
- 4.5.4. ACAS / ASAS compatibility
- 4.5.4.1. From an ATC perspective, the issuance of disruptive ACAS resolution advisories during ASAS lateral crossing procedures is likely to be considered as a lack of compatibility between the separation function provided by ASAS and the collision avoidance function devoted to ACAS.
- 4.5.4.2. Taking into account the frequency of the ASAS lateral crossing procedure estimated within the WP07 study based on modified radar data, **the mean likelihood of undesirable RAs during nominal ASAS operations was estimated to one per sector every 6 days**, regardless of any other RAs that may occur independently of the ASAS lateral crossing procedure.
- 4.5.4.3. It should be noted that almost all the ASAS encounters that caused an RA (i.e. about 92% within the WP06 study and 100% of the encounters within the WP07 and WP08 studies) occur above FL200, i.e. at an altitude where the ACAS logic operates with sensitivity level 7, and with an HMD between 4 NM and 5 NM at CPA, which correspond to the most numerous ASAS encounters whatever the ASAS scenario and the source of data.

- 4.5.4.4. The simulation results show that the issuance of the RAs is sensitive to the quality of the aircraft trajectories used in the simulations. As an example, the following figure shows the proportion of RAs that have been observed in the ASAS encounters derived from flight plan data with and without wobblations. As shown, whatever the ASAS scenario, the alert rate is multiplied by a factor of up to three when RNP-1 and RVSM compliant deviations are introduced in the trajectories.

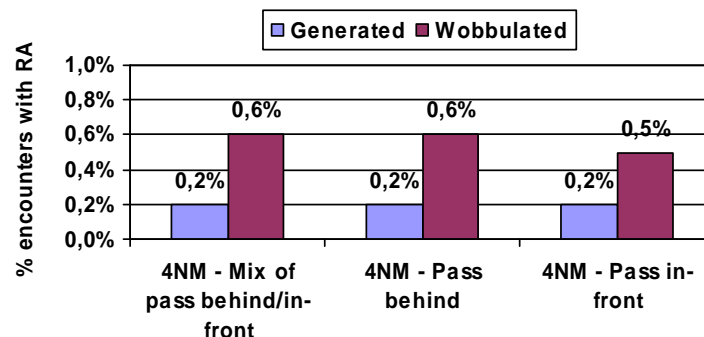


Figure 35: Likelihood of RAs in the ASAS encounters with and without wobblations

- 4.5.4.5. Further, in all three studies, the RAs triggered during the ASAS procedures were transitory alerts of small duration (i.e. between 8 and 13 seconds on average, depending on the ASAS scenario and the source of data). This feature is illustrated in the following figure, which shows the mean RA duration observed within the ASAS encounters derived from the European radar data, with respect to the time of the CPA (T<sub>cpa</sub>).
- 4.5.4.6. As shown in the figure, these transitory RAs are also characterised by the issuance of an early “Clear of Conflict” (CoC) generated while the aircraft are still converging.

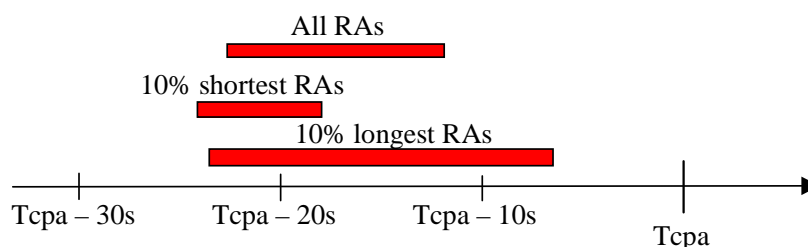


Figure 36: Illustration of RAs duration in the ASAS encounters derived from radar data

Note: These alert durations should be compared with the nominal TCAS II logic version 7.0 time thresholds for RAs, which is 35 seconds at high altitudes, possibly reduced to 25 seconds if the ‘Vertical Threshold Test’ (VTT) applies (cf. Appendix B for further details).

- 4.5.4.7. A specific analysis of the TCAS II logic version 7 in such situations was performed within the (WP08) study based on flight plan data, which confirms that alerts result from situations in which the circumstances of the encounter prevent the ‘Miss Distance Filter’ of the TCAS II logic from operating effectively.

Note: To avoid any side-effect linked to the TCAS surveillance function, this analysis was performed on the set of ASAS encounters derived from flight plan data before adding the wobbulations.

4.5.4.8. All the ASAS encounters looked at roughly follow the same scenario:

- At some point prior to the CPA, own aircraft is seen by the ACAS logic as manoeuvring, thus disabling the MDF and setting the HMD to a value of -1.
- Then the vertical test is passed (either because both the predicted VMD and the vertical distance are lower than ZTHR, or because TAUV becomes lower than TVTHR) and the range test is passed. As the HMD is set to -1, and is thus lower than any possible value of DMOD, the range test becomes equivalent to TAUR simply becoming lower than TRTHR. Hence, an RA is triggered.
- A few seconds later, own aircraft is no longer seen as manoeuvring, thus resetting the HMD parameter to its computed value, which is greater than DMOD because of the ASAS targeted spacing value of 4 NM.
- After 5 seconds of HMD being greater than DMOD, the range test is invalidated and the “Clear Of Conflict” is issued. As the initial RA has been issued far in advance of the CPA, the CoC advisory also occurs before the CPA.

4.5.4.9. Assuming a standard pilot reaction to the ACAS resolution advisories, these transitory RAs have a positive effect on the resulting vertical deviations. Hence, **the mean vertical deviation in response to RAs varies between 150 ft and 190 ft** depending on the ASAS scenarios and the source of data. Further, the incidence of RAs causing deviations of more than 300ft was not very high (i.e. less than 11%, 10% and 19% respectively for the WP06, WP07 and WP08 study) and none resulted in vertical deviations greater than 600 ft.

## **4.6. Sensitivity analysis depending on the applicable separation minimum**

### **4.6.1. Scope and approach**

4.6.1.1. The sensitivity of the ACAS / ASAS interaction to the separation minimum applicable during the ASAS lateral crossing procedure was explored within the study based flight plan data (WP08).

4.6.1.2. The focus was on the ASAS encounters which required a “pass behind” or a “pass in-front” manoeuvre to preserve various separation minimum values and examining the impact on the various ACAS / ASAS interaction indicators. All three ASAS scenarios defined in the IAPA simulation framework have been investigated with an applicable separation minimum ranging from 2 NM to 6 NM with 1 NM increments<sup>14</sup>.

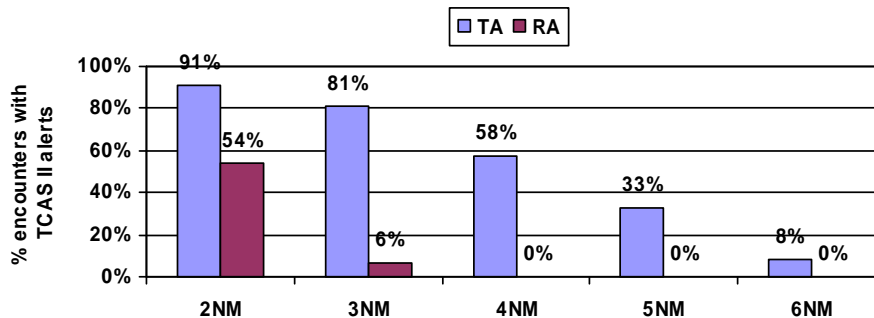
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<sup>14</sup> Although not operationally realistic (notably due to the wake vortex constraints), the 2 NM bound was investigated to confirm any trend observed below the demanding separation value of 4 NM. Further, the 6 NM bound was investigated to confirm the results of the IAPA case study [WP04/29].

4.6.1.3. It should be noted that, to avoid any side effect from the quality of the simulated trajectories, this investigation dealt only with ASAS encounters without wobbulations.

#### 4.6.2. Main results of the sensitivity analysis

4.6.2.1. The following figure presents the likelihood of ACAS alerts obtained for the “mix of pass behind/in-front” scenarios depending on the ASAS separation minimum used in the simulations.



**Figure 37: Likelihood of ACAS alerts depending on the ASAS separation minimum (“Mix of pass behind/in-front scenarios”)**

4.6.2.2. As shown, the sensitivity analysis indicated that **a minimum separation value of 7 NM was necessary to prevent TAs from being triggered** when an ASAS manoeuvre is required. Further, a minimum separation value of 5 NM was necessary to prevent the issuance of any RAs. A similar trend was observed for the two other ASAS scenarios, i.e. the “pass behind only” and the “pass in-front only” scenarios.

4.6.2.3. Whatever the scenario, all the ACAS alerts are triggered in the “heading” phase of the ASAS lateral crossing procedure (i.e. before the aircraft resume their navigation direct to track) with only one exception where the TA occurred 1s after the ‘Clear of Traffic’ advisory and where no subsequent RA was triggered.

4.6.2.4. All the RAs triggered within each of the ASAS scenarios are corrective RAs. Further, the great majority (between 93% and 96%) are positive RAs, i.e. “Climb” or “Descent” advisories, whatever the ASAS scenario.

4.6.2.5. As for the RAs whose initial advice requires that the flight crew reverse the aircraft vertical rate, they represent 6% to 9% of all the RAs depending on the scenario. Rate-reversing RAs are disruptive since the decision to reverse the vertical rate is harder to take and takes longer to implement.

### 4.7. **Comparison of the interaction with ACAS between ASAS and ATM**

#### 4.7.1. Scope and approach

4.7.1.1. The comparison of the ACAS / ASAS interaction between ATM and ASAS operations was explored within both the study based on the ASAS encounter model (WP06) and the study based on modified radar data (WP07).

4.7.1.2. A preliminary investigation of the compatibility of current ATM operations with ACAS was necessary. This was made at two distinct levels in the two IAPA studies:

- on a whole set of (about 400,000) encounters generated from the ATM encounter model, regardless of whether or not the ASAS procedure is applicable; and
- on the whole set of (12,350) horizontal crossing encounters with an ATC intervention extracted from the radar data, which constituted the candidate ASAS encounters in the WP07 study based on modified radar data.

4.7.1.3. In a second step, both studies made a comparative analysis of the interaction with ACAS observed in both the ATC and ASAS encounters. This comparison was limited to comparable sets of encounters, i.e. the set of encounters (with ASAS) where the ASAS procedure was applicable and the same subset of encounters but in their original form (without ASAS) that included the ATC intervention.

#### 4.7.2. Main ACAS simulation results for the generated ATM encounters

4.7.2.1. Taking into account the amount of flight hours represented by the generated encounters, the ACAS simulations based on the ATM encounter model resulted in about one TA every 4 flight-hours and about one RA every 20 flight hours.

4.7.2.2. These TCAS alert rates are markedly greater than those observed in real life (i.e. about one RA every 1,000 flight-hours and one RA every 40 TAs). The cause of these discrepancies is qualitatively understood and arises from limitations of the artificial encounters. Hence, the WP06 results cannot be considered as accurate estimates of absolute metrics of the interaction between ACAS and ATM.

4.7.2.3. Despite these limitations (which apply equally to the ATM encounters and the ASAS encounters), the comparative analysis performed between ASAS and ATM encounters was still considered meaningful since it was limited to comparable sets of encounters.

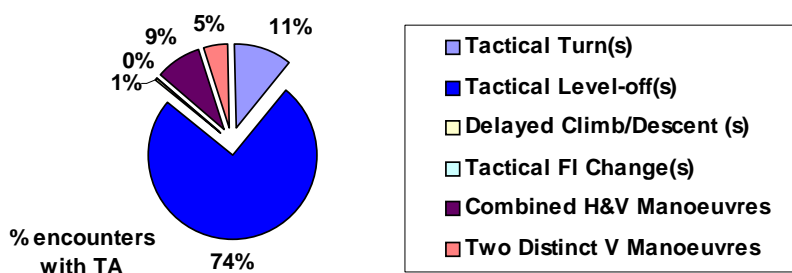
#### 4.7.3. Main ACAS simulation results for the radar horizontal crossing encounters

4.7.3.1. As previously mentioned, the investigation of ATM and ACAS compatibility within the WP07 study based on modified radar data was limited to the subset of radar encounters which correspond to horizontal crossing encounters with an actual ATC intervention. These encounters resulted in the issuance of some Traffic Advisories (in about 3% of aircraft), as well as a few Resolution Advisories (about 0.1% of aircraft).

Note: It was not possible to compute TCAS alert rates (per flight-hours) since the amount of flight hours represented by the subset of horizontal crossing encounters was not known.

4.7.3.2. No specific removal of observable pilot reaction to actual ACAS alerts was performed on the radar encounters. This may lead to an underestimation of the number of alerts, although the presence of ACAS responses does not normally prevent the issuance of the alerts during the ACAS simulations.

- 4.7.3.3. Since the radar encounters with loss of ATC separation have been discarded from the set of encounters of interest for the IAPA study, **all the ACAS alerts triggered during the ACAS simulations are “undesirable” alerts** occurring while the applicable ATC separation is maintained.
- 4.7.3.4. As shown in the figure below, which presents the distribution of encounters triggering at least one TA, **the great majority (about 75%) of TAs were triggered within encounters with either one or two level-off issued by ATC in order to preserve vertical separation**. A non-negligible proportion of TAs occurred within radar encounters with tactical turns (11%) or a combination of horizontal and vertical manoeuvres (9%).



**Figure 38: Distribution of Traffic Advisories in the original radar crossing encounters**

- 4.7.3.5. Further, **all RAs occurred during level-off encounters**. The encounters triggering an RA are necessarily a subset of the radar encounters triggering a TA.
- 4.7.3.6. It should be noted that ACAS simulations were also performed on the same subset of radar encounters, but following the removal of the identified ATC intervention. The increase in the amount of ACAS alerts when removing the ATC intervention is about 8 times more for TAs and about 70 times more for RAs.
- 4.7.3.7. Hence, the RA/TA ratio increases from 3% for the original radar encounters (with ATC) to about 30% for the modified ATM encounters (with the ATC intervention removed). These orders of magnitude seem reasonable taking into account the respective role of ATC and ACAS, i.e. the provision of separation and the prevention of collision.

#### 4.7.4. Comparative results for the ASAS and ATC scenarios

- 4.7.4.1. When comparing the ACAS simulation results obtained with the ASAS encounters sets and the original encounters (without ASAS) but with ATC intervention, slightly distinct trends were observed depending on the IAPA study:
- On one hand, the WP06 study based on the ATM encounter model resulted in a slightly lower TA rate in the ASAS lateral crossing procedures than when the encounters are managed by ATC, but the RA rate is higher (about four times greater) with ASAS than with ATC.

- On the other hand, in the WP07 study based on modified radar data, the number of TAs, respectively RAs, within the original radar encounters with ATC is about ten times less than the number of the same type of alerts within the ASAS encounters. Further, almost all original radar encounters with an RA trigger the alert in only one aircraft, which is not the case for the ASAS encounters.

4.7.4.2. The following table summarises the various TCAS alert rates observed depending on the IAPA study:

	ASAS encounter model		Modified radar data	
	Mix of pass behind/in-front scenario	Original ATM encounters (from encounter model)	Mix of pass behind/in-front scenario	Original radar encounters with ATC
TAs	15.0%	18.1%	18.5%	4.2%
RAs	1.2%	0.3%	0.6%	0.016%

**Figure 39: Comparative likelihood of ACAS alerts between ASAS and original ATM encounters (“mixed of pass behind/in-front” scenario)**

4.7.4.3. The different trend observed for the TA rate might be explained by the characteristics of the ATM encounter model, which generate encounters with horizontal miss distances no greater than 10 NM and vertical miss distances no greater than 2,000 ft, which is much smaller than the actual distributions observed in the original radar encounters (used to build the encounter model). It should be noted that this phenomenon is no more visible when looking at the prevalence of RAs between the ASAS and ATM encounters.

4.7.4.4. Detailed analysis of the ASAS encounters derived from the radar data and their original form with ATC has shown that the interaction with ACAS rather depends on the encounters characteristics:

- On one hand, the great majority (about 83% whatever the ASAS scenario) of the **ATM encounters triggering at least one TA correspond to level-off encounters**. Only a small proportion (less than 10%) of the original radar encounters with a tactical turn triggered a TA. Further, it should be noted that the tactical turns triggering at least a TA usually correspond to a composite aircraft separation, i.e. a shift from a horizontal separation to a vertical separation that results in a reduced horizontal separation at CPA.
- On the other hand, the TA likelihood varies depending on the subset of ASAS encounters (i.e. from about 65% for the ASAS encounters with a “pass behind” manoeuvre, 62% for the ASAS encounters with a “pass in-front” and less than 1% for the ASAS encounters with no manoeuvre required to preserve the ASAS separation). It should be noted that the latter encounters correspond to a separation at closest approach greater than the minimum separation value of 4 NM.

4.7.4.5. When comparing the encounters triggering ACAS alerts on a case by case basis, except for the 1,000 ft level-off geometry, the **current ATC operations** (as observed in the radar data) **appear to be much more compatible with ACAS than ASAS lateral crossing procedures** (with the minimum separation value of 4 NM).

- 4.7.4.6. It should be noted that the interaction with ACAS observed within the original level-off encounters could be reduced through the application of ASAS lateral crossing procedures, while reducing the need aircraft to level-off in climb or descent phases.

#### **4.8. Study based on real-time simulation data**

##### **4.8.1. Scope and approach**

- 4.8.1.1. Work Package 9 of the IAPA project studied the ACAS and ASAS interaction using real-time simulation data.
- 4.8.1.2. In the IAPA project plan [WP00/002D], it was assumed that real-time simulation results with and without the selected ASAS application would be available at the start of the IAPA Project. In fact, at the start of the IAPA project, only one real-time experiment involving ASAS lateral crossing procedures had been conducted at the EEC – the EACAC 2000 experiment. In addition, no other such experiments had been planned for 2003 nor 2004.
- 4.8.1.3. Using the EACAC 2000 data, an initial investigation into the potential ACAS / ASAS interaction was reported in [WP09/036]. The study focused on the three experiments with ASAS contribution. Unfortunately, the main finding was that none of the encounters with ASAS contribution produced any ACAS alerts, and that the detailed investigation into ACAS / ASAS interaction, anticipated in the IAPA project plan, looked to be compromised.
- 4.8.1.4. It was agreed that the merging phase of a Sequencing and Merging (S&M) ASAS procedure could produce similar encounter geometries to the heading phase of a lateral crossing ASAS procedure. Therefore, a sample real-time experiment involving S&M ASAS procedures was investigated to determine whether a significant number of such encounters could be found to justify a more detailed IAPA study. The CoSpace Nov 2002 real-time S&M experiment in an Extended-TMA environment was subsequently proposed for this analysis.
- 4.8.1.5. A preliminary analysis of the S&M real-time data was reported in [WP09/042]. The study focused on the four experiments with time-based and distance-based ASAS contribution. Once again, it was found that the ASAS encounters did not produce any ACAS alerts.
- 4.8.1.6. A further S&M real-time experiment in a TMA environment had been conducted in Nov-Dec 2003. This was considered to be potentially more interesting than CoSpace 2002, from the point of view of the IAPA project, due principally to the 3 NM standard ATC separation.
- 4.8.1.7. Consequently, a further investigation based on the CoSpace 2003 data was reported in [WP09/055]. The study focused on the six experiments with time-based ASAS contribution. Unfortunately, once again it was found that none of the ASAS encounters produced any ACAS alerts.
- 4.8.1.8. Despite the absence of ACAS alerts from real-time simulation ASAS encounters, it was considered of interest to investigate the range of encounters in the S&M simulations, and also to investigate how far the real-time experiment S&M operations were from triggering ACAS alerts. Consequently, a further investigation based on the real-time S&M encounters was made and reported in [WP09/067].



- 4.8.1.9. The various real-time experiments finally investigated in the IAPA study, as well as their main characteristics, are summarised hereafter.

Experiment	ASAS operations simulated	Main characteristics
EACAC 2000 (3 runs)	Lateral crossing & passing procedures	En-route environment
CoSpace 2002 (4 runs)	Sequencing and Merging operations	Extended-TMA environment Time-based and distance-based spacing
CoSpace 2003 (6 runs)	Sequencing and Merging operations	TMA environment Time-based spacing

**Table 10: Various real-time experiments investigated within the WP09 study**

4.8.2. Data collection and processing

- 4.8.2.1. The real-time traffic samples, on which the real-time experiments were based, were created from morning and afternoon real traffic samples from the Paris area. These traffic samples were also adjusted to represent increased traffic loads expected in the future airspace.

4.8.2.2. The execution and analysis of the ACAS simulations were conducted using the available tools at the EUROCONTROL Experimental Centre. These tools included InCAS and the ACAS Server:

- InCAS is a Windows-based interactive fast-time simulator for analysing both real and synthetic ACAS encounters. InCAS simulates TCAS surveillance, the TCAS II logic, TCAS-TCAS coordination, the cockpit annunciations and display of TCAS alerts, and has additional tools to analyse and represent TCAS data graphically.
- The ACAS Server is a Unix-based offline simulator capable of working directly with real-time experiment trajectory data. The ACAS Server simulates TCAS surveillance, the TCAS logic, and TCAS-TCAS coordination.

4.8.2.3. For the IAPA WP09 study, the ACAS Server was configured to run with all aircraft operating TCAS II version 7, and reporting altitude quantised to 25-ft. All instances of TCAS alerts were logged, and any encounter producing an RA was automatically output for more detailed investigation with InCAS.

4.8.2.4. A tool was developed to enable the extraction of any real-time encounter for investigation and replay with InCAS (regardless of whether any ACAS alert was generated in the ACAS Server simulation). Finally, the statistical analysis of real-time trajectory and encounter data was conducted using standard Microsoft Office tools (Access & Excel).

4.8.2.5. For the initial investigation, only the measured real-time exercises involving ASAS procedures were used in ACAS simulations and statistical analysis.

#### 4.8.3. Description of the real-time simulation data sets

##### EACAC 2000 lateral crossing study

4.8.3.1. In the EACAC 2000 experiment, all the traffic was equipped to receive ASAS lateral crossing and passing (C&P) instructions, thus offering maximum opportunities to use ASAS. However, although controllers were invited to use the ASAS procedures, they were not forced to.

4.8.3.2. A minimum applicable separation of 8 NM during lateral crossing manoeuvres was applied in the EACAC 2000 experiment. This is significantly greater than the 4 NM minimum applicable separation specified for the IAPA project studies.

4.8.3.3. The three measured exercises involving ASAS procedures totalled approximately 6h 25m of simulation and 434 flights. Around 20% of these flights were involved in an ASAS procedure, of which 97 were lateral crossings. However, only 85 lateral crossing encounters were compliant with the conditions of use of the ASAS lateral crossing application defined in the IAPA OED (cf. section 2.3).

##### CoSpace 2002 sequencing and merging study

4.8.3.4. In the CoSpace 2002 S&M experiment, a generic environment derived from an existing one (i.e. Paris TMA and Extended-TMA) was simulated. Traffic arriving at two major airports in proximity were sequenced and merged from 4 main streams of traffic.

- 4.8.3.5. The standard spacing at transfer between en-route and approach (except in case of explicit co-ordination with the approach) was 8 NM without ASAS and with distance-based ASAS spacing, and 90 seconds with time-based ASAS spacing. The minimum standard separation used was 5 NM in en-route, and 3 NM in approach. The use of ASAS spacing instructions was at the controller's discretion.
- 4.8.3.6. The four measured exercises with ASAS totalled approximately 5h 28m of simulation and 455 flights. Around 42% of these flights were given ASAS spacing instructions, from which 174 S&M encounters were suitable for the IAPA investigation.

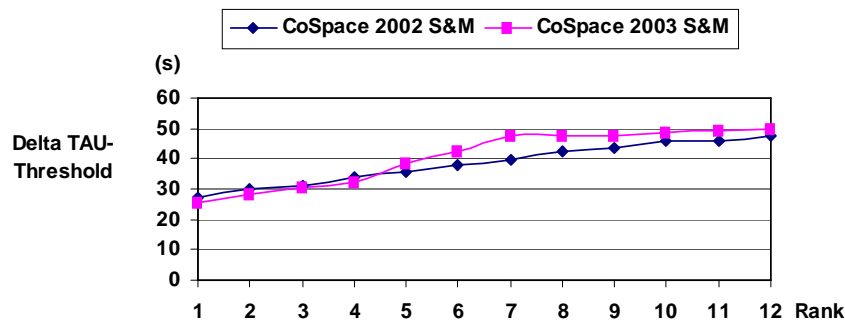
#### CoSpace 2003 sequencing and merging study

- 4.8.3.7. In the CoSpace 2003 S&M experiment, focus was on the assessment of time-based ASAS spacing instructions in the CoSpace TMA environment under very high traffic. The minimum standard separation was 3 NM, and the target spacing was 90 seconds. The use of ASAS spacing instructions was at the controller's discretion.
- 4.8.3.8. Six measured exercises with time based ASAS spacing instructions were investigated. The six exercises with ASAS totalled approximately 8h 19m of simulation and 626 flights. Around 79% of the flights were given ASAS spacing instructions, from which 510 S&M encounters were suitable for the IAPA investigation.

#### 4.8.4. Main ACAS simulation results

- 4.8.4.1. In the C&P real-time experiment investigation, no ACAS alerts were produced. This result is not surprising in view of the 8 NM minimum separation applied to the lateral crossings. In fact, with the margins used by ATC, most separations were observed to be in the region of 8 to 10 NM, well above the 4 NM minimum applicable separation selected for further investigation within the IAPA studies.
- 4.8.4.2. The lack of ACAS alerts in the C&P real-time experiment is in accord with the sensitivity analysis performed in the IAPA WP08 study, which indicated that ACAS alerts would be very unlikely to occur in lateral crossings with separations in excess of 7 NM.
- 4.8.4.3. In the S&M investigations, no ACAS alerts were produced. Moreover, of those encounters which came closest to producing an ACAS TA, it was found that the minimum Range-TAU in each case was still well above (i.e. more than 25 s) the TA threshold.

4.8.4.4. The following figure shows the difference that exists between the minimum Range-TAU and the TA threshold in the twelve most demanding encounters extracted from the CoSpace S&M simulations:



**Figure 40: Minimum Range-TAU encounters extracted from CoSpace S&M simulations**

- 4.8.4.5. This positive result indicates that the S&M procedures, with operational target spacing values, are robust against ACAS. This result is in accord with the preliminary analysis of S&M operations performed in the IAPA WP04 study.
- 4.8.4.6. From the point of view of the IAPA project, however, the available real-time data proved to be insufficient to support the ACAS performance measurements and detailed ACAS / ASAS interaction analysis, anticipated in the IAPA project plan.

## 5. Safety analysis of the ACAS / ASAS interaction

### 5.1. General

- 5.1.1. During the Phase II of the IAPA project, Work Package 10 performed a safety analysis of the interaction between ACAS and the ASAS application selected for further investigation, i.e. the ASAS lateral crossing application.
- 5.1.2. This safety analysis was supported by a set of methods and tools developed in previous ACAS studies [ACA1a], [ACA1b], [ASARP] and supplemented by complementary hazard assessment techniques. Advantage was taken of the guidelines of the Operational Safety Assessment methodology [ED78A] developed by a joint RTCA SC-189 / EUROCAE WG-53 committee and the EUROCONTROL Safety Assessment Methodology [SAM].
- 5.1.3. The objective of the IAPA safety analysis was the evaluation of the safety benefits (in terms of reduced risk of collision) than can be expected from ACAS when aircraft are engaged in ASAS operations. In the context of the IAPA study, this evaluation was limited to ASAS operations that derived from the use of the ASAS lateral crossing procedure as described in the IAPA OED [WP01/024].
- 5.1.4. In this perspective, some preparatory work was required which consisted of:
  - a review and refinement of Operational Hazard Assessment (OHA) material related to ASAS (taking into account the ACAS constraint);
  - the development of a contingency tree<sup>15</sup> (focused on the ACAS / ASAS interaction situations) that allows the computation of a full-system risk as a combination of ACAS logic risks and probabilities of other external events; and
  - the refinement of an existing European safety encounter model into an ACAS/ASAS safety encounter model (taking into account the anticipated effect of ASAS operations). These safety encounter models allow the computation of ACAS logic risk ratios from simulations with various scenarios of ACAS equipage and operation by the pilot.
- 5.1.5. Using the ACAS/ASAS safety encounter model and the IAPA contingency tree thus produced, the safety benefits that can be expected from ACAS during ASAS procedures were assessed for various operational scenarios.
- 5.1.6. The remainder of this chapter presents the methodological elements, together with the main assumptions and findings of each of these WP10 work areas (cf. [WP10/110] for further details).

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<sup>15</sup> The terms “fault-tree” and “event-tree” have been used in the former ACASA project and at the start of the IAPA project. The term “contingency tree” was finally preferred as the other terms have specific different meanings in the field of safety analysis.

## **5.2. Review and refinement of OHA material**

### **5.2.1. Scope and purpose**

- 5.2.1.1. The objective of the first WP10 work area was to produce an agreed Operational Hazard Assessment of the ASAS lateral crossing procedure that takes into account the effect of ACAS operations.
- 5.2.1.2. For this purpose, the work performed was broken down into three main subtasks:
- an OHA focused on the ACAS procedure [WP10/050];
  - an OHA focused on the ASAS procedure, without ACAS [WP10/063]; and
  - an analysis of the impact of the ASAS OHA on the ACAS OHA [WP10/069].
- 5.2.1.3. The OHAs enumerated the operational hazards related to each procedure, and were adapted for the specific purpose of the IAPA Project. The work also listed mitigating factors already identified in the IAPA Operational Environment [WP01/024], which supported safety even in the presence of a hazard.

### **5.2.2. OHA focused on the ACAS procedure**

- 5.2.2.1. The OHA focused on ACAS was supported by the guidelines provided by the EUROCAE Operational Safety Assessment methodology. This methodology has been developed to address the assessment of a system whose domain spans multiple fields, and more precisely an ATM system supported by data-link applications. It is also used in support of safety assessment of ASAS applications under development.
- 5.2.2.2. A team of ACAS experts used a “brainstorming” method, guided by the ACAS procedure represented by the three successive phases (i.e. TA occurs, RA occurs, and Completion of RA), to establish a list of hazards that can occur during the ACAS procedure. These hazards were identified as “causes” in the consolidated list of Operational Hazards (OH).
- 5.2.2.3. The severity assessment of possible operational consequences of these OHs was then classified according to the [ESARR4] matrix defined by EUROCONTROL to support risk assessment in ATM. The effects and classifications of operational hazards were assessed in relation to both environmental and procedural safety assumptions.
- 5.2.2.4. The **environmental safety assumptions** encompass the following items:
- All aircraft are TCAS II version 7.0 equipped; Therefore, all RA manoeuvres are co-ordinated;
  - Encounter configuration is such that last resort collision avoidance manoeuvre is effective; and
  - All aircraft have a single Cockpit Display of Traffic Information (CDTI), i.e. with shared ACAS and ASAS information.
- 5.2.2.5. The **procedural safety assumptions**, i.e. procedural features used as mitigation means during the OHA of the ACAS procedure, are listed hereafter.

Safety Assumptions Title	Related ICAO Documentation
ATC delivers appropriate traffic information to own aircraft	Annex 11, PANS-ATM
ATC provides appropriate instruction to own aircraft to ensure separation	Annex 11, PANS-ATM
Flight crew does not manoeuvre following TA	PANS-OPS Part VIII Chapter 3
Flight crew properly follows the RA	PANS-OPS Part VIII Chapter 3
Flight crew of intruder aircraft properly follows the RA	PANS-OPS Part VIII Chapter 3
Flight crew applies the regular “see and avoid” procedure on visually acquired intruder	Annex 2, PANS-OPS
Flight crew does not manoeuvre following RA if it jeopardizes own aircraft safety.	PANS-OPS Part VIII Chapter 3
In case of RA, flight crew does not follow ATC instruction	PANS-OPS Part VIII Chapter 3
In case of RA, flight crew notifies ATC	PANS-OPS Part VIII Chapter 3

**Table 11: ACAS procedural safety assumptions**

5.2.2.6. The following table presents the most severe OHs related to the ACAS procedure, which resulted from the consolidation of the various listed hazards:

Phase	OH Title	Possible Causes	Operational Consequences	Severity
P2	Flight crew manoeuvres in opposite sense to RA	ATC delivers instruction contrary to RA Flight crew misinterprets traffic situation Misinterpretation of TCAS II display or aural annunciation	If the ACAS logic operates properly, a reversal RA may be generated on-board both aircraft. However, the safety margins will be substantially reduced Large reduction in separation without flight crew or ATC controlling the situation.	2
P2	RA manoeuvre required by ACAS results in a risk of near mid-air collision <sup>16</sup>	ACAS logic Intruder does not manoeuvre as required by ACAS Wrong altitude reporting by intruder	If the flight crew does not identify that the RA increases the risk of collision, it will manoeuvre in such a way that the latter will be increased. Large reduction in separation without flight crew or ATC controlling the situation.	2

**Table 12: ACAS OHs of most severe potential consequences**

<sup>16</sup> A risk of Near Mid-Air Collision (NMAC) was assessed with a severity 2 within the study based on the assumption of full ACAS equipage and assuming that at least one flight crew properly follows the coordinated RA.

### 5.2.3. OHAs focused on the ASAS procedure

- 5.2.3.1. The OHA focused on ASAS was based on the EUROCONTROL SAM methodology and more precisely, its Functional Hazard Assessment (FHA) process. The SAM methodology has been developed to reflect best practices for safety assessment of Air Navigation Systems and to provide guidance for their application.
- 5.2.3.2. A team of ASAS and safety experts, guided by the ASAS procedure defined in the OED, and represented by the three successive phases (i.e. initialisation, execution, and completion of the procedure), identified the potential failures and hazards that can occur. The severity assessment of possible operational consequences was classified according to the [ESARR4] matrix.
- 5.2.3.3. The main results of the ASAS OHA are listed in Table 13: ASAS OHs of most severe potential consequences:

Phase	OH Title	Possible Operational Consequences	Recommendations	Severity
P2	Incorrect manoeuvre onto first leg detected by ATC	Risk of loss of separation Procedure is aborted Stress and additional workload for ATC and flight crew	Spacing value must be significantly greater than applicable separation standards to enable detection	3
P2	Late manoeuvre onto first leg	Risk of loss of separation Procedure is aborted Stress and additional workload for ATC and flight crew	Build time-to-go-to-CPA into procedure	3
P2	Insufficient flight crew monitoring of (1)spacing/ (2)separation – (1) detected by ATC	Procedure is aborted Stress and additional workload for ATC and flight crew	Improve CDTI HMI warnings on separation Review training	3
P2	Clear of traffic not determined by flight crew – undetected by ATC	Procedure is aborted Additional workload for ATC or inefficiency Risk of loss of separation with other traffic	Improve CDTI HMI indications of Clear of Traffic Review training	3

**Table 13: ASAS OHs of most severe potential consequences**

### 5.2.4. Analysis of the impact of the ASAS OHA on the ACAS OHA

- 5.2.4.1. The possible interaction between the ACAS and ASAS procedures was studied from three points of view:
- Change in likelihood of ACAS OH thanks to enhanced Air Traffic Situational Awareness (ATSAW);
  - Change in severity of ACAS OH; and
  - ASAS OH may cause an ACAS OH.



- 5.2.4.2. One of the main findings of this analysis was that **the interaction between ACAS and ASAS expresses itself differently depending on whether or not the ACAS intruder is the other aircraft involved in the ASAS procedure or a third aircraft.**
- 5.2.4.3. Furthermore, assuming an appropriate design of a single traffic display with shared ACAS and ASAS information, the analysis also revealed that **the severity and likelihood of some hazards may decrease thanks to the enhanced Airborne Traffic Situational Awareness of the flight crew.**
- 5.2.4.4. The following table presents two examples of the impact of ASAS on ACAS, which correspond to two distinct scenarios in terms of whether or not the ACAS intruder is the other aircraft involved in the ASAS procedure:

OH Title	Initial severity	Additional/Modified causes in an ASAS context	Potential trend of likelihood	Additional/Modified consequences in an ASAS context	Potential trend of severity
ACAS intruder is ASAS designated aircraft & flight crew manoeuvres aircraft following TA without visual acquisition	3 / 4	Less likely that the flight crew interprets wrongly the traffic situation thanks to ASAS/Enhanced ATSAW	Less	The ASAS procedure is impacted The ASAS procedure may be aborted due to manoeuvre Flight crew's ATSAW is enhanced thanks to ASAS thus severity may decrease	Less
ACAS intruder is not ASAS designated aircraft & the RA manoeuvre creates a conflict with a third aircraft	3 / 4		Same	The ASAS procedure is impacted The third aircraft could be the ASAS designated aircraft	Same

**Table 14: Examples of the impact of ASAS on ACAS OHs**

- 5.2.5. Review of the ACAS and ASAS OHAs in the context of the contingency tree
- 5.2.5.1. A review of the ACAS and ASAS OHAs [WP10/081] was conducted to determine whether each OH identified was already present in the ACASA event tree (on which the IAPA contingency tree was based), and whether the approximations used were acceptable. It was found that all of the OHs in the ACAS OHA were adequately represented in the ACASA event tree.
- 5.2.5.2. Nevertheless, the review of the ASAS / ACAS interaction OHA did reveal the need to introduce a high-level change (relative to the ACASA event tree) into the IAPA contingency tree [WP10/084] to address the asymmetry that exists between the reference aircraft and the threat aircraft (against which there is an ACAS RA).

- 5.2.5.3. In the ACASA event tree, the circumstances of the two aircraft on a close encounter course were treated symmetrically. In the IAPA contingency tree, these circumstances were different since the reference aircraft is actively engaged in an ASAS procedure, which is not the case for the aircraft against which the ACAS logic issues an RA (this latter being either the passive participant in the ASAS procedure or not involved at all in the ASAS procedure).
- 5.2.5.4. Further, to take into account the asymmetry identified in the ASAS / ACAS interaction OHA with regard to the nature of aircraft against which there is an ACAS alert, the IAPA contingency tree was split into two similarly structured parts at the top level: an “ASAS intruder branch” and a “third aircraft branch”. Most of the events on one branch are qualitatively duplicated on the other branch, but are assigned different probabilities that reflect the two different contexts.

### **5.3. Development of the IAPA contingency tree**

#### **5.3.1. General features**

- 5.3.1.1. The IAPA contingency tree is focused on the risk assessment (in terms of risk of near mid-air collision) for an individual aircraft actively engaged in an ASAS procedure and which operates ACAS [WP10/084]. Such an aircraft-centred approach was preferred to the airspace-centred approach usually used in ACAS safety studies to allow for the evaluation of the safety benefits of ACAS in the context of ASAS procedures in particular.
- 5.3.1.2. A central contributory factor to this risk assessment are the ACAS logic risks which relate directly to the probability of a collision occurring as a result of the manoeuvres undertaken by the pilots of the ACAS equipped aircraft involved in an encounter (cf. section 5.4).
- 5.3.1.3. In practice, the safety benefits derived from the collision avoidance advice of the ACAS logic are modified by environmental and human factors (e.g. ACAS may fail to track an intruder, or a pilot may elect not to follow an RA preferring instead controller advice or to exercise see-and-avoid).
- 5.3.1.4. These other factors and their probabilities of occurrence, as well as the logic risks, are taken into account in the branching structure of the contingency tree to calculate the overall probability of the top level event, which is that of a near mid-air collision. By setting the probabilities of appropriate events, the contingency tree enables a wealth of operational scenarios to be considered.
- 5.3.1.5. The various events included in of the IAPA contingency tree are summarised in the following table:

Type of events	Nature of the events and rationale	Example of events
Geometry events	Events related to the relative disposition of the two aircraft, defining the context of the encounter and the possibility of visual acquisition	Reference aircraft is on a close encounter course with the other aircraft involved in the ASAS procedure No line of sight to the threat aircraft A third aircraft is present

Type of events	Nature of the events and rationale	Example of events
Equipment events	Events related to the levels of ACAS equipage of the aircraft, and their actual functioning	Intruder is ACAS equipped Intruder is not transponder equipped No altitude data for Mode S equipped intruder Reference aircraft has no traffic display
ATC events	Events related to the presence and involvement of a controller	Controller is already involved (only in the “third aircraft branch” of the tree)
Human factors events	Events related to the actions of the pilots and the controller	Pilot ignores RA Pilot prefers controller advice Pilot responds promptly to RA
Visual acquisition events	Events related to the possibility of the pilot exercising ‘see-and-avoid’ in preference to following the RA	Pilot already has visual acquisition of the threat Pilot with traffic display fails to acquire the threat Pilot misperceives visually acquired aircraft
Logic events	Events related to the probability of mid-air collision as the result of pilot responses to ACAS logic and possible controller advice	One aircraft respond promptly, the other aircraft responds does not respond Aircraft are not in collision course but RA induces a collision Controller advice fails to resolve collision

**Table 15: Events included in the IAPA contingency tree**

### 5.3.2. ACAS equipage scenarios

5.3.2.1. The following table summarises the four scenarios relating to the ACAS equipage investigated with the IAPA contingency tree:

Equipage scenario	Reference aircraft	Threat aircraft
Baseline equipage	Unequipped	Unequipped
Nominal equipage	ACAS (in RA mode)	As ACAS mandate
Non-nominal equipage	Unequipped (or ACAS unserviceable)	As ACAS mandate
	TA-only mode	As ACAS mandate

**Table 16: Equipage scenarios investigated with the contingency tree**

- 5.3.2.2. The baseline equipage scenario gives the underlying risk (without ACAS) and was needed to assess the safety benefits that results from ACAS equipage. In the nominal scenario, those aircraft covered by the ACAS mandate are equipped and operating ACAS in full RA mode. The reference aircraft is assumed ACAS equipped and a proportion of other aircraft (83.5%) are assumed ACAS equipped.
- 5.3.2.3. In the non-nominal scenarios, the reference aircraft is not operating ACAS in full RA mode. Other aircraft covered by the ACAS mandate are equipped and operating ACAS in full RA mode. Further, to consider the potential situational awareness provided by ACAS TAs, distinction was made on whether or not the reference aircraft is able to receive TAs, i.e. whether ACAS was unserviceable or is operated in TA-only mode.

### 5.3.3. Assessment of Human Factor events

- 5.3.3.1. The probabilities of the principal Human Factor events were derived from the probabilities for the corresponding events that had been assigned in the ACASA study. Further, a qualitative assessment was made of each ‘human factor’ event associated with the reference aircraft and the designated aircraft respectively.
- 5.3.3.2. For those events for which ACASA probabilities were already available, a method was devised to adjust the values based on the ACASA primary and secondary values, the range of uncertainty, and the qualitative assessment [WP10/089].
- 5.3.3.3. Effort was also directed at obtaining a better estimate for the probability that the pilot will misidentify the visually acquired aircraft as the collision threat (and consequently not continue its search). To estimate this, a method based on variations in display quality (TCAS II display versus CDTI) and normal human error rates was used.
- 5.3.3.4. Finally, it was assumed that the probabilities of human factor events for any third aircraft would be the same as the corresponding values in the ACASA study.

### 5.3.4. Pilot response scenarios

- 5.3.4.1. In the contingency tree, the continuum of possible pilot responses to an ACAS RA is represented by three representative specific responses. Two of these cover the situation in which the pilot notes the RA, prefers it over any controller advice and follows the RA with either a prompt or a slow response<sup>17</sup>.
- 5.3.4.2. ‘No response’ covers the situation in which the pilot ignores any controller advice and also ignores the RA. When the intruder is not ACAS equipped, there is no need to model ‘no response’ as this produces no change in the encounters.
- 5.3.4.3. By varying the proportions of the pilot responses, distinction was made between:
  - ‘conscientious’ pilots who never ignore RAs and when they respond (because they do not prefer to follow controller advice) always respond promptly;
  - ‘typical’ pilots who generally respond promptly (75% of the time), but sometimes respond slowly (15%), and sometimes ignoring the RA (10%) (e.g. when responding to controller advice, or exercising see-and-avoid); and
  - non responding pilots who do not respond to RAs, either because they do not receive RAs (cf. equipment events) or because they systematically ignore them.

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<sup>17</sup> The ACASA study also considered a ‘wrong response’, in which a pilot responds in a direction contrary to the RA. However, the assumed proportion of wrong pilot responses (0.1%) was so small that the increased risk was found to have an insignificant effect on the overall risk. As a consequence a wrong response due to misinterpretation of the RA has not been considered in the IAPA study. Nevertheless, a response that is contrary to the RA because the pilot prefers controller advice is considered in the study.

## **5.4. ACAS safety model refinement and logic risk ratio computations**

### **5.4.1. General**

- 5.4.1.1. The logic risks are generally calculated by performing computer simulations of the performance of ACAS in a large set of close encounters that are representative of the airspace of interest.
- 5.4.1.2. The encounters that matter are those in which two aircraft are on a close encounter course (i.e. an encounter with a negligible Horizontal Miss Distance) in which there already exists a risk of collision or in which the response of pilots to ACAS alerts can result in a risk of collision.
- 5.4.1.3. These encounters can be generated by a ‘safety encounter model’, i.e. an encounter model that captures the properties of close encounters as a series of statistical distributions describing the parameters of a typical encounter and their interdependencies. A safety encounter model is distinct from an ATM encounter model in that it deals with a shorter timeframe and is concerned only with encounter in which there is a negligible horizontal miss distance<sup>18</sup>.
- 5.4.1.4. To support the computation of the ACAS logic risks during ASAS operations, an ACAS/ASAS safety encounter model was needed, which would define the properties of close encounters in ASAS operations.
- 5.4.1.5. An ACAS/ASAS safety encounter model was derived from an existing safety encounter model (i.e. the ASARP safety encounter model) describing the close encounters that can be expected to occur in the European airspace for current ATM operations [ASARP] but introduced the assumed effects of the ASAS procedures on encounter characteristics.

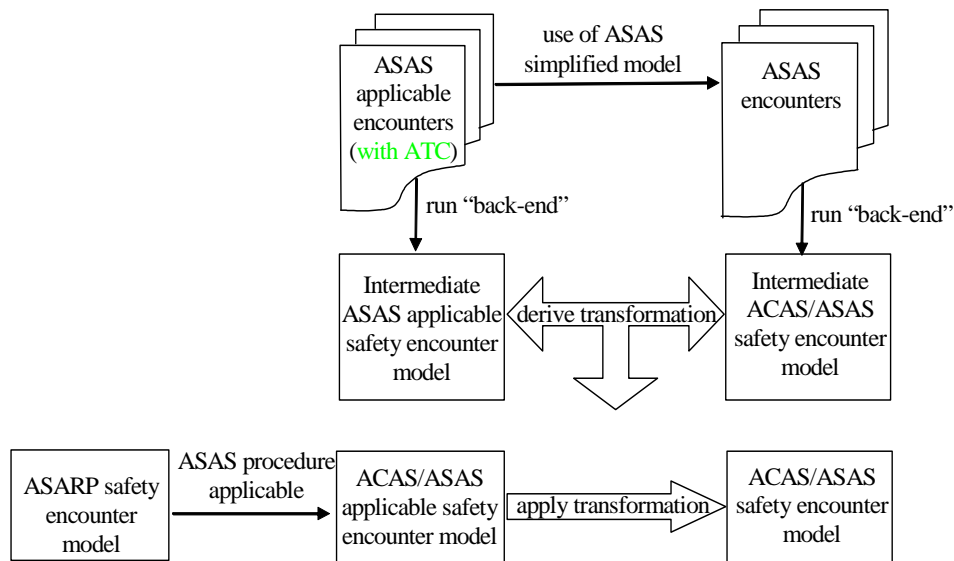
### **5.4.2. Derivation of the ACAS/ASAS safety encounter model**

- 5.4.2.1. As it stands the ASAS encounter set that supported the operational analysis of the ACAS / ASAS interaction (cf. section 4.3) is not suitable for a direct derivation of a safety encounter model since it consists of encounters in which there is generally a significant horizontal separation.
- 5.4.2.2. Nevertheless, it was assumed that the differences that exist between the ASAS encounter set and the ATM encounter set (restricted to the encounters where ASAS is applicable) could be used to characterise the effect of introducing the ASAS procedure into the airspace.
- 5.4.2.3. Therefore, two intermediate safety encounter models were built respectively from the ASAS-applicable ATM encounter set and the ASAS encounter set (using the ASARP “back-end” processor), which were then compared to determine the differences that exist between the two model’s sets of tables.

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<sup>18</sup> In a safety encounter model, no specific distribution exists for the HMD, which is assumed to be uniformly distributed between 0 feet to 500 feet.

- 5.4.2.4. From these differences, a transformation was derived that maps the distribution of parameters for the encounters in which the ASAS procedure would be applicable, into the distribution of parameters for the encounters in which the ASAS procedure is employed.
- 5.4.2.5. An ACAS/ASAS-applicable safety encounter model was obtained by splitting the ASARP safety encounter model into two separate complementary models depending on whether the ASAS procedure was applicable or not. Finally, the previous transformation was applied to the tables of the ACAS/ASAS-applicable safety encounter model to derive the ACAS/ASAS safety encounter model.
- 5.4.2.6. The overall process that supported the development of the ACAS/ASAS safety encounter model is shown in the following figure:



**Figure 41: Derivation of the ACAS/ASAS safety encounter model**

### 5.4.3. Underlying NMAC rates

- 5.4.3.1. The distribution of vertical miss distances modelled in the tables of a safety encounter model implies a certain underlying NMAC rate. It is necessary to ensure that the implied NMAC rate is realistic, so that a reliable value of the risk ratio is calculated on the basis of simulations of encounters generated by the model.
- 5.4.4. The ASARP safety encounter model describes close encounters in the altitude range 1,000 ft AMSL to FL415. In this range of altitudes the NMAC rate implied by the model is  $2.39 \times 10^{-7}$  per flight-hour. The IAPA study has assumed that ASAS procedures will be employed only in encounters above 5,000 ft AMSL. For this altitude range, the NMAC rate implied by the ASARP safety encounter model is  $1.09 \times 10^{-7}$  per flight-hour, cf. [ASARP].

- 5.4.4.1. In the encounters where the ASAS procedure is applicable, but when handled by conventional ATC, an NMAC rate of  $1.53 \times 10^{-7}$  per flight hour was estimated. When the ASAS lateral crossing procedure was employed in the same encounters an NMAC rate of  $1.85 \times 10^{-7}$  per flight hour was estimated, cf. [WP10/110].

	all close encounters above 5000 ft	ASAS-applicable close encounters	ASAS close encounters
NMACs	$1.09 \times 10^{-7}$ per flight hour	$1.53 \times 10^{-7}$ per flight hour	$1.85 \times 10^{-7}$ per flight hour

**Table 17: Underlying NMAC rates of the safety encounter models**

- 5.4.4.2. All other things being equal these rates would indicate that there would be an increase in the underlying NMAC when ASAS procedures are introduced. However, factors such as tighter navigational performance requirements, new procedures and improved training have not been taken into consideration. Therefore, these values should instead be viewed as evidence that **care will be needed to ensure that the introduction of ASAS procedures does not lead to an unacceptable rise in the underlying risk of collision.**

#### 5.4.5. Simulations of ACAS performance

- 5.4.5.1. The ACAS/ASAS-applicable safety encounter model and the ACAS/ASAS safety encounter model were each used to generate a set of 100,000 close encounters. These encounters were then used in simulations of the performance of ACAS for various ACAS equipage scenarios and pilot responses scenarios (cf. sections 5.3.2 and 5.3.4).
- 5.4.5.2. A prompt pilot response was modelled in the ACAS simulation of the ASAS-applicable close encounter set, and all combinations of prompt, slow and no response were modelled in the ACAS simulation of the ASAS encounter set. The models of prompt and slow pilot responses were to the same as those defined in the ACASA safety study [ACA1a].
- 5.4.5.3. The effect of altimetry error on the vertical miss distances (in the original encounters and the encounters with the pilot response to ACAS simulated) was included to estimate the logic risk of mid-air collision. The probability that perceived separation would be negated by altimeter error (and in consequence a near mid-air collision would occur) was determined using the mathematical model of altimetry error set up in the ACASA project [ACA1a].

#### 5.4.6. ACAS logic risks and risk ratios

- 5.4.6.1. The following table presents the various NMAC rates computed following the ACAS simulations for the various ACAS equipage scenarios (cf. section 5.3.2) under ideal circumstances, i.e. perfect surveillance of intruders and prompt pilot responses. At this stage, neither the interaction with the controller nor visual acquisition of the collision threat by the pilot has been taken into account. These figures therefore represent ‘logic risks’: the risk of collision when only the performance of the ACAS collision avoidance algorithms is considered.

	Baseline scenario	Nominal scenario	Non-nominal scenario
ASAS-applicable safety encounters	$1.53 \times 10^{-7}$ per flight hour	$1.07 \times 10^{-9}$ per flight hour	$3.02 \times 10^{-8}$ per flight hour
ASAS close encounters	$1.85 \times 10^{-7}$ per flight hour	$1.32 \times 10^{-9}$ per flight hour	$3.67 \times 10^{-8}$ per flight hour

**Table 18: Underlying NMAC rates for different ACAS equipage scenarios**

5.4.6.2. As shown, similar trends were observed for ASAS-applicable close encounter set and the ASAS close encounter set with respect to the safety benefit of provided by the ACAS logic, i.e.:

- the risk reduction (by a factor of about 140) when all mandated aircraft operate ACAS (i.e. nominal scenario) compared to the underlying risk of the encounter sets without any ACAS contribution (i.e. baseline scenario); and
- the risk increase (by a factor of about 30) if the pilot of the reference aircraft engaged in an ASAS procedure disables his ACAS equipment relying on the ACAS equipage of other aircraft (i.e. non-nominal scenario) when compared to the risk achieved when all mandated aircraft operate ACAS regardless of their involvement or not in an ASAS procedure.

5.4.6.3. By comparing the NMAC rate when all mandated aircraft are ACAS equipped (i.e. nominal scenario) with the underlying NMAC rate (when no aircraft are equipped with ACAS), a ‘procedure-centred’ logic risk ratio was determined that provides a measure of the safety benefits of ACAS equipage in encounters where ASAS is applicable.

5.4.6.4. The comparison between the NMAC rate when the reference aircraft is not operating ACAS but all other mandated aircraft do (i.e. non-nominal scenario) and the underlying NMAC rate provided an ‘aircraft-centred’ logic risk ratio measuring the benefits to an individual aircraft, engaged in an ASAS procedure and not operating ACAS in full RA mode, that results from the ACAS equipage of other aircraft.

5.4.6.5. Finally, a ‘progressional’ logic risk ratio of the deployment of ACAS on this reference aircraft given that all other mandated aircraft are operating ACAS, was determined by comparing the NMAC rates obtained in the nominal and non-nominal ACAS equipage scenarios. This indicates the benefit to the reference aircraft to be obtained by ensuring that he operates ACAS properly.

5.4.6.6. The following table shows these various logic risk ratios for both the ASAS-applicable close encounter set and the ASAS close encounter set:

	Procedure-centred logic risk ratio	Aircraft-centred logic risk ratio	Progressional logic risk ratio
ASAS-applicable close encounter set	0.7%	19.8%	3.5%
ASAS close encounter set	0.7%	19.8%	3.6%

**Table 19: Logic risk ratios for ASAS-applicable and ASAS close encounter sets**

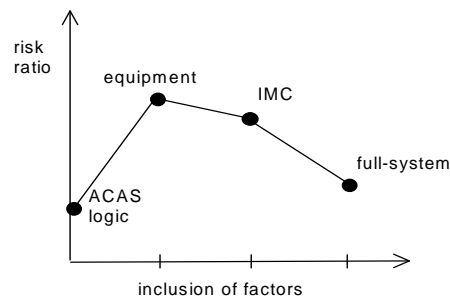


- 5.4.6.7. As shown, the ACAS mandate reduces the risk of mid-air collision to 0.7% of the risk that would be present if no aircraft were ACAS equipped. This risk ratio is virtually the same regardless of whether these encounters are handled by ATC or whether the ASAS lateral crossing procedure was employed.
- 5.4.6.8. The risk of near mid-air collision to an individual reference aircraft (not operating ACAS) is reduced by more than a factor of five due to the ACAS equipage of the other mandated aircraft whether engaged in an ASAS procedure or not, cf. ‘aircraft-centred’ logic risk ratios of 19.8%.
- 5.4.6.9. Finally, even when the reference aircraft receives a significant benefit from the ACAS equipage of the majority of other aircraft, the pilot of the reference aircraft can still achieve a further reduction in the risk of mid-air collision by operating his own ACAS, cf. ‘progressional’ logic risk ratios of 3.5% and 3.6% respectively for the ASAS-applicable close encounter set and the ASAS close encounter set.

## **5.5. ACAS safety benefits evaluation using the contingency tree**

### **5.5.1. Risk ratio scenarios**

- 5.5.1.1. The IAPA contingency tree was used to compute ACAS full-system risk ratios, and intermediate risk ratios, by considering the progressive inclusion of the various risk-influencing factors that are modelled in the tree.
- 5.5.1.2. Starting with the logic risk ratio, the benefit from the operation of the ACAS algorithms can be degraded when factors affecting the imperfect operation of the ACAS equipment are considered (giving an ‘equipment risk ratio’).
- 5.5.1.3. However, this equipment risk ratio is potentially improved when we also consider the ability of ACAS to prompt contact between the pilot and controller (giving an ‘IMC risk ratio’). Finally, further improvement in the risk ratio can be expected due to the ability of ACAS to prompt visual acquisition in visual meteorological conditions (giving the full-system risk ratio).
- 5.5.1.4. Such a sequence of risk ratios is illustrated schematically in the following figure:



**Figure 42: Illustration of the effect of various factors on the risk ratio**

### 5.5.2. Additional logic risk ratios

- 5.5.2.1. Logic risk ratios that were more representative were computed considering not only the two aircraft involved in the ASAS procedure (as in section 5.4.6), but also the possible near mid-air collision between the aircraft engaged in the ASAS procedure and a third aircraft. Further, the effect of typical pilot responses (in all three aircraft) was compared to that of prompt pilot responses.
- 5.5.2.2. These additional ACAS logic risk ratios computed for the ASAS close encounter set are presented in the following table:

Pilot response scenario (for ASAS pair and third aircraft)	Procedure- centred logic risk ratio	Aircraft- centred logic risk ratio	Progressional logic risk ratio
Prompt pilot responses	2.5%	26.0%	9.7%
Typical pilot responses	10.1%	40.6%	24.8%

**Table 20: Additional logic risk ratios for the ASAS close encounter set**

- 5.5.2.3. In all cases, there was an increase in the logic risk ratio compared to that previously obtained when considering only the pair of aircraft involved in the ASAS procedure (e.g. the procedure-centred logic risk ratio increases from 0.7% to 2.5% by taking into account the third aircraft).
- 5.5.2.4. Therefore, the ACAS logic proved to be less effective in reducing the risk when the reference aircraft is on a close encounter course with a third aircraft than in encounters involving the two aircraft participating to the ASAS procedure. This is because the third aircraft is potentially less “well behaved” than the passive aircraft of an ASAS procedure, which has been instructed to maintain course and heading.
- 5.5.2.5. Finally, in all cases, the logic risk ratio increased when considering typical pilot responses compared to prompt pilot responses (e.g. the procedure-centred logic risk ratio increases from 2.5% to 10.1%). **This result highlights the importance of pilots following their RAs and following them promptly if they wish to realise the maximum protection afforded by ACAS.** ASAS procedures are no different from other ATM operations in this respect.

### 5.5.3. Procedure-centred risk ratios

- 5.5.3.1. Assuming all mandated aircraft are ACAS equipped (i.e. nominal the nominal scenario of section 5.3.2), the various risk-influencing factors modelled in the IAPA contingency tree were then introducing in stages for three pilot response scenarios:
- All pilots respond conscientiously, i.e. they never ignore the RAs and when they follow the RAs (i.e. do not prefer to follow controller advice or exercise see-and-avoid), they follow them promptly;
  - All pilots respond typically (i.e. a proportion of pilots respond slowly or not at all); or
  - All pilots ignore their RAs, but possibly follow controller advice or exercise see-and-avoid. This scenario would not occur in practice and was included so that the effect of controller advice and visual acquisition alone could be determined.

5.5.3.2. The following table shows the sequence of risk ratios thus obtained:

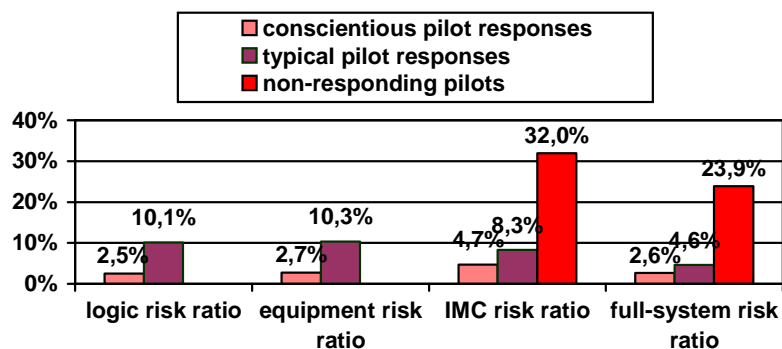


Figure 43: Procedure-centred risk ratios including various factors

5.5.3.3. As shown, similar trends were observed whatever the pilot response scenario with regard to the equipment risk ratio, i.e. **a small increase in the risk ratio when taking into account the possibility that ACAS does not track the intruder when compared to the ACAS logic risk ratio alone**. It should be noted that in the equipment risk ratio no account is taken of the possibility that ACAS alerts prompt either contact with the controller or visual acquisition.

5.5.3.4. When considering the effects of the controller involvement and assuming the pilots do not act on visual acquisition (i.e. the IMC risk ratios), contrasting trends were observed for conscientious and typical pilot responses:

- Controller involvement is assumed, usually, to be as effective as a prompt response to an RA, but sometimes is worse. Consequently, when pilots respond conscientiously to RAs, controller involvement generally makes no difference but occasionally exacerbates the situation and the overall effect of controller involvement is to increase the risk ratio.
- When considering typical pilots, who notably include a proportion (10%) of non-responding pilots, last minute avoidance advice from the controller can be more beneficial than the pilot response (or non-response) to an RAs. This effect was found to outweigh the competing effect between ACAS and controller advice that exist when all pilots respond conscientiously. So, with typical pilot responses, the IMC risk ratio is lower than the equipment risk ratio.

5.5.3.5. In all cases, **a decrease in the risk ratio was observed when considering the full-system risk ratios (including the effect of visual acquisition) compared to the IMC risk ratios** (e.g. with typical pilot responses to RAs, the full-system procedure-centred risk ratio in ASAS encounters is reduced to 4.6%). This reduction is more marked than that observed in previous studies due to the enhanced situational awareness afforded by ASAS and the higher ACAS equipage level of other aircraft when the reference aircraft is engaged in an ASAS procedure.

5.5.3.6. When considering pilots who do not respond to RAs but rely rather on controller advice and visual acquisition, the full-system risk ratio is 23.9% indicating that the alerting aspects of ACAS alone could reduce the risk of collision in ASAS procedures by just over a factor of four.

5.5.3.7. Nevertheless, this risk ratio is still more than twice the risk ratio that remains when only the benefit of ACAS RAs is considered, i.e. the 10.3% equipment risk ratio with typical pilot responses. **This demonstrates that the most important aspect of the ability of ACAS to reduce the risk of collision in ASAS procedures is the correct and prompt response to RAs.**

#### 5.5.4. Aircraft-centred and progressional full-system risk ratios

5.5.4.1. The operational analysis of the ACAS / ASAS interaction (cf. Chapter 4) indicated that the rate of ACAS alerts in ASAS procedures may be higher than that experienced in general operations. There may, therefore, be a temptation for individual pilots to operate ACAS in a non-nominal manner: ignoring RAs; operating ACAS in TA-only mode; or even disabling ACAS altogether.

5.5.4.2. To assess the impact of doing so on the safety benefit provided by ACAS, the ‘progressional’ full-system risk ratio was determined for various operational modes of ACAS by the reference aircraft engaged in an ASAS procedure. In all cases, it was assumed that the pilots of other ACAS equipped aircraft operate ACAS and respond to RAs in a typical manner.

5.5.4.3. The results are presented in the following table, together with the corresponding ‘aircraft-centred’ full-system risk ratios (these are a constant fraction of the ‘progressional’ full-system risk ratio):

ACAS operating mode (of reference aircraft)	Pilot response scenario (of reference aircraft)	Aircraft-centred full-system risk ratio	Progressional full-system risk ratio
Standby (effectively unequipped)	–	27.7%	100%
TA-only mode	–	10.4%	37.5%
Full RA/TA mode	Non-responding pilot	13.2%	47.8%
Full RA/TA mode	Typical pilot response	4.6%	16.5%
Full RA/TA mode	Conscientious pilot response	3.1%	11.2%

**Table 21: Progressional full-system risk ratios for various ACAS operating modes by the reference aircraft**

5.5.4.4. Obviously, the pilot engaged in an ASAS procedure will derive no benefit from operating ACAS in Standby mode (i.e. progressional risk ratio of 100%).

5.5.4.5. By operating ACAS in TA-only mode the pilot of the reference aircraft will obtain some benefit from the alerting aspects of ACAS. Comparatively, these benefits are reduced if the pilot operates ACAS in full RA/TA mode, but ignores the RAs that are generated.

5.5.4.6. With a typical response to RAs, the pilot engaged in an ASAS procedure who operates ACAS in full RA/TA mode can halve the risk of collision to which he is exposed compared to operating ACAS in TA-only mode. By responding conscientiously, the risk is further reduced to less than one third of the risk when operating ACAS in TA-only mode.

## **6. Main IAPA deliverables and study results**

### **6.1. General**

- 6.1.1. The IAPA study of the ACAS / ASAS interaction issue consisted of a comprehensive work programme supported by a set of sophisticated methods and tools, thus providing a high-level of confidence in the study results.
- 6.1.2. Phase I of the IAPA project consisted of selecting an ASAS application of particular interest for the project, i.e. an application with the potential for studying a maximum of significant and realistic issues from an ACAS safety and operational performance perspective. This selection was supported by a preliminary analysis of the ACAS / ASAS interaction issue (WP04) for a selected set of Package I Airborne Surveillance applications presenting the potential for an extension into airborne separation applications (Package II).
- 6.1.3. Phase II consisted of an in-depth investigation of the operational and safety issues potentially raised by the introduction of ASAS in the European airspace. This investigation was focused on the ASAS application selected during Phase I, i.e. the ASAS lateral crossing procedure.
- 6.1.4. The operational analysis of the potential ACAS / ASAS interaction issues was focused the two aircraft involved in the ASAS procedure. It was supported by a full set of simulations using different sources of data including:
  - an ASAS encounter model (WP06);
  - modified European radar data (WP07);
  - CFMU flight plan simulation data (WP08); and
  - data extracted from real-time simulation data (WP09).
- 6.1.5. Different sources of data were used to compensate for any individual limitations related to any one of them and to ensure that all relevant issues were identified. The use of the common simulation framework set-up during Phase I allowed the cross-validation of ACAS / ASAS interaction trends identified using each source of data, as well as the investigation of specific features depending on the source of data.
- 6.1.6. The safety analysis of the potential ACAS / ASAS interaction (WP10) investigated and assessed the impact of ASAS operations on the safety benefit provided by ACAS. This analysis considered not only the two aircraft involved in the ASAS procedures, but also the possible presence of a third aircraft. It was supported by a set of methods and tools developed in previous studies of ACAS safety and supplemented by other ATM safety assessment methodologies.
- 6.1.7. The remainder of this chapter presents a summary of the main outcomes of the IAPA project, including the methodological framework that supported the ACAS / ASAS interaction study, the main simulation results and the potential operational and safety issues identified.

## **6.2. IAPA methodology and tools**

### **6.2.1. General**

- 6.2.1.1. **The overall methodology set-up to investigate the ACAS / ASAS interaction issue is considered a major output of the IAPA project.**
- 6.2.1.2. This methodology is characterised by the performance of a comprehensive set of simulations supported by a common framework. This framework was tailored to the ASAS application selected for further investigation within IAPA, i.e. the ASAS lateral crossing procedure, but could be adapted to investigate the interaction between ACAS and other types of aircraft operations.
- 6.2.1.3. The complete work programme carried out within IAPA, and its supporting methods and tools, can thus be applied to the investigation of the ACAS interaction issue in the context of future ATM operations, including other ASAS applications but is not restricted to only this scope.
- 6.2.1.4. Among the various tools developed in support of the IAPA study, **the ATM encounter model is a major deliverable whose usefulness extends beyond just the ACAS / ASAS interaction study made within the project.**

### **6.2.2. Framework for the operational analysis of the ACAS / ASAS interaction**

- 6.2.2.1. The preliminary investigation of the ACAS / ASAS interaction issue (WP04) performed during Phase I was supported by a case-by-case analysis of relevant encounters featuring possible ASAS operations.
- 6.2.2.2. The analysis of the encounter characteristics likely to trigger an ACAS alert has proven useful in identifying the ASAS procedures with the potential for ACAS interaction. The same approach can also be applied to the preliminary investigation of the ACAS interaction issue in the context of future ATM operations likely to modify traffic patterns.
- 6.2.2.3. The comprehensive operational analysis of the ACAS / ASAS interaction issue was supported by a complete framework established during the initial phase of the IAPA project. Thus,
  - the selected ASAS application (i.e. ASPA-C&P, lateral crossing with “pass behind” and “pass in-front” procedures) and its operational environment have been defined (WP01);
  - a simulation framework has been proposed involving three different scenarios with full ASAS / ADS-B equipage and a set of ACAS / ASAS interaction indicators (WP02);
  - a simplified model of the selected ASAS application has been developed to simulate the nominal effects of the ASAS lateral crossing procedures on aircraft trajectories (WP03); and
  - an ATM encounter model has been specified, and then implemented and tuned using European radar data during Phase II. Further, it supported the development of an ASAS encounter model (WP05).

- 6.2.2.4. **This framework successfully supported the full set of simulations conducted within Phase II.** Further, specific methodologies, and associated sets of tools, were developed in support of the various data-oriented studies (cf. WP6, WP07, WP08 and WP09 work areas).
- 6.2.2.5. **The use of modified European radar data has proven particularly useful for an initial comparative assessment of the interaction of ACAS with current and future ATM operations.** This was possible due to the clear definition of the conditions of use of the ASAS procedures and the simplified modelling of their effects.
- 6.2.2.6. Finally, **the development of an ATM encounter model featuring the current aircraft operations is of particular interest for the investigation of other envisaged evolutions** in the provision of separation and their compatibility with ACAS.
- 6.2.3. Framework for the safety analysis of the ACAS / ASAS interaction
- 6.2.3.1. The safety analysis of the potential ACAS / ASAS interaction (WP10) performed during Phase II took advantage of a set of methods and tools previously developed in support of ACAS safety studies [ACA1a][ACA1b][ASARP], which were adapted for the IAPA purposes. Furthermore, it was supplemented by the use of the EUROCAE Operational Safety Assessment methodology [ED78a] and the EUROCONTROL Safety Assessment Methodology [SAM].
- 6.2.3.2. Operational Hazard Analysis was performed to identify and assess the ways in which the use of ASAS and ACAS could result in a safety issue, and particularly a near mid-air collision. The output of the OHA was used to adapt a contingency tree, previously developed in the ACASA project, to the context of the IAPA study and to ensure the completeness of the set of events that it considered.
- 6.2.3.3. This contingency tree combines ACAS logic risks (which consist of the probabilities of a near mid-air collision being caused by the RAs generated by the ACAS algorithms alone) with the probabilities of other external events (such as controller involvement and visual acquisition) and provides a full-system risk evaluation. By varying some of the scenario parameters of the ACAS simulations, many full-system risk estimates can be determined for distinct assumptions related to the ACAS equipage and operation by the flight crew.
- 6.2.3.4. To allow for the computation of ACAS logic risks in an ASAS environment, and the comparison with the logic risks in the airspace prior to the introduction of ASAS, a ACAS/ASAS-applicable safety encounter model (related to the close encounters in which the ASAS procedure would be applicable) and a ACAS/ASAS safety encounter model (related to the close encounters occurring during ASAS procedures) have been produced.
- 6.2.3.5. **Taken as a whole, these methods and tools , have proven useful in identifying the safety issues potentially raised by the ACAS / ASAS interaction, and assessing the safety benefits that can be expected from ACAS during specific ASAS operations.** The same approach can also be applied to the ACAS safety analysis of future ATM operations, which would modify either the characteristics of close encounters or any other external factors influencing the safety efficacy of ACAS.

### **6.3. ACAS / ASAS interaction during nominal operations**

#### **6.3.1. Main results for a set of Package I AS applications**

6.3.1.1. During IAPA Phase I, the preparatory analysis of the potential ACAS / ASAS interaction issue (WP04) concluded that **no interaction with ACAS is anticipated for the following ASAS applications:**

- The in-trail phases of the ASPA-S&M: “Enhanced sequencing and merging” operations whatever the altitude layer, assuming the Wake Vortex separation minima are preserved; and
- The lateral passing situations resulting from ASPA-C&P: “Enhanced crossing and passing” operations whatever the altitude layer, since the lateral spacing values required to trigger an ACAS alert during slow convergence situations are of the order of the ACAS minimum protection distance parameter (DMOD), e.g. 1.3NM for a TA above FL200. It is unlikely that such lateral spacing values would be operationally acceptable.

6.3.1.2. **Some interaction with ACAS potentially exists for the ASPA-S&M: “Enhanced sequencing and merging” operations, but only during merging situations close to the limit of what could be considered operationally acceptable.** In particular, some merging encounters with required spacing at the IAF close to the radar separation minimum in TMA (i.e. 3 NM) may trigger a TA. However, such spacing values between aircraft in sequence are unlikely to occur during typical merging situations.

6.3.1.3. Finally, the results of the preparatory analysis showed that **some interaction with ACAS potentially exists for the ASPA-C&P: ‘Enhanced crossing and passing operations’** during nominal operations. In particular, the following encounter situations were identified as likely to trigger TAs:

- Lateral crossing encounters with high closure rate and small horizontal separation between the aircraft at CPA, i.e. typically encounters with angles of convergence greater than 90 degrees and a Horizontal Miss Distance close to the applicable radar separation minima, i.e. 3 NM in TMA and 5 NM in en-route ECAC airspace; and
- Level-off encounters at the applicable vertical separation minima, i.e. 1,000 ft below FL415 in the ECAC airspace, with vertical rates operationally realistic for almost all aircraft types. In addition, 2,000 ft level-off encounters may trigger TAs in the altitude layer FL100-FL410 in case of significant, but realistic, relative altitude rates.

6.3.1.4. The 1,000 ft level-off encounters may even trigger ‘undesirable’ RAs below FL415 in case of significant, but realistic, vertical rates. It should be noted that the ACAS interaction issue raised by such encounters already exists for current ATM operations [EMO7]. Therefore, it is not solely linked to the introduction of ASAS operations.



- 6.3.1.5. With regard to the lateral crossing encounters, the specific case study performed on the ASAS Lateral Crossing application allowed the identification of the crossing situations that are more likely to trigger a TCAS II alert. The main influencing factors identified include the angle of convergence, the aircraft speed and the type of ASAS manoeuvre (i.e. “pass in-front” or “pass behind”).
- 6.3.1.6. The higher the resulting closing speed between the aircraft, the higher the likelihood of a TA. In particular, by increasing the initial rate of convergence, the “pass behind” manoeuvres are more likely to trigger TAs than the “pass in-front” manoeuvres. However, this does not mean the latter are safer than the former.
- 6.3.1.7. At the end of IAPA Phase I, the ASAS lateral crossing procedure was clearly identified as a demanding application in terms of possible interaction with ACAS. Therefore, the application was selected for further investigation within the IAPA project.

#### 6.3.2. Complementary results for the selected ASAS application

- 6.3.2.1. The ACAS simulations performed during IAPA Phase II on the ASAS Lateral Crossing application confirmed the **potential interaction that may exist between ACAS and ASAS with the demanding assumptions taken within IAPA** (e.g. a minimum horizontal separation value of 4 NM during ASAS lateral crossing procedures).
- 6.3.2.2. An investigation of ASAS operations, with distinct assumptions, was performed through the study based on real-time simulation data (WP09), which dealt with both “ASPA-Crossing & Passing” and “ASPA-Sequencing & Merging” procedures with ASAS spacing values close to current ATC practices. The analysis of the available real-time simulation data did not reveal any ACAS interaction issue.
- 6.3.2.3. On the other hand, the various data-oriented studies that dealt with the ASAS lateral crossing procedures using the framework developed for the IAPA study purposes (i.e. the WP06, WP07 and WP08 studies) highlighted a set of potential operational issues, which are discussed hereafter.

##### Potential impact of ACAS on ASAS performance

- 6.3.2.4. The possible issuance of “undesirable” ACAS alerts during the execution of ASAS lateral crossing procedures (with a minimum separation value of 4 NM) is likely to **affect the performance of the ASAS procedures, and therefore, their expected benefits.**
- 6.3.2.5. Although all three IAPA studies provided different estimates of the ratio of ASAS procedures triggering at least one TA, a similar trend was observed whatever the source of data used in the simulations. The likelihood of TAs is estimated between 13% and 18% of the ASAS procedures, regardless of whether or not a manoeuvre is required to ensure the ASAS separation. It increases to in between 42% and 67% when considering ASAS encounters with a “pass behind” or “pass in-front” manoeuvre.

- 6.3.2.6. With regard to the likelihood of RAs, all three studies provided comparable results, i.e. on average just under 1% of the ASAS procedures triggering at least one RA, whatever the scenario. Nevertheless, this proportion varies noticeably depending on the precise form of the ASAS encounters, and particularly whether or not a manoeuvre is required to ensure ASAS separation.
- 6.3.2.7. In line with the initial results of the IAPA case study (WP04), all three studies observed a slightly increased likelihood of TCAS II alerts for the “pass behind” manoeuvres compared to the “pass in-front” ones.

Potential impact of the ACAS / ASAS interaction on pilot acceptance

- 6.3.2.8. The **frequent, but non-systematic, issuance of Traffic Advisories** by the ACAS logic against the other aircraft involved in an ASAS lateral crossing procedure **is likely to be considered as disruptive from the pilot perspective, and therefore, a major ACAS / ASAS interaction issue**. Further, this is likely to affect pilots' confidence in the ASAS procedure and system.
- 6.3.2.9. The mean likelihood of undesirable TAs during ASAS operations has been estimated as up to one per ten flight hours, regardless of any other TAs that may occur independently of the ASAS lateral crossing procedure. This result is highly dependent on the frequency of the ASAS procedure, which has itself been estimated to be between one to five times per ten flight hours in the study based on modified radar data (WP07).
- 6.3.2.10. It should be noted that, in all three IAPA studies, the likelihood of TAs during the ASAS lateral crossing procedure appears to be greater at high altitudes, i.e. within sensitivity level 7 of the TCAS II logic version 7.0. Furthermore, a non-negligible proportion of repetitive TAs has been observed, i.e. in between 1% to 3%, depending on the source of data.

Potential incompatibility between ACAS and ASAS operations

- 6.3.2.11. **The possible occurrence of disruptive and undesirable Resolution Advisories by the ACAS logic during nominal ASAS operations is a major ACAS / ASAS interaction issue**. Such alerts might indeed be viewed as a lack of compatibility between the separation function provided by ASAS and the collision avoidance function provided to ACAS. Further, this is likely to affect the operational applicability of the ASAS procedures.
- 6.3.2.12. Assuming a nominal performance of the ACAS surveillance, the mean likelihood of undesirable RAs during nominal ASAS operations has been estimated up to one per sector every 6 days, regardless of any other RAs that may occur independently of the ASAS lateral crossing procedure. Once again, this result is highly dependent on the frequency of the ASAS procedure, which has been estimated to be at least one ASAS lateral crossing procedure every two hours per sector, and possibly up to three times per hour and per sector, for the European core area.
- 6.3.2.13. The various simulation results show that the issuance of the RAs is quite sensitive to the quality of the aircraft trajectories used in the simulations. A specific analysis of the TCAS II logic version 7.0 conducted in the study based on flight plan simulation data (WP08) highlighted the effects of simulated trajectory variations on the ability of the ‘Miss Distance Filter’ of the TCAS II logic to effectively prevent the issuance of undesirable RAs.

6.3.2.14. ACAS / ASAS compatibility is likely to depend on the minimum separation value applicable during the ASAS operations. In this respect, **the demanding value of 4 NM appeared to cause compatibility issues when compared with current separation margins applied by ATC.**

6.3.2.15. The sensitivity analysis (conducted in the WP08 study based on flight plan simulation data) indicated that a minimum separation value of 7 NM was necessary to prevent TAs from being triggered when an ASAS lateral crossing manoeuvre was required. Further, a minimum separation value of 5 NM was necessary to prevent the issuance of any RAs.

### 6.3.3. Comparison between ASAS and ATM operations under nominal circumstances

6.3.3.1. IAPA Phase II was also the opportunity to make a comparative analysis of the interaction with ACAS between current ATM operations and future operations following the possible introduction of ASAS applications. Because of the forward looking nature of the IAPA study, this comparison was limited to the ASAS application selected for further investigation, i.e. the ASAS lateral crossing procedure.

6.3.3.2. Despite this limitation, it is worthwhile to mention that complementary results have been obtained through two IAPA studies, i.e. the study based on the ASAS encounter model (WP06) and the study based on modified radar data (WP07).

6.3.3.3. **Current ATC practices with the typical separation margins applied by ATC appears to be much more compatible with ACAS than the ASAS lateral crossing procedures with the demanding separation minimum of 4 NM** investigated within the IAPA study, except for the 1,000 ft level-off encounters.

6.3.3.4. Depending on the source of data used for the ASAS simulations, the ratio of ASAS encounters triggering an RA compared to the original encounters with ATC increases by a factor of four with the ASAS encounter model and by a factor of forty with the modified radar data.

6.3.3.5. It was thus not possible to draw precise conclusions on the extent to which the introduction of ASAS lateral crossing procedures would increase the issuance of undesirable ACAS alerts during ASAS operations since both IAPA studies provided distinct alert rates. However, both studies provided a similar trend with regard to the prevalence of RAs between ASAS and ATM encounters.

### 6.3.4. Possible impact on ASAS application or ACAS system

6.3.4.1. The various IAPA studies that dealt with the operational aspects of the ACAS / ASAS interaction have shown that ACAS needs to be taken into consideration when developing ASAS applications. Further, the various simulations performed highlighted some specific features that are of particular importance and need specific attention.

6.3.4.2. It has thus been demonstrated that **ACAS may result in additional implications for the development of ASAS** procedures and system. In particular, care should be taken to ensure that the separation minima applicable during ASAS procedures and the ACAS logic parameters are compatible.

- 6.3.4.3. In this respect, taking into account the specific scope of the various data-oriented studies of IAPA Phase II (which were focused on demanding ASAS lateral crossing procedures), care should be taken not to conclude that the ACAS / ASAS interaction would preclude the applicability of any ASAS procedures.
- 6.3.4.4. In the perspective of a wide-spread operational use of ASAS procedures with reduced separation values when compared to current ATC practices, **the existing ACAS system may have to evolve to ensure compatibility with nominal, but demanding, ASAS operations.**
- 6.3.4.5. In particular, the initial role of the Traffic Advisory (as the precursor to a Resolution Advisory), which is no more true in current ATM operations, may be further questioned by demanding ASAS operations. Indeed, when triggered by the other aircraft involved in the ASAS procedure, the alerting role of the TA is likely to be affected by the fact that the pilot is already aware of this traffic and does not require any alert under normal circumstances.
- 6.3.4.6. To increase the compatibility between ACAS and such demanding ASAS applications, the ACAS logic for TAs, which does not currently include any filtering feature that would prevent the issuance of undesirable TAs in case of predicted large horizontal miss distances, may have to be revisited to allow for such filtering.
- 6.3.4.7. In this respect, the effectiveness of the TCAS II ‘Miss Distance Filtering’ feature that exists for RAs has proven to be of particular importance to prevent the issuance of undesirable RAs during nominal ASAS operations.

#### **6.4. ACAS / ASAS interaction during non-nominal operations**

##### **6.4.1. General**

- 6.4.1.1. The safety analysis conducted during Phase II (WP10) performed an initial evaluation of the level of safety that can be expected from the operation of ACAS when aircraft are engaged in ASAS procedures. This level of safety was assessed both qualitatively in terms of consequences and severity of hazards, and quantitatively in terms of the reduced risks of collision.
- 6.4.1.2. Because of the forward looking nature of the IAPA study, this evaluation was limited to the ASAS application selected for further investigation, i.e. the ASAS lateral crossing procedure.

##### **6.4.2. Operational hazards and IAPA contingency tree**

- 6.4.2.1. Two separate Operational Hazard Analyses were first conducted on the ASAS procedure and the ACAS procedure respectively, which were used as the basis for an analysis of the impact of the ASAS OHA on the ACAS OHA. This analysis revealed that **the interaction with ACAS is different depending on whether or not the ACAS intruder is the other aircraft involved in the ASAS procedure or a third aircraft.**

- 6.4.2.2. Furthermore, the analysis highlighted that the **enhanced Airborne Traffic Situational Awareness of the flight crew that can be expected in an ASAS environment can be a safety-contributing factor** that either mitigates the consequences or reduces the likelihood of some operational hazards related to the ACAS procedure.
- 6.4.2.3. The main findings of the ACAS / ASAS interaction OHA have been used to support the development of the IAPA contingency tree (which derives from the former ACASA event tree). Confirmation was made that all the identified hazards that may affect the safety benefits provided by ACAS during ASAS operations (within the assumptions of the study) had been taken into account in the contingency tree.
- 6.4.2.4. The two possibilities of the reference aircraft being on a close encounter course with the other aircraft in the ASAS procedure, or being on a close encounter course with a third aircraft, were handled by a high-level split of the contingency tree into an 'ASAS intruder branch' and a 'third aircraft branch'. Many, of the events on one branch were qualitatively duplicated on the other branch, but were assigned different probabilities that reflect the two contexts.
- 6.4.3. Safety encounter models and underlying NMAC rates
- 6.4.3.1. A crucial factor in evaluating the risk reduction provided by the operation of ACAS is the underlying NMAC rate of the considered airspace. The ACAS/ASAS-applicable safety encounter model and the ACAS/ASAS safety encounter model were thus used to determine the underlying NMAC rate (before and after the introduction of ASAS in the airspace) in those encounters in which the ASAS lateral crossing procedure would be applicable.
- 6.4.3.2. For the ASAS-applicable close encounter set (when handled by conventional ATC), an NMAC rate of  $1.53 \times 10^{-7}$  per flight hour was estimated. For the ASAS close encounter set (when applying the ASAS lateral crossing procedure in the same encounters), an NMAC rate of  $1.85 \times 10^{-7}$  per flight hour was estimated.
- 6.4.3.3. Rather than indicating that there will be a rise in the underlying NMAC rate when ASAS procedures are introduced, these values should instead be viewed as evidence that **care will be needed to ensure that the introduction of ASAS procedures does not lead to an unacceptable rise in the underlying risk of collision.**
- 6.4.4. Risk ratio calculations
- 6.4.4.1. The ACAS logic risk ratios calculated using both the ACAS/ASAS-applicable safety encounter model and the ACAS/ASAS safety encounter model revealed that the safety performance of ACAS is similar in both environments. **The introduction of ASAS procedures into the airspace does not present any particular problems for the ACAS logic, which will continue to act as an effective safety net.**
- 6.4.4.2. The ACAS full-system risk ratios calculated using the ACAS/ASAS safety encounter model revealed that the deployment of ACAS in ASAS procedures could typically be expected to reduce the risk of collision to 4.6% of the risk in the absence of ACAS.

- 6.4.4.3. The alerting aspects of ACAS (the prompting of contact with the controller and/or visual acquisition of the threat) are contributory factors in achieving this overall reduction, but the most important factor is the resolution advice (i.e. RAs) generated by the ACAS logic.
- 6.4.4.4. By operating ACAS and responding to RAs in the same typical manner as other pilots, the pilot engaged in an ASAS procedure can reduce the risk of collision to which he is exposed to 16.5% of the value applicable if he were not ACAS equipped.
- 6.4.4.5. By improving his own response to RAs (whilst the response of other pilots remains typical), the risk of collision to which pilot engaged in an ASAS procedure is exposed can be further reduced to 11.2% of the value applicable if he were not ACAS equipped.
- 6.4.4.6. By not responding to RAs, a pilot seriously compromises the safety benefit that can be afforded by ACAS equipage. Operating ACAS in RA mode, but ignoring the RA it generates, a pilot would expose himself (and the unwitting pilot of the other aircraft) to a risk of collision that is over four times greater than it can be if pilot typically respond to the RAs.
- 6.4.4.7. If, for some reason, an aircraft is unable to comply with RAs it is preferable that the system be placed in TA-only mode. In this circumstance the risk of collision is reduced, compared to the case of ignoring RAs, because ACAS in equipped threats is free to choose the most effective RA.
- 6.4.4.8. Nevertheless, ACAS should not be routinely operated in TA-only mode. By operating ACAS in RA mode and following the RAs that are generated, the risk of collision to a pilot engaged in an ASAS procedure is less than half the risk to which he would be exposed if he operates ACAS in TA-only mode.

## 7. Conclusions and recommendations

### 7.1. *Main achievements*

#### 7.1.1. General

7.1.1.1. The IAPA project is a substantial European contribution to the understanding of the potential interaction between ACAS and ASAS procedures. Such a contribution was required given the envisaged evolution of the European ATM system with a greater involvement of the flight crews in separation provision, which may impact the forecasted performance of both ACAS and the new ATM system itself.

7.1.1.2. The IAPA study of the ACAS / ASAS interaction issue has demonstrated that:

- ACAS remains effective as the last resort safety net and the demonstrated safety benefits underline the need to operate ACAS during ASAS operations;
- The ACAS constraints must be taken into account when developing ASAS procedures envisaged for implementation; and
- The existing ACAS system may need to evolve to improve compatibility with ASAS applications envisaged for implementation.

7.1.1.3. All conclusions drawn from the IAPA study results should be considered taking due account of the various study assumptions and limitations. These assumptions may be challenged by a specific implementation of ASAS. If so, there will be a need to further assess the interaction between ACAS and ASAS taking into account the specific environment in which ASAS would be envisaged to be operated.

7.1.1.4. Taking into account the experience gained through the IAPA project, there is evidence that a comprehensive and robust methodological framework will be required to support such future investigation of the ACAS / ASAS interaction issue. In this respect, the complete work programme carried out within IAPA is a substantial body of work on which further work should build on.

#### 7.1.2. ACAS safety net during ASAS operations

7.1.2.1. The safety analysis conducted within IAPA Phase II demonstrated that, if nominally operated, ACAS would continue to provide positive safety benefits during ASAS operations.

7.1.2.2. It confirms that operating ACAS in RA mode, but ignoring the RAs that it generates, is more dangerous than operating ACAS in TA-only mode. However, operating ACAS in TA-only mode during ASAS procedures entails a risk of collision that is more than twice what it would be if pilots engaged in ASAS procedures operate ACAS in accordance with standard operating procedure.

7.1.2.3. The standard operational procedure should be that in ASAS procedures, as at all other times, ACAS should be operated in RA mode and the RAs that are generated should be followed, and followed promptly for best benefits.

### 7.1.3. Effect of ACAS on ASAS application development

- 7.1.3.1. The preliminary analysis made during IAPA Phase I has demonstrated that the interaction with ACAS depends strongly on the nature of the ASAS application and its main assumptions with regard to the type of separation applied, i.e. lateral, longitudinal or vertical separation with applicable separation minima.
- 7.1.3.2. It also allowed the identification of possible ACAS / ASAS interaction issues that may affect a set of Package I Airborne Surveillance applications during nominal operations. In particular, some interaction with ACAS potentially exists for:
- the ASPA-C&P: ‘Enhanced Crossing and Passing operations’, for lateral crossing situations in case of demanding applicable separation minima; and
  - the ASPA-S&M: “Enhanced Sequencing and Merging operations” during the merging phases, but only during marginal situations.
- 7.1.3.3. The in-depth investigation of the ACAS / ASAS interaction issue performed during IAPA Phase II on the ASAS Lateral Crossing application confirmed the initial results achieved during Phase I. Furthermore, it demonstrated the influence of the separation minimum applicable during ASAS operations on the interaction with ACAS.

### 7.1.4. Possible effect of ASAS applications on ACAS

- 7.1.4.1. With regard to the ACAS / ASAS compatibility, the various simulations performed during IAPA Phase II have shown to what extent a demanding ASAS application can trigger undesirable ACAS alerts.
- 7.1.4.2. This is particularly the case for the possible issuance of frequent, but non-systematic, TAs against the other aircraft involved in the ASAS procedure. To avoid affecting the performance of demanding ASAS procedures, and therefore, their expected benefits, it may hence be required to revisit the current TCAS II algorithms governing the generation of for TAs.
- 7.1.4.3. Further, it will be critical to ensure that the desirable role of the ‘Miss Distance Filter’ of the TCAS II logic version 7.0 (in preventing the issuance of undesirable RAs) is effective.

### 7.1.5. Strength and relevance of the IAPA methodology

- 7.1.5.1. The IAPA methodology has proven successful in assessing the ACAS / ASAS interaction issue and would equally benefit to any future investigation of the interaction between ACAS and ATM changes in the provision of separation.
- 7.1.5.2. The performance of various simulations based on different sources of data is key to identify a comprehensive set of issues, while compensating for any limitation related to each source of data. Further, the use of a common simulation framework allows the cross-validation of the interaction trends identified with each source of data and ensures a high-level of confidence in the results.



- 7.1.5.3. The use of European radar data is key to operational relevance. It is particularly valuable in obtaining a precise understanding of the current ATC practices and allows a comparative analysis between current and future ATM operations. Furthermore, the ATM encounter model developed within IAPA (based on real encounters extracted from radar data) is a powerful tool for evaluating ATM changes and their interaction with ACAS.
- 7.1.5.4. Finally, the sophisticated methods and tools that supported the safety analysis of the ACAS / ASAS interaction allows identifying potential safety issues and assessing the ACAS safety benefits during ATM operations.

## **7.2. Recommendations**

### **7.2.1. General**

- 7.2.1.1. ACAS must be operated during ASAS procedures as in any ATM operations. Furthermore, the possible impact on the safety benefits provided by ACAS should be carefully assessed prior to any particular ASAS implementation.
- 7.2.1.2. The ACAS constraints must be taken into account when developing ASAS applications so as to achieve an appropriate ACAS / ASAS compatibility. In this regard, particular attention should be paid to the determination of the separation minima applicable during ASAS operations.
- 7.2.1.3. When implementing ASAS operations, appropriate consideration should be given to ACAS developments that would improve the compatibility with ASAS while preserving the independence of ACAS.

### **7.2.2. Future work**

- 7.2.2.1. The role of Traffic Advisories issued by the existing ACAS system in the context of ASAS operations should be reviewed so as to ensure appropriate pilot acceptance of future ASAS operations.
- 7.2.2.2. The feasibility and benefit of a ‘Miss Distance Filtering’ feature for TAs should be investigated when envisaging the implementation of demanding ASAS applications, i.e. applications with the potential for a significant interaction with ACAS from an operational performance perspective.
- 7.2.2.3. Any future investigation of ACAS / ASAS interaction issues should be supported by a comprehensive and robust methodological framework such as the one established during the IAPA project.
- 7.2.2.4. European radar data should be used in support of any future comparative analysis of the interaction with ACAS between current ATM operations and envisaged ASAS operations.
- 7.2.2.5. The demonstrated utility of the IAPA ATM encounter model for the modelling and the evaluation of future ATM operations, and particularly ASAS operations, should be noted.

## 8. References

### 8.1. IAPA references

WP	Number	Title	Version	Date	Nature
Phase I					
00	001	The IAPA Project (SCRSP paper)	1.1	18-10-02	Working Document
00	002	Project Management Plan	1.1	03-12-02	Deliverable
00	003	Notes on the Kick Off Meeting	1.0	26-11-02	Working Document
00	004	Document Format	1.0	26-11-02	Working Document
04	005	Rough Case Study	1.0	14-03-03	Working Document
01	006	Potential ASAS application identification	1.2	14-04-03	Working Document
01	007	ASAS application selection	1.2	14-04-03	Working Document
00	008	Notes on the first Phone Conference	1.0	17-01-03	Working Document
01	009	Traceability matrix for comments arising for 1 <sup>st</sup> & 2 <sup>nd</sup> progress meeting on WP006 and WP007	2.0	14-04-03	Working Document
00	010	Notes on the Progress Meeting #2	1.0	12-02-03	Working Document
02	011	Performance indicator definition	1.1	10-06-03	Working Document
01	012	Review and refinement of OSED material for lateral crossing procedure with ASAS	1.1	04-07-03	Working Document
02	013	ACAS and ASAS/ADS-B scenario definition	1.1	31-07-03	Working Document
00	014	Notes on the second Phone Conference	1.0	09-04-03	Working Document
03	015	Possible uses of the simplified model of the ASAS application behaviour	1.1	19-05-03	Working Document
01	016	Traceability matrix for comments on WP012	2.0	23-05-03	Working Document
00	017	Notes on the Progress Meeting #3	1.0	05-05-03	Working Document
01	018	Traceability matrix for comments on WP012 arising for 3 <sup>rd</sup> progress meeting	1.0	23-05-03	Working Document
05	019	Issues associated with development of ATM encounter model specification	0.2	19-06-03	Working Document

WP	Number	Title	Version	Date	Nature
03	020	Simplified model definition	2.2	13-09-04	Working Document
00	021	Notes on the Phone Conference #3	1.0	10-06-03	Working Document
04	022	Overview of the case study content	1.0	20-06-03	Working Document
05	023	Further issues associated with development of ATM encounter model specification	0.2	23-06-03	Working Document
01	024	IAPA operational environment definition	1.2	15-10-03	Deliverable
02	025	IAPA simulation framework definition	1.1	29-09-03	Deliverable
00	026	Notes on the Progress Meeting #4	1.0	01-07-03	Working Document
03	027	Simplified model of the application behaviour	1.5	10-12-04	Deliverable
04	028	Detailed case study	1.1	17-09-03	Working Document
04	029	IAPA Case study report	1.1	10-10-03	Deliverable
05	030	ATM encounter model – description and specification	1.10	06-01-05	Deliverable
05	031	ATM encounter model specification	0.1	16-10-03	Deliverable
00	032	IAPA Project Interim Report – Phase I	1.0	05-11-03	Deliverable
05	033	Traffic Mix and Vertical Speeds in Encounters	1.0	29-08-03	Working Document
00	034	Notes on the Phone Conference #4	1.0	03-09-03	Working Document
00	035	ACAS / ASAS interaction – IAPA Project (ASAS TN slides)	2.0	06-10-03	Working Document
09	036	Description of EACAC 2000 Real-Time Experiment Lateral Crossing Encounters	0.0	22-09-03	Working Document
08	037	Preparation of fast-time simulations	1.0	22-09-03	Working Document
03	038	Simplified model validation	2.0	15-10-03	Working Document
00	039	Notes on the Progress Meeting #5	1.0	01-10-03	Working Document
00	040	Notes on the Phone Conference #5	1.0	20-10-03	Working Document
Phase II					
10	041	Note on the development of the IAPA OHA	1.0	20-11-03	Working Document
09	042	Description of CoSpace Nov 2002 Real-Time Experiment Sequencing Encounters	0.0	18-11-03	Working Document

WP	Number	Title	Version	Date	Nature
08	043	Initial results of preliminary fast-time simulations with CFMU data	1.0	20-11-03	Working Document
07	044	Report on data recordings	2.1	16-01-04	Working Document
05	045	Outline methodology for WP05.2 (Analysis tool adaptation and radar data analysis)	1.3	16-04-04	Working Document
00	046	EEC Newsletter IAPA	1.0	01-04-04	Working Document
10	047	Extracts from selected SAM/OHA/FHA material	0.1	27-11-03	Working Document
00	048	Notes on the Progress Meeting #6	1.0	05-12-03	Working Document
10	049	Additional notes on the development of the IAPA OHA	0.0	15-12-03	Working Document
10	050	IAPA preliminary OHA focused on the ACAS procedure	1.1	16-07-04	Working Document
00	051	Notes on the Phone Conference #6	1.0	16-01-04	Working Document
07	052	Discussion about the encounter capture criteria	1.1	27-01-04	Working Document
08	053	Results of the optimization of the crossing detection methodology	1.0	26-01-04	Working Document
07	054	Overlap area between French and European radar data	2.0	18-03-04	Working Document
09	055	Description of CoSpace 2003 Real-Time Experiment	0.0	23-01-04	Working Document
00	056	Notes on the Progress Meeting n°7	1.0	06-02-04	Working Document
09	057	Summary of real-time simulation investigations for the IAPA project	1.0	27-02-04	Deliverable
00	058	Notes on the Phone Conference n°7	1.0	04-03-04	Working Document
07	059	Further discussion about the encounter capture criteria	1.1	02-04-04	Working Document
00	060	IAPA Project – Proposed IP for SCRSP/1	1.0	01-04-04	Working Document
07	061	Initial radar data processing	1.0	18-03-04	Working Document
07	062	Influence of track deviation tolerance on the simplified model applicability	1.0	18-03-04	Working Document
10	063	IAPA preliminary OHA focused on the ASAS procedure	1.2	07-07-04	Working Document
08	064	Initial results of ACAS simulations on encounters modified by the simplified model	1.1	25-05-04	Working Document

WP	Number	Title	Version	Date	Nature
10	065	Discussion and plans for WP10.2 (Event tree development)	1.0	02-04-04	Working Document
10	066	The ACASA contingency tree	1.0	14-03-04	Working Document
09	067	Range TAU analysis of S&M real-time simulation encounters	1.0	25-05-04	Working Document
00	068	Notes on the Progress Meeting n°8	1.0	31-03-04	Working Document
10	069	Impact of ASAS on IAPA preliminary OHA focused on ACAS	1.1	19-07-04	Working Document
10	070	Detailed plans for WP10.2 (Contingency tree development)	1.0	26-04-04	Working Document
05	071	Approach to development of ATM & ASAS encounter models	1.1	22-04-04	Working Document
09	072	Final report of real-time simulation investigations for the IAPA project	1.0	05-07-04	Deliverable
07	073	Set of ATM encounters extracted from French radar data	1.0	26-05-04	Working Document
08	074	Analysis of the RAs occurring in encounters extracted from fast-time simulations	1.1	17-06-04	Working Document
00	075	QinetiQ progress report for phone conference no. 8 (28th May 2004)	1.0	27-05-04	Working Document
00	076	Notes on the Phone Conference n°8	1.0	03-06-04	Working Document
07	077	Set of ATM encounters extracted from Maastricht radar data	1.0	07-06-04	Working Document
07	078	Plans for the modification of encounters extracted from radar data	1.3	29-10-04	Working Document
05	079	Identifying inappropriate aircraft	1.2	01-11-04	Working Document
10	080	Assumptions in IAPA contingency tree	1.0	21-06-04	Working Document
10	081	Review of ACAS and ASAS OHAs in the context of the contingency tree	1.1	18-03-05	Working Document
00	082	Notes on the Progress Meeting n°9	1.0	30-06-04	Working Document
10	083	Human Factors events in IAPA contingency tree	1.1	22-10-04	Working Document
10	084	Development of the IAPA contingency tree	1.1	03-11-04	Working Document
00	085	Notes on the Phone Conference n°9	1.0	31-08-04	Working Document
07	086	Identification and modification of radar encounters of interest	2.1	15-11-04	Working Document

WP	Number	Title	Version	Date	Nature
08	087	Results of ACAS simulations on encounters modified by the simplified model	1.0	27-09-04	Working Document
10	088	Plans for IAPA WP10.3 – Safety analysis based on OSA methodology: ACAS safety model refinement	1.1	14-03-05	Working Document
10	089	Proposed method for assessing Human Factors events probabilities	1.2	25-11-04	Working Document
00	090	Notes on the Progress Meeting n°10	1.0	08-10-04	Working Document
05	091	Removal of tactical ATC intervention in modelled encounters	1.3	22-12-04	Working Document
07	092	Coordinated approach for the ATC intervention processing	0.3	29-11-04	Working Document
05	093	Analysis of turns by the back-end software	1.1	02-11-04	Working Document
00	094	Notes on the Phone Conference n°10	1.0	05-11-04	Working Document
10	095	Contingency tree event “visual information is wrong”	1.0	04-11-04	Working Document
07	096	Results of ASAS simulations on the modified radar encounters	1.1	02-12-04	Working Document
07	097	Results of ACAS simulations on the ATM and ASAS encounters	1.1	14-12-04	Working Document
07	098	Analysis of turns within ATM radar encounters	1.0	29-11-04	Working Document
08	099	Results of ACAS simulations on wobulated ASAS encounters	1.0	26-11-04	Working Document
00	100	Notes on the Progress Meeting n°11	1.0	16-12-04	Working Document
05	101	<a href="#">Derivation of the ASAS encounter model</a>	1.0	22-12-04	<a href="#">Deliverable</a>
Phase III					
00	102	Project Status Report	1.0	21-01-05	Working Document
07	103	<a href="#">IAPA study report on modified radar data</a>	1.1	02-05-05	<a href="#">Deliverable</a>
08	104	<a href="#">IAPA study report on fast-time data</a>	1.0	15-04-05	<a href="#">Deliverable</a>
00	105	Notes on the Phone Conference n°11	1.0	01-02-05	Working Document
11	106	A contribution to the synthesis and guidelines	0.2	25-05-05	Working Document
05	107	Statistical analysis on ATM model correlations	1.0	27-04-05	Working Document
06	108	<a href="#">IAPA Study – Report on ASAS Encounter Model</a>	1.4	21-09-05	<a href="#">Deliverable</a>
00	109	Notes on the Progress Meeting n°12	1.0	22-03-05	Working Document

WP	Number	Title	Version	Date	Nature
10	110	<a href="#">IAPA Study – Report on Safety Assessment based on OSA Methodology</a>	1.5	03-10-05	Deliverable
00	111	IAPA list of actions	9.0	05-09-05	Working Document
08	112	Answer to QinetiQ WP08 comments	1.0	08-04-05	Working Document
05	113	Proportion of rate reversing aircraft in the ATM Encounter Model	1.0	08-04-05	Working Document
11	114	<a href="#">IAPA Project Final Report – Synthesis and guidelines</a>	1.2	28-10-05	Deliverable
07	115	Answer to QinetiQ WP07 comments	1.0	27-04-05	Working Document
00	116	Notes on the Phone Conference n°12	1.0	03-05-05	Working Document
05	117	Review of the IAPA ATM encounter model from an operational perspective	1.0	16-05-05	Working Document
06	118	Complementary results of a study based on ASAS Encounter Model	0.3	02-06-05	Working Document
05	119	Proportion of encounters in which both aircraft turn in ATM encounter model	1.1	18-06-05	Working Document
00	120	Notes on the Progress Meeting n°13	1.0	16-06-05	Working Document
00	121	IAPA Dissemination Forum – Agenda	1.0	30-06-05	Working Document
00	122	Notes on the Phone Conference n°13	1.0	31-08-05	Working Document
00	123	Agenda and project overview (Forum slides)	1.0	08-11-05	Working Document
00	124	Framework of the IAPA study (Forum slides)	1.0	08-11-05	Working Document
00	125	Selecting an ASAS application (Forum slides)	1.0	08-11-05	Working Document
00	126	Operational analysis of the ACAS / ASAS interaction – Method and data (Forum slides)	1.0	08-11-05	Working Document
00	127	Operational analysis of the ACAS / ASAS interaction – Consolidated results (Forum slides)	1.0	08-11-05	Working Document
00	128	Safety analysis of the ACAS / ASAS interaction (Forum slides)	1.0	08-11-05	Working Document
00	129	Project conclusions and recommendations (Forum slides)	1.0	08-11-05	Working Document
10	130	Comments to IAPA WP10 report (110D version 1.0)	1.1	11-09-05	Working Document
00	131	Notes on the Final Progress Meeting n°14	1.0	16-09-05	Working Document

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## 9. Appendix A: Wake turbulence separation minima

### Wake turbulence aircraft categories

Cf. [PANS-ATM], Chapter 4, General Provisions for Air Traffic Services.

Wake turbulence separation minima shall be based on a grouping of aircraft types into three categories according to the maximum certificated take-off mass as follows:

- a) HEAVY (H) — all aircraft types of 136,000 kg or more;
- b) MEDIUM (M) — aircraft types less than 136,000 kg but more than 7,000 kg; and
- c) LIGHT (L) — aircraft types of 7,000 kg or less.

### Wake turbulence radar separation minima

Cf. [PANS-ATM], Chapter 8, Radar Services.

Unless otherwise prescribed, the horizontal radar separation minimum shall be 9.3 km (5.0 NM). This radar separation minimum may, if so prescribed by the appropriate ATS authority, be reduced, but not below:

- a) 5.6 km (3.0 NM) when radar capabilities at a given location so permit; and
- b) 4.6 km (2.5 NM) between succeeding aircraft which are established on the same final approach track within 18.5 km (10 NM) of the runway end. A reduced separation minimum of 4.6 km (2.5 NM) may be applied, provided in particular that:
  - v) wake turbulence radar separation minima in table below, or as may be prescribed by the appropriate ATS authority (e.g. for specific aircraft types), do not apply;

Preceding aircraft category	Succeeding aircraft category	Wake turbulence radar separation minima
HEAVY	HEAVY	7.4 km (4.0 NM)
”	MEDIUM	9.3 km (5.0 NM)
”	LIGHT	11.1 km (6.0 NM)
MEDIUM	LIGHT	9.3 km (5.0 NM)

The wake vortex radar separation minima set out above shall be applied to aircraft in the approach and departure phases of flight when:

- a) An aircraft is operating directly behind another aircraft at the same altitude or less than 300 m (1,000 ft) below; or
- b) Both aircraft are using the same runway, or parallel runways separated by less than 760 m; or
- c) An aircraft is crossing behind another aircraft, at the same altitude or less than 300 m (1,000 ft) below.

## 10. Appendix B : ACAS collision avoidance logic

### 10.1. General

This appendix provides a brief overview of:

- the ACAS logic as described in the Guidance Material of the ACAS SARPs published by ICAO [ACAS], as well as
- the existing ACAS compliant equipment, i.e. version 7 of TCAS II.

### 10.2. ACAS logic

#### General

An intruder becomes a threat when it penetrates a protected volume enclosing own aircraft. The protected volume is defined by means of a range test (using range data only) and an altitude test (using altitude and range data).

The collision avoidance algorithm parameters which establish how far into the future positions are extrapolated, and which establish thresholds for determining when separations are “small”, are selected in accordance with the sensitivity level (SL) at which the threat detection algorithms are operating.

#### Range test

Essentially, the range test gives a positive result if, when approximately TAU seconds remain before closest approach, the relative velocity vector can be projected to pass through a circle of radius  $M_c$  centred on the ACAS aircraft and placed in the plane normal to the relative velocity vector ( $\Delta V$ ).

For the realizable range test, the radius of the maximum cross section through the protected volume in a plane normal to the instantaneous relative velocity vector is  $M_c$ .

This represents the maximum miss distance for which an alert can be generated if the relative velocity at the time of entry to the protected volume is maintained to closest approach.

$$M_c = \sqrt{DMOD^2 + (\Delta V * TAU)^2 / 4}$$

The constraints on the range test are designed to give a nominal warning time of TAU seconds allowing for a manoeuvre producing a displacement of DMOD (or  $D_m$ ) normal to the relative velocity vector.

### Altitude test

The objective of the altitude test is to filter out intruders that give a positive result for the range test but are nevertheless adequately separated in the vertical dimension. One of its essential feature is that it gives a positive result if the projected vertical miss distance is less than  $ZTHR$  (or  $Z_m$ ).

Since the main interest is in intruders with projected miss distances less than  $DMOD$  (or  $D_m$ ), an ideal altitude test (in combination with an ideal range test) would give a positive result if, the relative velocity vector were projected to pass through the critical area shown by the solid outline in Figure A-7.

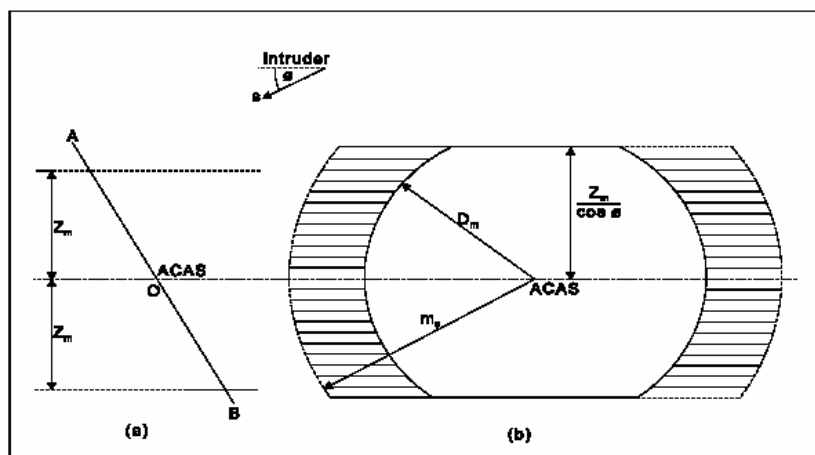


Figure A-7. Critical area for ideal altitude test

In practice, the altitude test and the range test tend to be satisfied if the vector passes through the larger area defined by the broken outline. Those intruders passing through the shaded areas are likely to give rise to unnecessary alerts.

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### 10.3. TCAS II logic version 7.0

Version 7 of TCAS II equipment complies with ACAS SARPs published by ICAO. Compared to version 6.04a, which is not ACAS compliant, version 7.0 further improves TCAS compatibility with the air traffic control system.

The most significant enhancements introduced in version 7.0 are:

- A horizontal ‘Miss Distance Filter’ (MDF),
- Reduced thresholds for compatibility with RVSM (Reduced Vertical Separation Minima) operations and 1,000 ft level-off geometries,
- Reduced frequency of rate reversing RAs,
- A 25-ft vertical tracking, and
- The reduction of electromagnetic interference.

The MDF feature permits allows RAs to be inhibited when the sequence of range measurements indicates a significant horizontal miss distance. This filter uses the bearing and bearing rate measurements to verify that neither aircraft is accelerating; the filter is disabled if the bearing measurements are not consistent with the estimated miss distance.

The ‘Vertical Threshold Test’ (VTT) feature allows a reduction in the rate of unnecessary RAs during 1,000 ft level-off geometries. When the VTT logic applies, reduced TAU threshold values are used by the ACAS logic.

The major thresholds values used by the TCAS II logic version 7.0 depend on the sensitivity level (SL) and altitude at which the threat detection algorithms are operating, as follows:

Altitude	SL	TAU values (s)		DMOD values (NM)		ZTHR values (ft)	
		TA	RA (~vtt)	TA	RA	TA	RA
0ft – 1000ft	2	20	No RA	0.30	No RA	850	No RA
1000ft – 2350ft	3	25	15~15	0.33	0.20	850	600
2350ft – FL50	4	30	20~18	0.48	0.35	850	600
FL50 – FL100	5	40	25~20	0.75	0.55	850	600
FL100 – FL200	6	45	30~22	1.00	0.80	850	600
FL200 – FL420	7	48	35~25	1.30	1.10	850	700
> FL420	7	48	35~25	1.30	1.10	1200	800

## 11. Acronyms

ACAS	Airborne Collision Avoidance System
ACASA	ACAS Analysis
ADS-B	Automatic Dependent Surveillance - Broadcast
AS	Airborne Surveillance
ASAS	Airborne Separation Assistance System
ASARP	ACAS Safety Analysis post-RVSM Project
ASPA	Airborne Spacing
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
ATSAW	Air Traffic Situational Awareness
BADA	Base of Aircraft Data
BASILE	Basic Aircraft Simulator for Logic Evaluation
C&P	Enhanced Crossing and Passing operations
CARE	Cooperative Actions of R&D in EUROCONTROL
CASCADE	Co-operative ATS through Surveillance and Communication Applications Deployed in ECAC
CDTI	Cockpit Display of Traffic Information
CFMU	Central Flow Management Unit
CNS	Communication, Navigation and Surveillance
CoC	Clear of Conflict
COOPATS	Cooperative ATS
CPA	Closest Point of Approach
CPP	Closest Point of Proximity
DSNA	Direction des Services de la Navigation Aérienne
ECAC	European Civil Aviation Conference
EEC	EUROCONTROL Experimental Centre
EUROCAE	European Organisation for Civil Aviation Electronics
ESARR	EUROCONTROL Safety Regulatory Requirements
FHA	Functional Hazard Assessment
FL	Flight Level
fpm	ft per minute

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ft	feet
HMD	Horizontal Miss Distance
HMI	Human-Machine Interface
IAF	Initial Approach Fix
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organization
IAPA	Implications on ACAS Performances due to ASAS implementation
IMC	Instrument Meteorological Conditions
InCAS	Interactive Collision Avoidance Simulator
MA-AFAS	More Autonomous – Aircraft in the Future ATM System
MASPS	Minimum Aviation System Performance Specification
MDF	Miss Distance Filter
MFF	Mediterranean Free Flight
MOPS	Minimum Operational Performance Standards
NM	Nautical Mile
NMAC	Near Mid-Air Collision
NEAN	North European ADS-B Network
NUP	NEAN Update Programme
OED	Operational Environment Definition
OH	Operational Hazard
OHA	Operational Hazard Assessment
OI	Operational Improvements
OSA	Operational Safety Assessment
OSD	Operational Service and Environment Definition
OSCAR	Off-line Simulator for Collision Avoidance Resolution
R&D	Research and Development
RA	Resolution Advisory
RFG	Requirements Focus Group
RNP	Required Navigation Performance
RVSM	Reduced Vertical Separation Minimum
RWG	Requirement Working Group
S&M	Enhanced Sequencing and Merging operations
SARPs	Standards and Recommended Practices

SC	Special Committee
SCRSP	Surveillance and Conflict Resolution Systems Panel
SOFREAVIA	Société Française d'Etudes et Réalisations d'Equipements Aéronautiques
SRR	Secondary Surveillance Radar
STAR	Standard Arrival Route
TA	Traffic Advisory
TCAS	Traffic alert and Collision Avoidance System
TIS-B	Traffic Information Service - Broadcast
TMA	Terminal control Area
TSO	Technical Standard Order
VMD	Vertical Miss Distance
VTI	Vertical Threshold Test
WG	Working Group
WP	Work Package
WPT	Waypoint

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