European Union Aviation Safety Agency

EASA.2012.FC02 SC.005

EUROCAE Study:

Analysis of TCAS II use on RPAS within European environment

An agency of the European Union

EUROCAE COMMUNICATION

Subsidiary of EUROCAE Association
The European Organisation for Civil Aviation Equipment

EASA – EUROCAE Framework contract N° EASA.2012.FC02

Special Contract N° 005

Analysis of TCAS II use on RPAS within European environment

EUROCAE COMMUNICATION
102 rue Etienne Dolet
92240 Malakoff, France
www.eurocae.net
Tel : 33 1 40 92 79 30 / Fax : 33 1 46 55 62 65

SARL au capital de 50 000 € - RCS Nanterre B 424 467 066
TVA intracommunautaire FR 51 424 467 066 - APE : 7490B
Code SIRET : 424 467 066 000 25

Authoring & Approval

Prepared By		
Luc Deneufchatel	Technical expert	
Reviewed By		
Anna von Groote	Technical Programme Manager	
Approved By		
Christian Schleifer	Director	

Document History

Edition	Date	Status	Author	Justification
00.00.01	29/7/2016	Draft	Luc Deneufchatel	
00.01.00	23/9/2016	Final	Luc Deneufchatel	Updated after internal review
00.01.00		Approved	Christian Schleifer	Completed deliverable

Table of content

List of Appendix

Glossary of terms

Term	Definition
ACAS	Airborne Collision Avoidance System
ACAS X	New generation of ACAS currently developed in the U.S
ACAS Xa	ACAS X - active surveillance
ACAS Xu	ACAS X - unmanned aircraft
ADS-B	Airborne Dependent Surveillance – Broadcast
AP/FD	Auto Pilot / Flight Director
ATC	Air Traffic Control
ATM	Air Traffic Management
CA	Collision Avoidance
CAS	Collision Avoidance System
DAA	Detect And Avoid
EASA	European Aviation Safety Agency
EDA	European Defense Agency
MASPS	Minimum Aviation System Performance Standard
MIDCAS	MIDair Collision Avoidance System (EDA project)
MOPS	Minimum Operational Performance Standard
RA	Resolution Advisory
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
SESAR	Single European Sky ATM Research Programme
SSR	Secondary Surveillance Radar
TA	Traffic Advisory
TCAP	TCAS Alert Prevention
TCAS	Traffic alert and Collision Avoidance System
UAS	Unmanned Aircraft System
VLJ	Very Light Jet

1. Introduction

Special Contract SC005 has been signed as part of EASA framework contract N° EASA.2012.FC02.

To conduct this special contract EUROCAE has set up a working team lead by Luc Deneufchâtel from the Eurocae Secretariat and composed of external experts on ACAS. These experts are:

- Thierry Arino and Beatrice Raynaud from Egis-avia
- Ken Carpenter

These experts are well known from the world wide ACAS community and they have been very active within EUROCAE WG 75 on ACAS/TCAS.

1.1 Scope & Objectives

This document is a EUROCAE study report on the possible implications of operating RPAS equipped with TCAS II in European airspace. The objective of the study is to document, and to propose an approach to address, the issues that could arise from fitting TCAS II to RPAS in Europe. While these issues apply to any collision avoidance system, TCAS II was designed and implemented before the advent of RPAS.

The issues arising from fitting TCAS II to RPAS are most notably due to:

- the impact of the weaker performance of RPAS (in particular in terms of rate of climb/descend) on the efficiency of the Collision Avoidance (CA) algorithms;
- the nature of responses to RAs;
- the characteristics of European airspace and traffic, which justify specific validation exercises for Europe.

Building on experience gained from past TCAS II studies, the specific characteristics of the European airspace and the impact of TCAS II equipage on RPAS in the airspace are discussed and a possible work programme to address the potential resulting issues is proposed.

1.2 Background & Context

In Europe, the carriage and operation of ‘Airborne Collision Avoidance System’ (ACAS) compliant equipment (i.e. TCAS II) has been mandatory for civil aircraft since 1st January 2005. TCAS II is now an integral part of ATM operations in Europe, and represents an essential element of safety in the airspace. Although not subject to the world-wide ACAS mandate, there is a possibility that some stakeholders would equip Remotely Piloted

Aircraft System (RPAS) with TCAS II to enable operation in non-segregated airspace including in European En-Route airspace. Indeed, current thinking in RTCA SC-228 is that TCAS II will be used on some UAS (their terminology) during an interim Phase 1 of the introduction of UAS into US airspace. Fitting TCAS II to RPAS is mentioned as "an acceptable interim solution for UAS to meet Phase I Detect And Avoid (DAA) MOPS" in the concept document for ACAS XU [Ref. [39], see section 3.1, page 14; Ref. [40] and Ref. [41], see slides 5 and 8].

The ACAS Xu CONOPS, which is an RTCA SC-147 working document, includes the following extract concerning the option of fitting TCAS II to UAS [40]

"*TCAS is a mature, standard, independent system that is already accepted worldwide for CA on manned aircraft. While it may be an acceptable interim solution for UAS to meet Phase I DAA MOPS, there are several concerns that may preclude extended operation in Phase II DAA and beyond. TCAS was designed for manned aircraft, relying on the flight crew to perform see and avoid operations on non-cooperative traffic. It does not support alternative sensor inputs for non-cooperative traffic, providing no CA on such traffic. UAS may not be able to support the required 2500 fpm climb and descent rates modeled in TCAS for some CA maneuvers. Modifying the logic to specifically support UAS performance would be time consuming and expensive, as would modifying the surveillance system to support alternative sensors.*

However, the TCAS II system has been developed and proven to be safe specifically for manned fixed-wing turbine-engined aircraft commonly operated in commercial air transport (i.e. with a Maximum Take-Off Mass exceeding 5,700 kg or a maximum approved passenger seating configuration of more than 19 passengers). Also, experience from TCAS II implementation in Europe has shown that several factors influence the protection afforded by TCAS II, including the traffic and encounter situations likely to occur in the airspace, the quality of the surveillance data (including altimetry errors) and the actual responses to TCAS II Resolution Advisories. Hence, should TCAS II equipage on RPAS be approved by a foreign national authority (such as the FAA), this might not directly warrant safe operations in European airspace.

Initiatives are in hand for the evolution of TCAS II into a new generation of Collision Avoidance systems for both manned and unmanned aircraft. These include:

- ACAS X, which is being developed in the U.S. and has several variants including ACAS Xu, the variant customized for Unmanned Aerial Systems (UAS); and
- Various initiatives in Europe over the recent years to develop Detect And Avoid (DAA) functionalities, including Collision Avoidance (CA) function, for RPAS (refer to https://www.eurocontrol.int/rpas for details).

To approve RPAS fitted with TCAS II (or any other CA system) in Europe, EASA would therefore benefit from appropriate evidence that this will not affect the safety of aircraft operations in European airspace, including that of manned civil aircraft subject to the TCAS II mandate. In support of this, EUROCAE is conducting this scoping study into the impact of permitting TCAS II equipage on RPAS operating in European airspace.

1.3 References

1.3.1 Standards and performance documents

Ref. [1] **EASA Certification Specifications - European Technical Standard Orders (CS -ETSO)**, TCAS II, referenced ETSO-C119c, available at: http://SJU.europa.eu/agency-measures/certification-specifications.php

Ref. [2] **EUROCAE TCAS Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II)**, ED-143, latest edition, available for purchase at: http://boutique.eurocae.net/catalog/product_info.php?products_id=300

Ref. [3] **EUROCAE Minimum Operational Performance Standards (MOPS) for Flight Guidance System (FGS) coupled to Traffic alert and Collision Avoidance System (TCAS)**, ED-224, latest edition available for purchase at: http://boutique.eurocae.net/catalog/product_info.php?products_id=300

Ref. [4] **EUROCONTROL Performance Review Report 2014 -** An Assessment of Air Traffic Management in Europe during the Calendar Year 2014, available at: http://www.eurocontrol.int/sites/default/files/publication/files/prr-2014.PDF

Ref. [5] **EUROCONTROL - FAA 2013 Comparison of Air Traffic Management-Related Operational Performance: U.S./Europe**, available at: https://www.faa.gov/air_traffic/publications/media/us_eu_comparison_2013.pdf

Ref. [6] **ICAO Annex 10, Volume IV**, “Surveillance Radar and Collision Avoidance” Systems”, 4th Edition available for purchase at: www.icao.int

Ref. [7] **ICAO PANS-ATM**, Doc 4444, 15thEdition available for purchase at: www.icao.int

1.3.2 European studies of ACAS performance

Ref. [8] **EUROCONTROL ACAS website**, documents available at: http://www.eurocontrol.int/articles/acas-ii-studies

Ref. [9] **ACASA Final Report,** EUROCONTROL, ACASA/WP10/222D, Version 1.1, March 2002

Ref. [10] **ACASA European Encounter Model**, Specifications and Probability tables, CENA/Sofreavia & QinetiQ, ACASA/WP1/186D, July 2001

Ref. [11] **EMOTION-7 Final Report,** European Maintenance of TCAS II Version 7.0, EMOTION7/WP5/107/D, Version 2.0, January 2003

Ref. [12] **IAPA Project Final Report**, IAPA/WP11/114D, Version 1.2, October 2005

Ref. [13] **IAPA ATM Encounter Model**, Description and specification, IAPA/WP5/30D, Version 1.1, January 2005

Ref. [14] **ASARP Final report on the safety of ACAS II in the European RVSM environment**, ASARP/WP9/72D, Version 0.1, February 2006

Ref. [15] **ASARP Final Report on post-RVSM European safety encounter model**, ASARP/WP2/34D, Version 1.1, January 2006

Ref. [16] **ASARP Final report on the investigation of the multiple aircraft encounter issue**, ASARP/WP7/53D, Version 1.1, February 2006

Ref. [17] **SIRE Project Final Report**, SIRE/WP4/58D, Version 1.0, December 2005

Ref. [18] **SIRE Safety encounter model focused on issue SA01a**, SIRE/WP2/21D, Version 1.0, April 2005

Ref. [19] **SIRE+ TCAS II performance in European TMAs, Part 1: Analysis**, SIRE+/WP8/81D, Version 1.1, February 2009

Ref. [20] **AVAL Final Report**, Safety benefits of ACAS in the future European ATM environment with Very Light Jets, AVAL/WA7/41D, Version 1.3, November 2009

Ref. [21] **AVAL European safety-encounter model incorporating VLJ operations**, AVAL/WA4/30D, Version 1.1, May 2009

Ref. [22] **PASS Final Report**, PASS/WA5/WP3/171D, Version 1.1, November 2010

Ref. [23] **PASS Encounter model for safety-net related occurrences – Specification**, PASS/WA2/WP5/75D, Version 2.3, May 2010

Ref. [24] **Potential improvements to the PASS Encounter Model**, PASS/WA2/WP5/139W, Version 1.1, February 2010

Ref. [25] **CAUSE - Unmanned Aircraft Systems – ATM Collision Avoidance Requirements**, CND/COE/CNS/09-156, Version 1.3, May 2010

Ref. [26] **SESAR P04.08.02-D06-VR-APFD** Validation Report for automatic responses to ACAS RAs, 00.01.00, April 2011

Ref. [27] **SESAR P04.08.02-D07-SPR-APFD** Safety and Performance Requirements for automatic responses to ACAS RAs, 00.01.01, October 2011

Ref. [28] **Validation of the FGS coupled to TCAS MASPS Requirements** (for EUROCAE), Egis Avia N130036, Version 1.0, May 2013

Ref. [29] **SESAR P04.08.02-D03-VR-TCAP** Validation Report for new possible altitude capture laws, 00.01.01, November 2011

Ref. [30] **SESAR P04.08.02-D04-SPR-TCAP** Safety Performance Requirements for new possible altitude capture laws, 00.01.00, September 2011

Ref. [31] **TCAP impact on US airspace** (Step 1 for AIRBUS), Deeper investigation on TCAP performance in the European airspace, Egis Avia, DEP/C2560/N120015, Version 1.0, March 2012

Ref. [32] **TCAP impact on US airspace** (Step 1 for AIRBUS), TCAP impact on US airspace – Analysis on the US-like model, Egis Avia, DEP/C2560/N120014, Version 1.0, March 2012

Ref. [33] **TCAP US Step 2 Final Report** (for AIRBUS), TCAP impact on US airspace, Egis Avia & MIT/LL, TLSE/C2593/N120061/CM, Version 1.1, October 2012

Ref. [34] **Safety and Suitability Performance Assessment of ACAS Xa**, ICAO Aeronautical Surveillance Panel, IP ASP13-02, Washington D.C., 25-28 September 2012

Ref. [35] **04.08.01-D88 SPR-ACASX-CURRENT** Safety assessment of ACAS Xa in Europe, Edition 00.01.02, May 2015

Ref. [36] **04.08.01-D89 VALR-ACASX-CURRENT** Validation report for the evaluation of ACAS Xa in Europe, Edition 00.01.01, February 2015

Ref. [37] **04.08.01-D101-GEN-ACASX-Acceptability** SESAR vision of European acceptability criteria for ACAS Xa development, Edition .01.01, October 2015

1.3.3 Other References

Ref. [38] **SESAR 2020, Multi-annual Work Programme,** Edition 1.0, July 2015

Ref. [39] **Concept of Use for the Airborne Collision Avoidance System ACAS X_U**, version 2, FAA, ACAS-CON-15.001-V2R0, 15 September 2015

Ref. [40] **Concept of Use for ACAS XU,** Walter Bender, ACAS XU Concept Lead, JHU/APL and Charles Leeper, ACAS XU Lead, JHU/APL, Briefing to the joint EUROCAE WG-73 and WG-75 XU Workshop at EUROCONTROL HQ on September 21, 2015, available from EUROCAE

Ref. [41] **"Unmanned Aircraft System (UAS) Standards Development: RTCA SC-228 Statement Update",** presented to WG-73 by Sheila Mariano. FAA, 28 June June 2016

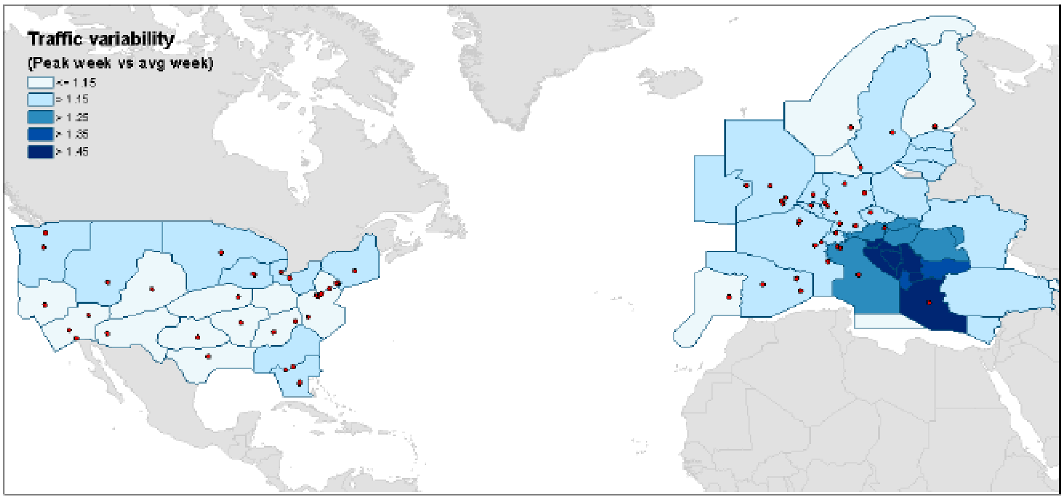
2. The characteristics of European airspace and air-traffic

2.1 Airspace & traffic characteristics

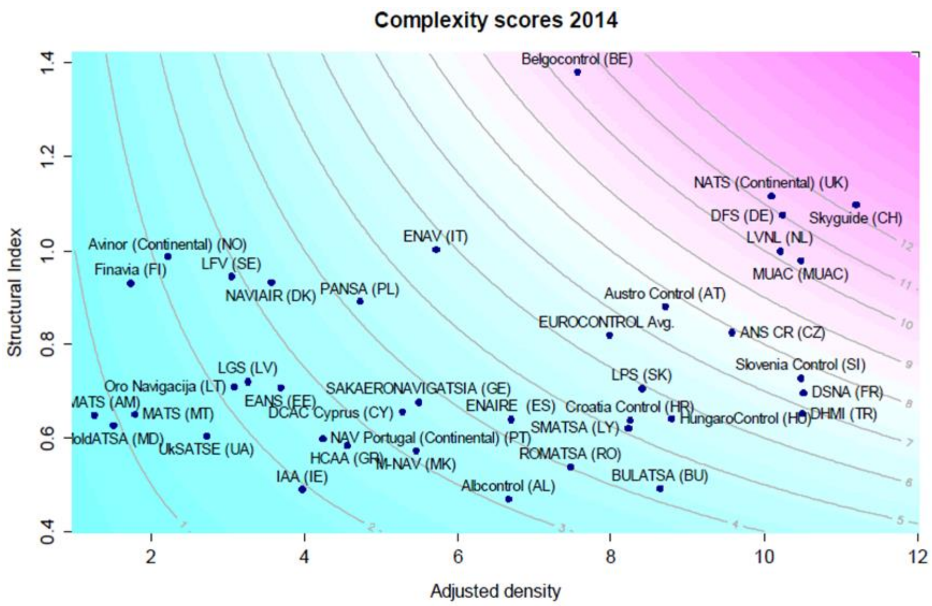
Experience has shown that TCAS II performance is very sensitive to the characteristics of the airspace in which it is operated. In other words, changes in 'encounter' types that may seem small can have a large effect on safety benefits and operational acceptability of TCAS II RAs.

Key characteristics of European airspace that have been shown to influence the encounter characteristics in the airspace include:

- Some variability of the traffic all over Europe: greater seasonal variability notably in South East Europe compared to the U.S., but also variability in space with some specific areas having high traffic complexity scores;

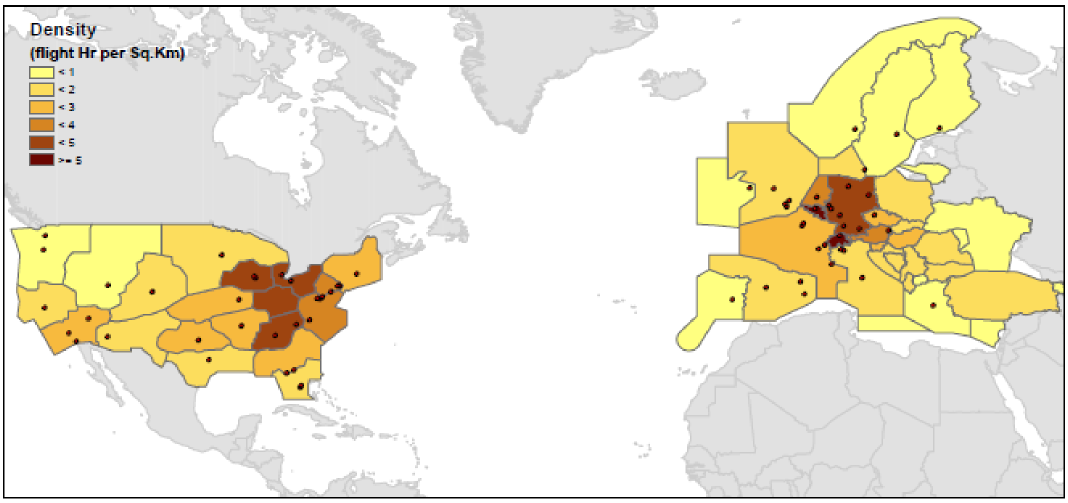


Source EUROCONTROL - FAA 2013 Comparison of ATM-Related Operational Performance [Ref. [5], section 3.1.4, page 32]



Source EUROCONTROL Performance Review Report 2014 [Ref. [4], figure 2-10, page 10]

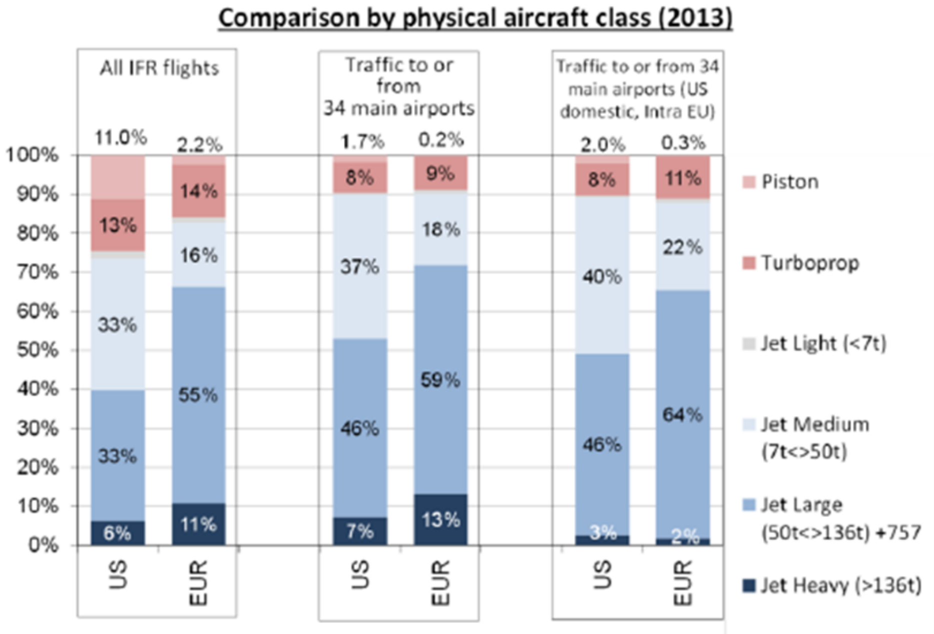
- Dense and complex traffic demand in the European "core area", with main airports in relatively close proximity and high traffic levels in En-Route airspace with structural complexity linked to potential horizontal, vertical and speed interactions between aircraft;



Source EUROCONTROL - FAA 2013 Comparison of ATM-Related Operational Performance: U.S./Europe 2013 [Ref. [5], section 3.1.2, page 30]

Note: The figure above shows the traffic density in US and European En route centres measured in annual flight hours per square kilometre for all altitudes in 2013. For Europe, the map is shown at State level because the display by En route centre would hide the centres in lower airspace. In Europe, the "core area" comprising of the Benelux States, Northeast France, Germany, and Switzerland is the densest and most complex airspace due among others to the close location of several major airports (depicted by black dots in the figure).

- Limited traffic mix in terms of type of flights and aircraft performances (compared to the U.S.), with a relatively small share of General Aviation traffic and smaller piston and turboprop aircraft compared to the share of Commercial Aviation Traffic and jet aircraft subject to the ACAS II mandate;



Source EUROCONTROL - FAA 2013 Comparison of ATM-Related Operational Performance Ref. [5], section 3.1.5, page 33]

- Different ATC working practices in the various European ATS Units, some of them more likely to generate "hot-spot" of alerts. These include:
  - the design of STAR and SID procedures at major airports with the horizontal and vertical convergence between the arrival and departure traffic flows separated only vertically, by 1,000 feet, at the procedure intersection points;
  - the use of composite horizontal and vertical separation in constrained European En-Route airspace inducing vertical crossing encounters.

2.2 Key features influencing ACAS II performance

These European airspace and traffic characteristics have been shown to influence the performance of ACAS II in today's ATM operations notably due to:

- A higher proportion of 1,000 feet level-off encounters in Europe than in the US in Terminal sectors and En-Route airspace, particularly in areas with high traffic complexity and between arrival and departure flights at major airports;
- A higher proportion of IFR/IFR encounters in Europe than in the US, encounters which are more likely to require coordinated ACAS Resolutions in case of high convergence rate or risk bearing encounters;
- A higher proportion of encounters involving IFR flights in vertical evolution with high vertical rates in Europe than in the US, due to the greater proportion of large and medium jet aircraft in the airspace and the close proximity of major TMAs particularly in the European core area;
- A smaller proportion of IFR/VFR encounters and "hot-spots" of alerts at low altitudes in Europe than in the US, due to the limited use of visual separation operations in Europe compared to the US;
- A greater proportion of vertical crossing encounters between IFR flights in Europe than in the US, particularly at specific locations in Europe due to local ATM working practices in constrained airspace.

3. The history and content of the methods used to validate the various TCAS versions for Europe

3.1 Past studies of TCAS II performance in Europe

Since the deployment phase of TCAS II in Europe (*circa* 2000), there have been several significant projects examining the implications of potential changes to ATM or Aircraft operations (e.g. RVSM implementation, Very Light Jets, RPAs, TCAS AP/FD, i.e. Coupling TCAS with auto-pilot / flight director, etc.) for the safety benefit provided by TCAS II in Europe.

More recently, the safety and operational benefits of ACAS Xa, which is envisaged as a successor for TCAS II for the commercial air traffic subject to the ACAS II mandate, has been evaluated within the frame of the SESAR R&D work programme.

Relevant past studies about TCAS II / ACAS performance in Europe include the following:

Study about TCAS II / ACAS performances in Europe	Topics under evaluation
SESAR P04.08.01 (Enhanced Safety Nets for En-Route and TMA Operations) project (2010-2016)	Safety performance assessment of the AIRBUS AP/FD TCAS function and operational performance assessment of the TCAP (TCAS Alert Prevention) function in Europe, in support of the development of MASPS for Flight Guidance System coupled to TCAS (ED-224). Safety and operational performance assessment of ACAS Xa in Europe, in support of ACAS X MOPS development and Safety & Performance Requirements determination for Europe.
CAUSE (Unmanned Aircraft Systems – ATM Collision Avoidance Requirements) project of EUROCONTROL (2010)	Assessment of various aspects of potential UAS equipage with a collision avoidance system as part of the UAS's Sense & Avoid functionality, including the benefits of fitting UAS with ACAS II.
PASS (Performance and safety Aspects of STCA, full Study) of EUROCONTROL (2007-2010)	Assessment of performance and safety aspects of Short Term Conflict Alert (STCA), including human performance aspects and consideration of interactions between operational use of STCA and ACAS II
AVAL (ACAS on VLJs and LJs – Assessment of safety Level) project of EUROCONTROL (2007-2009)	Assessment of the possible safety benefits resulting from equipping Very Light Jets (VLJs) and Light Jet (LJs) with ACAS II, and of the potential implications for the performance of TCAS II as a whole in European airspace.

Study about TCAS II / ACAS performances in Europe	Topics under evaluation
IAPA (Implications on ACAS Performances due to ASAS implementation) project of EUROCONTROL (2002-2005)	Investigation of the interaction between TCAS II and ASAS (Airborne Separation Assistance System), in support of the development of future ASAS applications in Europe: • Assessment of the operational implications for TCAS II performance due to possible ASAS implementation, and • Assessment whether the benefits expected from ASAS could be compromised due to the operations of TCAS II.
ASARP (ACAS Safety Analysis post-RVSM Project) of EUROCONTROL (2004-2006)	Assessment of the actual safety performances of TCAS II in European RVSM airspace after a few years of RVSM operations.
SIRE+ (Safety Issue Rectification Extension) project of EUROCONTROL (2006-2008) **SIR (Safety Issue Rectification) project of EUROCONTROL (2003-2005)**	Development, validation, support of MOPS amendments and the certification of TCAS II logic changes to ensure European needs and safety concerns were addressed in the revised TCAS II version 7.1 standards. Specific issues identified in Europe, and rectified in version 7.1, include: • Failure of TCAS to reverse some RAs when a reversal is required to resolve the collision threat (referred to as SA01 issue, the Überlingen-like scenario), and • Observation that, not infrequently, flight crews unintentionally manoeuvre in the wrong direction to a specific type of RA (referred to as SA-AVSA issue).
ACASA (ACAS Analysis) project of EUROCONTROL (1998-2001)	Investigation of TCAS II operational implementation, in support of the mandate for the carriage of ACAS II in Europe, including the implications of potential changes to ATM operations (like the introduction of RVSM operations) upon the safety benefits provided by TCAS II in the European airspace

Table 1: Past studies concerning TCAS II performance in Europe

3.2 Key factors influencing ACAS performance

Experience from these past projects and studies of TCAS II performance has shown that the safety benefits of ACAS depend on the efficacy of the Collision Avoidance System (CAS) logic, but are also highly affected by:

- the environment in which ACAS is being operated,
- the way it is operated by the pilots, and

- the possible interaction between ACAS and other lines of defence against the risk of mid-air collision, i.e. clearances and instructions issued by ATC in controlled airspace and the manoeuvres resulting from the application of the See & Avoid principle.

In addition, the CAS logic issues only vertical advisories and makes assumptions about the climb and descent performance of own aircraft. Provision is made to prevent positive climb or descend RAs in restricted flight regimes (e.g., descend RAs close to the ground and, for a small number of aircraft types, climb RAs at high altitude), but the logic generally assumes that positive RAs (1500fpm) and increased rate RAs (2500fpm) can be followed. A restricted ability to climb or descend will limit the efficacy of the CAS logic. This limitation will be particularly critical in encounters where the logic selects an altitude crossing RA because, in these cases, a slow or inadequate response will increase greatly the risk that the RA reduces altitude separation.

Before envisaging fitting RPAS with TCAS II to allow their operation in non-segregated airspace, it will be essential to demonstrate that TCAS II is effective for RPAS taking into account the particular characteristics of the platform concerned. It will also be essential to show that the safety and operational performance of TCAS II on other aircraft is not degraded.

Before envisaging of fitting RPAS with a new ACAS (e.g. ACAS Xu or some other European DAA system) for unsegregated operations, it will be essential to demonstrate that it is interoperable with TCAS II and will not degrade the safety benefit that TCAS II equipage delivers to medium and large commercial air traffic.

For further details on the key factors influencing ACAS performance refer to Appendix B.

3.3 Assessing CAS logic performances

The performance of an ACAS, and its CA logic, is generally assessed along two main threads:

- the safety benefits that can be expected from the ACAS, in terms of reduction of the risk of mid-air collision, and
- the operational suitability of ACAS operations, in terms of compatibility with ATM operations in the considered airspace and with the operation of the aircraft fitted with the ACAS.

Regarding the safety benefits of aircraft equipage with ACAS, it is worth distinguishing between the reduction of the risk of mid-air collisions (risk ratio measure) in the airspace as a whole (the airspace perspective), and the reduction of the risk of mid-air collisions afforded to an individual aircraft when fitting them with ACAS (the aircraft perspective).

The cornerstone of the evaluation of the safety and operational benefits of ACAS in Europe is the encounter-model based methodology (see §3.6 for further details). This methodology builds on experience gained from several European and US projects conducted over the two last decades and is also acknowledged in the EUROCAE / RTCA context.

This methodology has been used extensively in past studies related to TCAS II (and more recently ACAS Xa) development, validation and standardisation, and has proven to be valuable to:

- Identifying potential safety and operational issues related to TCAS II operations prior to a change in airspace characteristics (e.g. RVSM operations) or when envisaging fitting on a new fleet of aircraft with TCAS II (e.g. Helicopters, VLJs or RPAS);
- Identifying potential safety and operational issues during TCAS II or any new CAS logic development (prior to deployment phase) thanks to independent validation activities using comprehensive simulation framework (different from the one used for design);
- Influencing the design of new CAS logic (e.g. ACAS Xa for medium and large manned commercial air traffic) through the analysis of relevant metrics during the design process;
- Determining minimum safety and performance requirements for the Collision Avoidance function, in support to MOPS development.

In addition, TCAS monitoring data and radar data recordings are used to get an insight into the compatibility of ACAS Xa with local ATC practices at challenging locations (see §2.2 for further details). The use of large quantities of radar data from particular locations is a quick and effective means of anticipating the operational behaviour of an ACAS at that location. However the amount of radar data available is usually not enough to get statistically significant measurements of the safety benefit afforded by ACAS in the airspace.

3.4 Driving the development of new CAS logic

Experience has shown that it is essential to validate any change in ACAS logic to find any potential safety or operational issues that might otherwise be revealed late and affect timescales for MOPS definition and operational introduction, or be discovered in service.

This was notably the case at the time of TCAS II v7.1 development (cf. SIR, SIRE+ projects) with an extensive validation of two logic Change Proposals that rectify specific issues identified in Europe:

- The improvement of the reversal logic (CP112E) to address logic shortfall identified during the early operational monitoring of TCAS II version 7.0 and highlighted by the Überlingen mid-air collision investigation;
- The replacement of the “Adjust Vertical Speed, Adjust” (AVSA) RA to a “Level-Off, Level-Off” RA (CP115) to prevent inappropriate pilot’s response to RAs.

More recently, in the context of the SESAR R&D work programme related to ACAS Xa, SESAR partners have conducted a series of validation activities to analyse the safety benefits and operational suitability of ACAS Xa operations in Europe, including compatibility with TCAS II operations, with a specific focus on the European environment.

These analyses, conducted on various logic Runs, have shown that the safety performance (by risk ratio measure) of ACAS Xa in European airspace should exceed that of TCAS II. However, the analyses also revealed a number of encounter scenarios and aspects of performance (of which a number were more prevalent in European airspace than in US airspace) where the logic needed to be improved[1].

Before envisaging fitting RPAS with a new CAS logic (e.g. ACAS Xu or some other European DAA system), it will be essential to demonstrate that the RPAS operations are safe and do not degrade the safety and operational benefits afforded by TCAS II in the airspace.

3.5 Validating new CAS Safety & Performance Requirements

Experience has shown that it is essential to validate any change in TCAS II operations to determine minimum Safety and Performance Requirements sustaining safe and efficient TCAS II operations in Europe.

Such a validation was conducted in the frame of the SESAR R&D work programme to assess:

- The safety performance of automatic responses to ACAS RAs (AIRBUS Solution AP/FD TCAS);
- The operational performance of new altitude capture laws to prevent the issuance of unnecessary ACAS RAs while approaching the Selected Flight Level (AIRBUS TCAP Solution).

Building on the results of these validation activities, SPR (Safety and Performance Requirements) documents have been produced by SESAR partners to support the development of MASPS for Flight Guidance System coupled to TCAS (ED-224).

When envisaging fitting RPAS with TCAS II or any new ACAS, it will be essential to demonstrate that the avoidance manoeuvres engaged by remote pilots or flown automatically by the UAS are effective, acceptably safe and compatible with ATM and TCAS II operations in the airspace.

[1] The lesson was learnt, which is the important point. At the time of writing, the latest version of ACAS Xa (Run 15) is considered superior to TCAS II in very nearly all respects (possibly all); of course, this has to be validated for Europe, preferably by European workers.

3.6 Encounter model-based methodology

Because the situations where ACAS is likely to play a role are rare events, the development of TCAS and the validation of its performances required the establishment of a new methodology relying on a set of models replicating the environment in which ACAS is operated. These models notably include:

- encounter models which capture the properties of encounters likely to occur in the airspace and in which ACAS is likely to play a role;
- models of pilot reaction in response to RAs; and
- models of altimetry errors.

Details regarding the "Encounter model-based methodology" could be found in Appendix D

3.7 Use of local radar recordings

To complement the encounter model-based methodology described above, TCAS II monitoring data and radar data recordings are recommended to be used for evaluating the impact of an ACAS in specific challenging local environments.

This was notably the case at the time of TCAS II v7.1 development, with a specific analysis of the operational and safety effect of CP112E and CP115 introduction in three major European TMAs.

More recently, in the context of the SESAR R&D work programme related to ACAS Xa, SESAR partners have used recorded TCAS encounters and radar data to investigate the operational performance of ACAS Xa at specific locations. Similarly in the U.S. the FAA and MIT/LL teams are using TCAS monitoring data from the TOPA (TCAS Operational Performance Assessment) program to assess the operational suitability of ACAS Xa/Xo in challenging local Terminal Areas.

Experience has shown that analysis of operational safety performance of ACAS using real representative surveillance data is essential to avoid unexpected operational issues, often specific to 'hotspot' high density airspaces or to particular local ATM or air traffic operations, which are more difficult to identify using the broader model-based methodology.

4. RPAS characteristics and their potential impact on TCAS logic

In this section the differences between RPAS operation and the operation of the aircraft for which TCAS II was designed, how these differences might influence the performance of TCAS II, are presented. It also covers the performance differences that might vary between the US and Europe.

4.1 Operational Concept

TCAS II offers advice in three forms: a traffic display; Traffic Advisories (TAs); and Resolution Advisories (RAs).

Pilots (of manned aircraft) undoubtedly use the traffic display as an aid to situational awareness, but neither the display nor TCAS II as a whole was originally designed for this use, and the display is not necessarily sufficiently comprehensive to be relied upon for this function. During the Limited Installation Program in the late 1980s, one of the two installations under test displayed traffic only when there was a TA or when the pilot requested the display. As it happened, the display proved so popular (as opposed to useful) that it was made standard. More importantly, the surveillance system is designed to support TAs and RAs; it is not designed to support the traffic display. The relevance of these comments to the fitting of TCAS II to RPAS is that TCAS II should not be relied upon to provide the information on proximate aircraft that the pilot of the RPA might need.

TAs are generated to prompt the pilot to carry out a visual search for the potential threat (aided by the traffic display), and to prepare the pilot for a possible RA. It is uncertain what either of these means for the pilot of an RPA, and it could be questioned whether TAs serve any purpose for RPAS.

The overriding design objective for TCAS II was to provide reliable and useful RAs. The potential value of RAs for RPAS is obvious but the response to RAs can be generated in two quite different ways: an automatic response, generated by and on the aircraft; or remotely by the pilot. These two approaches have rival merits and raise quite different problems, which are discussed in section 4.2.5.

At the time of writing, it is not certain which approach will be adopted in the TCAS II installation on RPAS , and in practice the approach could vary between platforms.

4.2 System components

At the highest level, TCAS II in operation relies on the following:

- a surveillance system to track other aircraft,
- CAS logic that generates TAs and RAs,

- SSR based communications to coordinate RAs with other aircraft,
- display and enunciation components announcing the TAs and RAs to the pilot,
- a pilot that responds to the TAs and RAs,
- flight deck controls that convey the pilot's instructions to the aircraft systems, and
- an aircraft that executes the avoidance manoeuvres.

This list is incomplete and simplified but the authors believe it is sufficient to identify all aspects of the system that could lead to unsatisfactory performance when installed on RPAS. Having identified those aspects of the system that require discussion, we are further concerned with those issues where a difference could exist between the US and Europe.

These system components are discussed below and aspects of the system that require further discussion here are **highlighted in bold** and followed by a [number].

4.2.1 Surveillance

TCAS II uses two techniques to acquire information on proximate aircraft: SSR interrogation and the receipt of ADS-B broadcast from other aircraft. It **tracks only SSR transponder equipped aircraft**, a fact that might be more significant for RPAS than for conventional aircraft. [1] The importance of this limitation is an operational and policy issue beyond the scope of this paper. It is a matter where there could be a difference between different regulatory regimes.

SSR interrogation requires aerials to be mounted on the aircraft in a way that provides a satisfactory ground plane. It might be difficult to find **satisfactory mounting for the aerials on some RPAS**, **or to provide sufficient power**. [2] These issues are not specific to RPAS; they also affect many small aircraft, helicopters and even large aircraft (e.g. Concorde). Furthermore, they are purely technical and an installation that is found satisfactory in one regulatory regime will probably be universally acceptable.

The **SSR environment** varies from one location to another, so there is potential for the quality of the TCAS II to vary and for the impact of TCAS II on the environment to vary. [3] However, the authors are not aware of any reason to regard this as a more significant issue for RPAS than for conventional manned aircraft.

4.2.2 CAS Logic

As has been discussed above, the performance of the logic depends on several factors: the response of the pilot; the response of the aircraft (i.e. its ability to climb and descend and to change vertical rate); and the characteristics of its encounters in an airspace. Pilot response and the performance capabilities of the aircraft are discussed below in sections 4.2.5 and 4.2.7

The overall performance of the CAS logic in an airspace depends on the characteristics of the encounters in that airspace. The differences between the USA and Europe in how TCAS II operates [4] have been described above. This means that evidence of satisfactory performance in one regime cannot be sufficient to conclude that it will be satisfactory in another regime.

4.2.3 Coordination

TCAS II uses 1030/1090 crosslink to coordinate the RAs when two TCAS II equipped aircraft meet. Whilst reliable coordination is critical to the safe operation of TCAS II, the issue is identical for manned aircraft and RPA, and there are no differences between the USA and Europe to explore.

4.2.4 Display and Enunciation

The display of traffic and alerts and enunciation of alerts to pilots of RPA could be quite different from that on manned aircraft but, provided the pilot interface has been designed well, it is difficult to see how this would have any effect on the performance of TCAS II. Failure of the link between the pilot and the RPA is discussed in the next section. Latency on the link would cause the pilot to respond slowly, it is also discussed in the next section.

Displays and alerts found satisfactory in one regulatory regime will probably be universally acceptable.

4.2.5 The Pilot response

It is difficult to speculate how pilots of RPA might behave differently from the pilots of conventional manned aircraft (assuming similar training level), nor do we know how they might want to use the traffic display and the TAs. Moreover, it would be difficult to substantiate an imagined difference between the USA and Europe in this respect. However, the pilot, or automatic, response to RAs is critical to the performance of the logic, and this might have an effect on the differences in CAS logic performance between the USA and Europe.

In the case where the pilots execute the RA response, latency on the link will delay the pilot's response to RAs, which will have a detrimental effect on the performance of the CAS logic. The differences in the types of encounters and RAs typical in Europe and the USA mean that the magnitude of this detrimental effect might also differ. It will be essential to model the increased delay in RA response due to the latency [5] when validating the CAS logic for Europe.

An automatic response to RAs would avoid the problems of a delayed pilot response and also ensure that TCAS II continues to function in the event of link failure. Such a technical solution implemented in an installation that is found satisfactory in one regulatory regime will probably be universally acceptable.

However, this approach deeply limits the ability of the pilot to identify spurious or false RAs, putting pressure on the quality of build standards.

4.2.6 Control of the Aircraft

Delay on the control link would have the same effect as a delayed pilot response, and link failure would have the same effect as the pilot failing to respond. Again, automatic responses to RAs would avoid these problems but, as in the previous section, require more demanding build standards for the TCAS II that generates the RAs.

4.2.7 Aircraft Performance

TCAS II RAs assume vertical accelerations of 0.25g and vertical rates of 1500fpm, sometimes 0.33g and 2500fpm. **Limited performance capability will degrade the performance of the CAS logic**. [6].

As with the effect of increased pilot response latency, this needs to be assessed separately for Europe because of its particular airspace characteristics.

4.3 Summary

This review of the potential impact of RPAS characteristics on TCAS II has identified six issues.

	Issues	Proposed mitigations
1	tracks only SSR transponder equipped aircraft	operational and policy issue
2	aerial mounting and power supply	technical, no US/European distinction
3	SSR environment	no distinction from manned aircraft
4	USA/Europe differences in CAS logic operation	CAS logic requires European validation
5	latency delay in RA response[2]	to be included in the logic validation
6	limited aircraft performance capability	to be included in the logic validation

Certification of a TCAS II installation on an RPAS would raise many issues, some shared with manned aircraft and some new for RPAS. Operational, policy and RF issues are also raised. However, the only factor where there is a significant technical difference between the USA and Europe, due to differences in airspace characteristics, that requires examination is the performance of the CAS logic, which needs to take account of the effect of link latency delays in RA response and aircraft performance limitations.

In addition to the airspace characteristics, the validation of the CAS logic needs to incorporate the nature of the pilot response and any aircraft performance limitations

At the time of writing, it is not certain which approach will be adopted in the TCAS II installation on RPAS, and in practice the approach could vary between platforms.

[2] This encompasses both significant latency delay, and none because the response is automatic.

5. A European validation case for RPAS fitted with TCAS II

5.1 General

5.1.1 Need for specific validation of TCAS II fitted to RPAS in Europe

The scenario envisaged in this section is that military US operators, and possibly civilian US operators, of RPAS choose to equip with TCAS II and that these operators seek access to European airspace. It is anticipated that they would rely on the fact that their installation has been properly approved by the appropriate US regulators and that their configuration is safe in US airspace. We are not aware of any European plans to equip RPAS with TCAS II. Similarly, there are no plans within SESAR 2020 to study this configuration.

Section 4 examined the issues that need to be addressed when TCAS II is fitted to RPAS from the perspective that TCAS II was designed for use on traditional manned aircraft and that there are differences between traditional manned aircraft and RPA. It also concentrated the differences between the US and Europe because there is likely to be a wealth of US studies demonstrating that the use of TCAS II on RPAS is acceptable in the US, and thus, arguably, anywhere. Section 4 concluded that the performance of the TCAS logic (or any ACAS logic, as it happens) should be validated specifically for Europe. This section discusses the work required for this specifically European validation of the performance of the TCAS logic for RPAS.

The additional dimension associated with the introduction of RPAS in non-segregated airspace is the variability of RPAS operations. Therefore the specific validation activities should cover the specific RPAS operation scenario that will emerge with the development of this new industry segment. This leads one to recognize that specific validation activities will be required to cope with any new operation scenario for RPAS within non-segregated airspace.

The more general issue of validating future ACAS for RPAS is addressed in section 6.

5.1.2 Nature of the validation required

This discussion concerns validating the efficacy of TCAS II as a collision avoidance system for RPAs in Europe prior to authorizing the use of TCAS II as a collision avoidance system for RPA. It is usual also to validate that the ACAS operates acceptably, for both pilots and to ATC, in routine day-to-day operations. This operational validation is not discussed here. Its objectives would depend very much on the nature of the RPAS operations in question but it would be reasonable to assume that much of what is said here concerning efficacy (aka safety) would be relevant to an operational evaluation.

The efficacy of the collision avoidance logic needs to be demonstrated through simulation of very many encounters. The encounters need to be realistic individually and as an ensemble. This means they must be representative of the airspace under study (whether that is a very small area or a whole region), and also representative of the small minority of encounters in which there is either a pre-existing risk of collision (because something has gone wrong) or there is a risk that the CAS can induce a collision (when nothing else has gone wrong).

The standard encounter models already in use need to be adapted to reflect RPAS operations as opposed to manned aircraft operations. The adaptation needs to ensure that the trajectories modelled for the RPA are realistic in view of the performance characteristics of the RPA and the operations planned. Further, the encounters (as opposed to the trajectories of individual aircraft) have to be realistic, and form a realistic model for the airspace when viewed in ensemble. This sort of work is not new, but it will be important to verify that the adaptation of the models to RPAS operations is realistic and representative.

The standard encounter models are not the only tools available to validate the performance of ACAS but, due to the extreme rarity of near mid-air collisions, they are the only tool that quantifies the effect of ACAS on the risk of collision in an airspace. This advantage arises because care is taken to ensure that separate encounter types are sampled with a frequency that reflects their frequency in the real world. SSR data for actual encounters can be used to study the behavior of TCAS in actual encounters or, using many encounters, the effect of ACAS on ATM operations. Unfortunately, useful quantities of SSR data for encounters involving RPA are unlikely to be available. The use of large numbers of entirely artificial encounters (generated by a Fast Time Encounter Generator – FTEG) has been found useful in identifying circumstances in which an ACAS does not perform well. FTEG could be used (and is being used in the development of ACAS X_A) to confirm that fitting TCAS II to RPA is effective in the great majority of situations; it can demonstrate that a design is robust, but cannot quantify the effect of TCAS II on the risk of collision. We are not aware of any plans to use FTEG prior to equipping RPA with TCAS II in the USA.

The encounter models would be used to generate very large numbers of encounters. The evolution of the encounter as one or both aircraft respond to TCAS II RAs can then be simulated, using two further models. The first is the pilot model, which describes the response of the pilot, <u>or the automata</u>, to the RA; it specifies the delay before there is a pilot input following the RA, and can sometimes include the acceleration commanded. The second model is aircraft performance model, which specifies the response of the aircraft to the control surface and thrust commands, and the vertical speeds achieved; this aircraft performance model will reflect the performance limitations of the RPA. In both cases it is necessary to know or make assumptions about the platform and the concept for the use of TCAS II.

A choice between two pilot models must be made depending on whether or not the response to an RA is automatic. Depending on the range of configurations being studied and the operational concepts in use, it is not necessarily required to investigate both choices. If the remote pilot is to respond to the RA, the time to transmit the RA command to the ground and the pilot's response to the aircraft should be added to the time taken for the pilot to initiate a response having seen or heard the RA. If the response is automatic then the total delay in initiating the response to the RA is that written into the design, currently 3s. (This 3s delay is proposed, and used in the Airbus design for Airbus TCAS AP-FD, to allow the pilot to take control of the response to the RA rather than allow the automation to run its course.)

The aircraft performance model reflects the performance capabilities of the RPA. The simulations model the trajectory of the aircraft following the RA and thus the vertical acceleration and peed that can be attained. This requires knowledge or assumptions concerning the platform.

The simulations would be used to quantify the effect of TCAS II on the risk of collision in encounters between two RPA and in encounters between an RPA and a manned aircraft. It is a policy and regulatory question the results have to match those of the effect of TCASII in encounters between manned aircraft. From the perspective of the RPA, it might be considered sufficient that TCAS II does indeed reduce the risk of collision. Section 5.2.2 considers this question from the point of view of the manned aircraft. There it is suggested that it would not be tolerable for TCAS II to be less effective in encounters between a manned aircraft and an RPA, both equipped with TCAS II, than it is in encounters between a manned aircraft and an aircraft not equipped with TCAS II.

A limited number organizations have expertise in this area. We recommend that the work needs to be carried out by such an organization, which would have the advantage of experience and the availability of established tools. Such an organization should first propose and quantify a comprehensive plan to identify all the specifically European issues involved in fitting TCAS II to RPA using this paper as a starting point.

5.1.3 Monitoring of early deployment of TCAS II fitted to RPAS

Experience has demonstrated the value of monitoring the operation of new ACAS closely. The issues discovered in this way range from installation issues, through unsatisfactory operation of the interface between the TCAS II and the Mode S transponder to unexpected logic performance. Even though equipping RPAS with TCAS II is seen as a temporary measure pending the development of ACAS Xu, the performance of TCAS II on RPAS should be monitored.

ACAS monitoring is achieved through pilot and controller reports, on-board recordings and the capture of RA messages transmitted from the aircraft using Mode S data exchange. In the scenario under discussion, only the last of these options is wholly under the control of European experts. The use of the established network monitoring TCAS II at present should be reinforced for RPAS in view of their novelty.

5.2 Validating the safety benefits of fitting RPAS with TCAS II in Europe

5.2.1 Evaluation of the overall safety benefits in the European airspace

The validation would be designed to confirm that TCAS II operates as a satisfactory safety net for RPAS, reducing the risk of collision when the separation is lost between an RPA and another, or several other, aircraft.

This requires the development of encounter models for RPA. Such models must incorporate a fully balanced and realistic variation in the trajectories of other aircraft, and anticipates the ways in which the trajectories of RPA in encounters will vary from those of other aircraft.

The simulations based on these models will model the response of RPA to RAs. This response will not always be typical of that for traditional manned aircraft because it needs to take account of the performance limitations of the RPA. Additionally, they need to distinguish two cases: the response to the RA is automatic and commences 3sec after the RA is issued; or it will commence after a period of time that allows for link delay and a reasonable pilot response time. In both cases, advice on the response time will be needed from the operator of the RPAS. A 3sec delay for automatic responses corresponds to the Airbus design for automatic responses and it needs to be confirmed what period of elapsed time is used for the specific RPAS. In the case of manual responses, advice from the operator is required on typical link latency.

5.2.2 Evaluation of the impact on the safety benefits delivered to manned TCAS II equipped aircraft

The introduction of novel RPA in unsegregated airspace will introduce a new collision risk for other aircraft. As a matter of principle, this risk should be controlled through airspace management and separation services, including self-separation if judged appropriate. DAA is part of this process but not when it is fulfilling its CA function. Separation should ensure that other aircraft do not experience an increased number of collision risk bearing encounters.

Nevertheless, present understanding of the performance of TCAS II on traditional manned aircraft is based on encounters with traditional manned aircraft. RPA might well present differently from manned aircraft in encounters with manned aircraft. It will need to be confirmed that the TCAS II on the manned aircraft performs satisfactorily in encounters with RPA. To gain a full understanding of the interaction between TCAS II on manned aircraft and RPAS, it will be necessary to determine the risk of collision in encounters between manned aircraft equipped with TCAS II and a number of different threat aircraft scenarios as listed below:

A. Manned aircraft not equipped with TCAS II (e.g. General Aviation aircraft or commercial aviation aircraft not subject to the TCAS European mandate),

B. RPA not equipped with TCAS II,

C. Manned aircraft equipped with TCAS II,

D. RPA equipped with TCAS II.

Comparison of scenario B against scenario A and of scenario D against scenario C would indicate the change in risk facing the manned aircraft due to the fact that the intruder is an RPA.

Comparison of scenario D against scenario B would indicate the value to the manned aircraft of equipping the RPA with TCAS II.

Scenario A and C would provide alternative acceptable levels of performances for TCAS II on own manned aircraft in encounters with TCAS II equipped RPA (scenario D). On one hand it could be argued that it is satisfactory for performance in scenario D to match that in scenario A; as a threat, an RPA equipped with TCAS II would be no worse than unequipped manned aircraft. On the other hand it could be argued the performance in scenario D should be comparable with that in scenario C; TCAS II should perform as well for RPAS as it do for manned aircraft.

The choice between the alternatives outlined above, and indeed the general determination whether or not the performance is satisfactory, is a policy or regulatory issue. Experience indicates that the extra work involved in providing the full range of scenarios outlined above is small in comparison to the totality of the work necessary to demonstrate the safety of new aircraft operations.

6. The need for a dedicated European validation

Beyond the need for a European validation case for RPAS fitted with TCAS II, EASA needs to monitor the development of future ACAS, currently ACAS Xa for conventional aircraft, ACAS Xu for RPAS and MIDCAS. In particular, validation of these systems needs to demonstrate interoperability with other ACAS, and efficacy and operational acceptability in European airspace.

Interoperability of ACAS X with TCAS II, and mutual interoperability between the various versions of ACAS X, should and can be expected to be a standard part of the development process for ACAS X, i.e. work that takes place predominantly in the USA. However, the responsibility for ensuring that ACAS X systems are properly adapted for European airspace lies naturally in Europe.

The MIDCAS project presents different issues. Here the need is to ensure that MIDCAS, and any other DAA/CA system developed in Europe, is validated to the same standards as other pre-existing ACAS. It is reasonable to imagine that this would require access to the expertise and tools developed over the years in the validation of TCAS II and ACAS X.

At the time of writing, the draft plans for SESAR2020 include a package:

- to validate ACAS Xa,
- to develop proposals for IFR RPAS integration in non-segregated airspace, including the technical development of Airborne Detect and Avoid (DAA) Systems, and
- to influence the design and standardisation of ACAS Xu through the validation of candidate designs for Europe.

However, at the time of writing not all the related SESAR 2020 project proposals have been accepted by the SESAR Joint Undertaking. Furthermore gaps have already been identified that may deserve complementary validation activities under the EASA umbrella: they are described hereafter

6.1 The validation activities planned within SESAR 2020

A series of SESAR projects are planned to address Collision Avoidance aspects of RPAS operations within the SESAR 2020 work programme (2016 – 2021), 1.3.3.

Project ID & Title	Project scope related to ACAS and RPAS
PJ.10 Separation Management En-Route and TMA	*"It is intended that **Civil RPAS** will integrate safely and transparently in non-segregated airspace, in a multi-aircraft and manned flight environment, guaranteeing the interoperability with the ATM system. **Operational considerations specific to RPAS will be identified and technological needs, if any, coordinated with PJ.13**.* *"Specific research needs to determine the impact of integration of RPAS on ATM in some areas presuming RPAS may not be able to comply with all existing manned operations rules, especially in case of control & command data-link loss between RPAS and the remote pilot, or some emergency cases."*
PJ.11 Enhanced Air and Ground Safety Nets	*"Within SESAR 1, the adaptation of ACAS to trajectory-based operations should have been brought to V2 maturity and can be further progressed. The adaptation of ACAS to new separation modes and to new categories of airspace users has not been studied.* *There is a need to anticipate the required evolution of ACAS for the future operations in Europe and take into consideration potential adaptations required in the European context. **The current strategy is to contribute to ACAS X development and standardisation**. ACAS X is a set of FAA collision avoidance systems currently under development: ACAS Xa for normal operations of Commercial Air Transport (CAT), ACAS Xo for specific operations of CAT, **ACAS Xu for RPAS operations** and ACAS Xp for GA/RC operations. A priority issue is the analysis of the ACAS X systems operational and pilot acceptability."*
PJ.13 Air Vehicle Systems	*"The technical solutions that will be addressed into the present project cover two main areas: **integrated RPAS operations, specifically Airborne Co-operative Detect and Avoid (D&A)** and General Aviation and Rotorcraft (GA/R) operations."* *"The RPAS must be capable of detecting and avoiding cooperative and non-cooperative traffic and performing avoidance manoeuvres without inducing secondary conflicts. Avoidance manoeuvres can either be Collision Avoidance (CA) or Traffic Avoidance (TrA). The manoeuvre has to comply with the existing rules and regulations for manned aircraft. **The D&A system for RPAS must issue instructions and/or take actions which, where appropriate, make it interoperable with present and future ACAS/TCAS systems**."* *"Although little work has so far been done on ACAS Xu, it is necessary to ensure that RPAS D&A work takes ACAS X developments fully into account, and that work is undertaken in a fully coordinated and standardized manner. Consequently, it is vital that this Solution is conducted with the closest cooperation with PJ.11, to minimize the risk of duplication or of conflicting initiatives."*

Source SESAR 2020 Multi-annual Work Programme
(still to be checked when the actual projects will be launched)

6.1.1 Solution PJ.10-05: IFR RPAS Integration

Research activities for IFR RPAS Integration (SESAR Solution PJ.10-05 – V3 in Wave 2) include consideration of many aspects of the management of RPAS in non-segregated airspace. Some will have an effect on the typical trajectories to be expected of RPAS when they come into conflict with other aircraft. Examples of work that is planned where this is evident include:

- assessment of whether RPAS might, in the early phases of ATM integration, not behave exactly the same as other aircraft, because of the latency and a different flight awareness of the crew, and the consequent impact of these factors on separation provision;
- understanding of RPAS-specific trajectories that are not easy to describe in the existing Business/Mission Trajectory format - RPAS might also stay on station in a given area that can be across several airspaces boundaries for a very long time, compared to manned aviation, when loitering on a mission for example, and
- for RPAS to be able to fly VFR in managed IFR airspace where VFR flight is permitted, the RPAS will need to be able to meet the obligations of VFR flight, including 'traffic avoidance', maintaining VMC conditions and terrain avoidance;

Whenever ACAS logic is validated for operations that do not currently exist, the encounter models, which are based on current experience, require modification that reflect the anticipated behaviour of aircraft for the new operations. The work in this SESAR 2020 project, in particular the tasks listed above, should inform the changes needed in the present encounter models to improve their representation of RPAS operations.

6.1.2 Solution PJ.11-A2 Airborne Collision Avoidance for RPAS Operations – ACAS Xu

Research activities related to Airborne Collision Avoidance for RPAS – ACAS Xu (SESAR Solution PJ.11-A2 – V3 in Wave 2) are under definition by the SESAR partners involved in PJ11. Apart from one missing ANSP, the partners are those involved in the SESAR 1 work programme. The work planned is described as follows:

"In coordination with the FAA development team and with PJ.13, the project will investigate if ACAS Xu helps the integration of RPAS in the European airspace and to provide elements to improve the ACAS X concept for Europe. The project will research any additional factors affecting collision avoidance with the platform in question being unmanned. This will include, inter alia, human factors and system latency.

The project has to provide RTCA/EUROCAE with inputs that allow EUROCAE to influence ACAS Xu design & standardisation. The objective is to achieve full benefits and to ensure safety and operational acceptability in European airspace by integrating European targets & requirements."

At the time of writing, it is not certain which approach will be adopted in the ACAS Xu MOPS regarding the pilot response to RAs (remote or automatic), and in practice the approach could vary between platforms. Additionally, the tuning of the core CAS logic will depend on the approach adopted (just as it will depend on the performance characteristics of the platform). The work in this SESAR 2020 project would need to take this into consideration.

Also part of PJ11 work plan is the development and maintenance by EUROCONTROL of a European collision avoidance validation platform called CAFÉ (Collision Avoidance Fast-time Evaluator) for ACAS X evaluation by EUROCONTROL and partners in SESAR

2020 (cf. roadmap for CAFÉ in Ref. [37]). This platform will include an up-to-date encounter model of the European airspace to be used as a basis for developing more futuristic scenarios such as those resulting from RPAS operations. Informally, there are divergent views on the realistic timescale for the development of CAFÉ and thus, for that reason only, its full availability for the SESAR 2020 validation of RPAS operations work.

6.1.3 Solution PJ.13-01-01: Airborne DAA Systems supporting integrated RPAS operations.

As for each individual solution of the project, research activities related to Airborne Detect and Avoid Systems supporting integrated RPAS operations (SESAR Solution PJ.13-01-01 – V3 in Wave 1 R8) include:

- Analysis of operational requirements
- Feasibility assessment
- Functional analysis
- Technical specifications
- Safety Cases
- Preliminary cost/benefit analyses, where appropriate
- Prototyping of target solutions
- Support to validation[3]
- Support to international standardisation activities.

The project will only address technical developments; hence the evaluation of operational aspects will be performed in the operational projects (PJ.10 and PJ.11). At the time of writing the SESAR 2020 partner proposal for this project has been rejected by the SJU, and it is not known if and by when this project will become a reality. Besides, it is likely that, its programme of work will not include tasks specifically addressing ACAS. DAA is usually considered comprising two sub-functions:

- self-separation, a.k.a. traffic avoidance (and several other appellations),
- collision avoidance.

However, these two sub-functions can be considered separately and independently and the work required to develop and validate the collision avoidance sub-function is almost indistinguishable from that required for stand-alone ACAS. That said, work on ACAS is likely to be directly useful to the tasks listed above, particularly functional analysis, safety cases, validation and standardisation.

Most importantly, the traffic avoidance sub-function and the ACAS component have to interoperate safely, effectively and acceptably. The need for the traffic avoidance system on one aircraft to be aware of the RAs generated against it by ACAS by the other aircraft in an encounter has already been identified.

[3] PJ13 is led by industry partners and is offering support to PJ10 and PJ11 validation activities through the provision of RPAS function prototypes. But no specific validation activities have been identified so far within this project.

6.2 The need for complementary activities outside SESAR framework

6.2.1 Gaps in planned validation activities related to RPAS

As described above, some validation work on the Collision Avoidance aspects of RPAS operations is expected within the SESAR 2020 work frame. This work is focused on identifying technological needs, developing and validating system functionalities and some operational validation (i.e. by PJ.10 for Air Traffic Control aspects and PJ.11 for Collision Avoidance aspects). This is likely to be carried out by operational partners with the support of industry partners.

However, experience has shown that it is very difficult satisfactorily to progress the validation of ACAS performance at European level without the clear and effective commitment of European agencies and organisations. Also from the TCAS II experience, it is clear that the encounter model-based methodology is essential to the validation of CAS logic performances at airspace level, but the methodology requires specific expertise and the availability of model(s) alone provides almost no-benefit without the appropriate know-how.

In the SESAR 1 frame work, Project P04.08.01 in charge of the evolution of ground and airborne safety nets had a comprehensive ACAS Xa work Programme in four phases aiming at V3 maturity level of the ACAS Xa Solution for Europe, based on the extensive use of the encounter model-based methodology. However, due to the limited available resources from the P04.08.01 partners involved in ACAS X work (i.e. DSNA, EUROCONTROL and NATS), SJU launched complementary activities (i.e. the CAAS[1] project led by Egis Avia) that aimed at supporting Phase 2 validation activities on ACAS Xa. This complementary validation work was not continued for the two last Phases of Project P04.08.01 project, which had to focus its ACAS X performance assessment to a based on a limited set of performance metrics. As a consequence, only a V2 maturity level of the ACAS Xa Solution will eventually be achieved at the end of the SESAR Programme.

The ACAS Xa work is expected to be continued in SESAR 2020 in the frame of PJ11 with the Solution PJ.11-A1: Enhanced Airborne Collision Avoidance for Commercial Air Transport normal operations - ACAS Xa, yet with fewer partners and limited more resources.

Without appropriate complementary activities by organisations with relevant expertise, it is likely that the same difficulties will be experienced during the SESAR 2020 work programme related to the validation of Collision Avoidance aspects of RPAS operated in non-segregated European airspace.

It is very difficult to be precise about the scope and the precise nature of these complementary activities at this stage. There are two particular reasons for this difficulty. The first is that a programme of work that seems adequate can be designed only to find

[1]CAAS stands for "Performance of Complementary Activities on ACAS X to SESAR programme".

that the work defined exceeds the funds available; the inadequacy of the funds does not make the work any less necessary but choices have to be made to fit the work proposed within the budget provided. In other words, necessary tasks have to be transferred to another funding source or are left undone. The second is that the structure of SESAR tends to assume a stable environment with a well laid out plan that is being methodically progressed; on the contrary, it has been found that work on ACAS is fast moving, plans are liable to change and fresh needs for specific studies can arise at short notice. [4] It is quite possible that if such pop-up tasks, to address specific European concerns, are not completed in a timely way, the development of the system will have progressed too far on the basis of unsatisfactory assumptions.

6.2.2 Need for independent validation of new RPAS Collision Avoidance System

In case of new CAS development for RPAS (e.g. ACAS Xu or MIDCAS), validation activities conducted by independent organisations must be favoured. These activities need to be carried out in close cooperation with the industry partners developing Collision Avoidance functions for RPAS and relevant European organisations in charge of standardisation or regulation of RPAS operations in Europe

MASPS and MOPS development phase is an outstanding opportunity to influence system design and requirements. However, comprehensive validation activities are necessary to achieve the development of "validated" standard (fit for purpose). In fact it is difficult and costly to update MOPS standards to address safety-critical and operational issues identified as late as the deployment phase.

The ability to validate ACAS design flexibly during the development and design phase requires the existing tools and expertise to be maintained and built up. The proposal to develop CAFÉ is a case in point; the need for an enhanced and transportable validation tool has been identified and validation work should not be delayed to allow for its development. In practice, maintaining such a team is likely to take the form of sympathetically considering proposals for a series of well-defined tasks, each justified by a description of the context, and supporting the team in taking an active role in the MASPS or MOPS development work.

[4] ACAS X is a US programme under FAA management, funded by the FAA. This particular programme is managed by assembling a team of trusted experts and funding them in a way that gives considerable flexibility in the approach they take. These experts each anticipate difficulties, have ideas, change the way in which particular parts of the system are expected to function. This implies work to address the difficulties, validate the ideas, test alternative ways of functioning. On the US side, funding is adequate to address these issues without challenging the project schedule; indeed, a challenge to the project schedule is the one thing that is not tolerated. On the European side, the implication is that there can be an unexpected need to address the European aspects of some proposal very quickly.

6.2.3 Validating the interoperability of new RPAS CAS logic with ACAS in Europe

As a prerequisite for RPAS integration within non segregated airspace, there is a need to determine and quantify, based on the data available and traffic forecast for Europe, any safety dis-benefit to conventional airspace users if RPAS are not fitted with a compatible Collision Avoidance system

Such analysis and assessment cannot be made without intensive usage of European encounter models adapted to include various envisaged specific RPAS operations in the airspace. It must be noted that the confidence in such analysis will be directly dependent on the completeness of the RPAS operation scenarios considered regarding in particular the pilot response to RAs (remote or automatic), the response of the aircraft (i.e. its ability to climb and descend and to change vertical rate) and the characteristics of the RPAS encounters in the airspace..

Subject to final work programme agreed within SESAR 2020, the complementary activities to be set up could be in three steps as follows.

6.2.3.1 Initial evaluation of DAA/CA and ACAS logic compatibility

An initial analysis (supported by desktop simulations) of operationally relevant encounter situations involving RPAS and TCAS II or ACAS Xa equipped aircraft (either model-based encounters or encounters created from radar recordings depending on data available) would be very useful in order to:.

- identify as soon as possible the potential interaction issues between RPAS DAA/CA function and ACAS / TCAS II RAs on board civil manned aircraft
- influence (if necessary) the design of RPAS DAA/CA function for improved compatibility with TCAS II/ACAS Xa equipped aircraft
- refine validation scope, scenarios, to be addressed in the next steps

6.2.3.2 In-depth evaluation of DAA/CA and ACAS logic compatibility

When the concept of RPAS operations in non-segregated airspace will be mature enough, more comprehensive validation activities using the encounter-model-based methodology and adapted models reflecting the envisaged type(s) of RPAS operations in Europe, could be envisaged:

- To measure and compare, in a statistically and operationally significant way, how potential manoeuvres prompted by RPAS DAA/CA function are compatible with TCAS II Resolution Advisories
- To influence (if necessary) the design of RPAS DAA/CA function for improved compatibility with TCAS II/ACAS Xa equipped aircraft

- To derive minimum performance requirements for the RPAS DAA/CA function for compatibility with TCAS II (in the prospect of standardisation work)

This work would be essential to gain confidence in the DAA/CA function when operated by RPAS in civil controlled airspace will not degrade the safety benefits brought by TCAS II /ACAS Xa to manned aircraft operating in the airspace.

6.2.3.3 Integrated evaluation of DAA/CA and ACAS system compatibility

To demonstrate the level of compatibility achieved between the RPAS DAA/CA function and TCAS II/ACAS Xa before authorizing RPAS operations in non-segregated airspace, large scale validation activities would be required, which could consist in fast-time simulations using Industry-Based Platform and/or flight trials using industrial RPAS DAA/CA prototype.

7. Conclusions and recommendations

This study has shown the major differences between Europe and USA in terms of airspace configuration, airport density and traffic density. Such differences have in the past led to specific adjustments of the CAS logic to ensure that the safety net provides effective mitigation in collision risk bearing encounters and is operationally acceptable.

These airspace differences have always led European stakeholders to conduct specific validation activities to ensure that ACAS is efficient and effective in Europe.

The specific issues associated with RPAS fitted with TCAS II potentially operating within the European airspace justify specific validation activities adapted to European airspace. Such validations are necessary due mainly to the differences between TCAS II aircraft and TCAS II RPAs, including the potentially lower performance of RPAs, the latency of the link between the RPA and its remote pilot and the specific mission profiles associated with RPAS within non segregated airspace. The validations have to be specific to Europe because of Europe's distinctive airspace characteristics as documented within this report.

To prepare to assess such RPAS operations within European airspace, EASA should set up a validation activity to cover this specific case that could make use of existing expertise and associated validation tools.

The need to develop a validation activity to cope with the specific issue of RPAS fitted with TCAS II could be considered as a step towards the development, validation and deployment of ACAS Xa and ACAS Xu technologies in European airspace. The introduction of these new ACAS generation within European airspace for manned and unmanned aircraft in the coming decade will require significant specific validations complementing those conducted by the FAA for US airspace. The SESAR 2020 programme that is about to start will contribute to such activities dedicated to European environment but only to a certain extent and it appears clear that further validations will be required to reach maturity for operational approval and to cover the wider scope of RPAs operational flight profile.

EASA should be deeply involved in all these activities in order to assess the level of validation achieved within the SESAR framework and to identify the complementary activities required for operational approval within European airspace.

This much deeper involvement could require the support of external expertise and associated simulation and validation tools that could be initially used to address the specific problem of TCAS II fitted RPAS in European airspace.

The two following recommendations are made as a result of this study:

Recommendation 1:

EASA to establish a dedicated team to address the specific issues associated with RPAS fitted with TCAS II operating in European non segregated airspace. In order to provide access to tested and known validation tools, the EASA team should be supported by the few European subject matter experts.

Recommendation 2:

EASA to use the dedicated team set up in response to the previous recommendation to monitor and assess the validation activities undertaken within SESAR 2020 for ACAX Xa and ACAS Xu. The European subject matter experts, with their validation tools, will complement the EASA team.

Recommendation 3:

EASA considers the option to use EUROCAE as the appropriate framework to provide the European subject-matter expertise by federating their contributions as it was done for this study.

Appendix A: Relevant extracts from Eurocontrol PRC reports

Performance Review Report - 2014

European traffic outlook (2015-2021)

The traffic outlook over the next seven years (see Figure 2-6) continues to show a contrasted picture between the mature markets in Western Europe struggling to recover from the economic crisis and the emerging markets in Central & Eastern Europe for which a substantial growth is foreseen between 2014 and 2021.

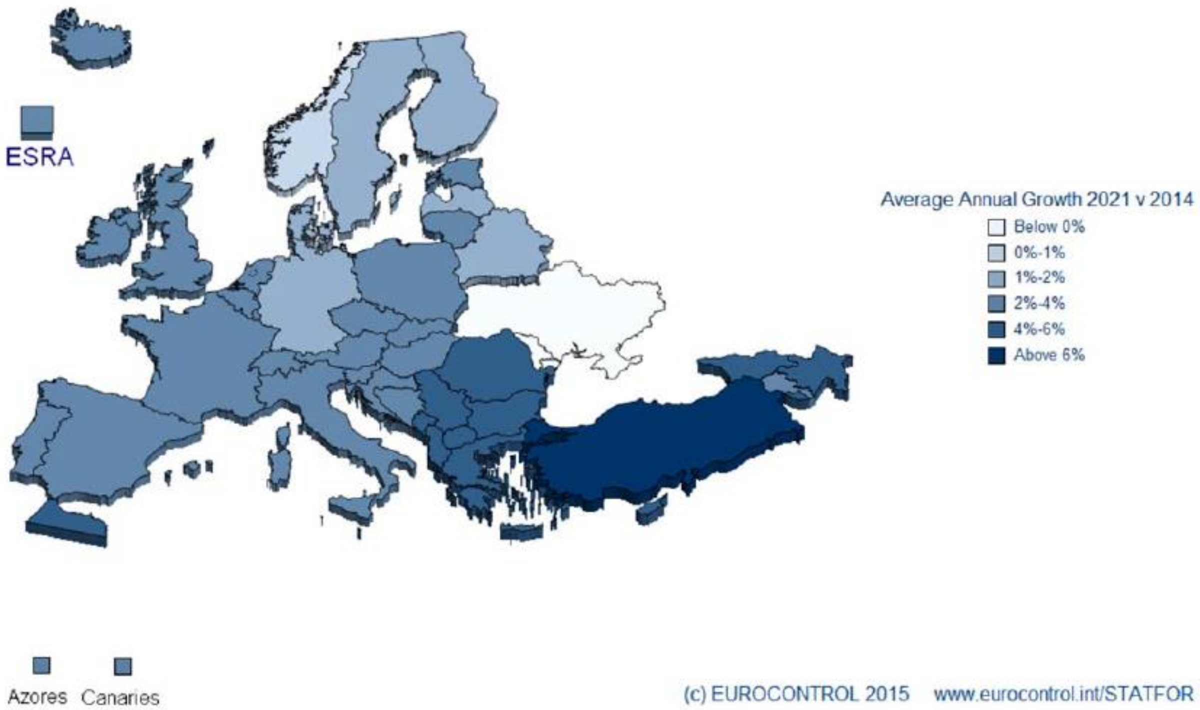


Figure 2-6: Forecast traffic growth 2014-2021

European traffic characteristics

Traffic variability *is a factor that needs to be taken into account in ATM performance review. If traffic is highly variable, resources may be underutilised, or made available when there is little demand. Variability in traffic demand is therefore likely to have an impact on productivity, cost-efficiency, service quality and predictability of operations.*

Variability can be broadly characterised as seasonal variability (difference in traffic level between different times of the year), temporal variability (difference in traffic levels between different times of the day), and spatial variability (variability of demand within a given airspace).

Figure 2-7 compares the peak day for each year to the average daily number of flights.

Different types of variability require different types of management practices, processes, and training to ensure that an ANSP can operate flexibly in the face of variable traffic demand. To a large extent, variability can be statistically predictable, and therefore adequate measures to mitigate the impact of variability could in principle be planned (for example, overtime, flexibility in breaks, and flexibility to extend/reduce shift length).

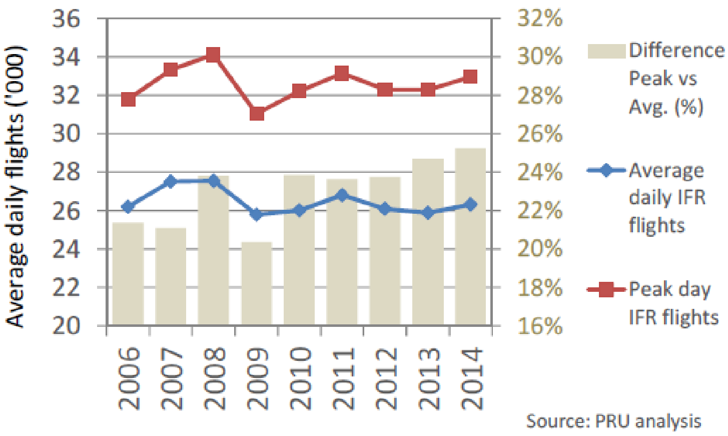


Figure 2-7: Peak day vs. avg. day traffic (Europe)

In 2014, the peak day was 25.2% higher than the average day but still below the peak day in 2008. It is interesting to note that there was a notable increase in the difference between peak and the average day between 2011 and 2014.

Seasonal variability is particularly difficult for an ANSP to adapt to, as working practices that are practically feasible have only a limited ability to deal with high seasonal variability.

Figure 2-8 provides an indication of seasonality by comparing the average weekly traffic to the peak week in 2014. The European core area shows only a moderate level of seasonality (at high traffic levels) whereas a high level of seasonal variability linked to holiday traffic is observed in South East Europe.

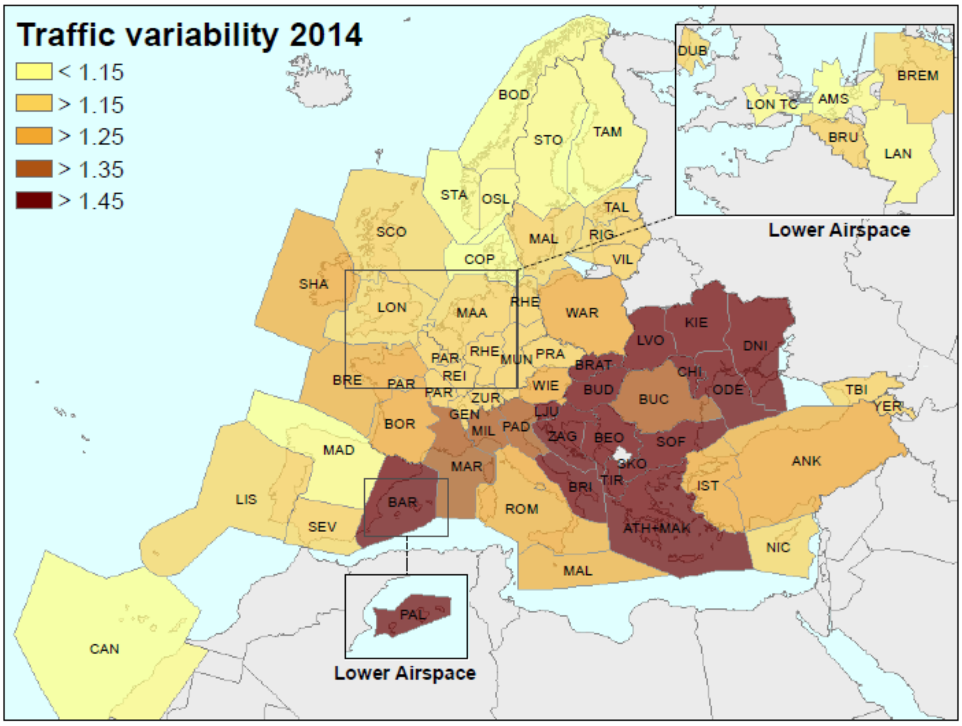


Figure 2-8: Seasonal traffic variations at ATC-Unit level (2014)

Figure 2-8 also clearly shows the impact of the Ukrainian crisis in terms of traffic variability as a result of traffic shifting to adjacent States following the closure of the airspace at the Eastern border of Ukraine (Dnipropetrovs'k FIR) as a result of the downing of Boeing 777 MH17 in July 2014.

Traffic complexity *is generally regarded as a factor to be considered when analysing ANS performance. In 2005, a composite measure of "traffic complexity" combining traffic density (concentration of traffic in space and time) and the intensity of potential interactions between traffic (structural complexity) was developed together with interested stakeholders (see grey box).*

Structural complexity and adjusted density are independent. Traffic in an area could be dense, but structurally simple; equally, traffic could be structurally complex but sparse.

Traffic complexity

The complexity score in this report is a composite measure which combines a measure of traffic density (concentration of traffic in space and time) with structural complexity (structure of traffic flows) [Ref. 7].

The structural complexity is based on the number of potential horizontal, vertical or speed interactions between aircraft in a given volume of airspace (20x20 nautical miles and 3.000 feet in height).

For example, a complexity score of 8 corresponds to an average of 8 minutes of potential interactions with other aircraft per flight hour in the respective airspace.

The relationship between "traffic complexity" and ATM performance in general, is not straightforward. High density can lead to a better utilisation of resources but a high structural complexity entails higher ATCO workload and potentially less traffic.

[…] at local level the picture is more contrasted and the complexity scores differ significantly.

Figure 2-10 shows structural complexity and the adjusted density at ANSP level in 2014. ANSPs with the highest overall complexity score are located in the top right corner. The two enable to better µunderstand the underlying drivers of the overall complexity score.

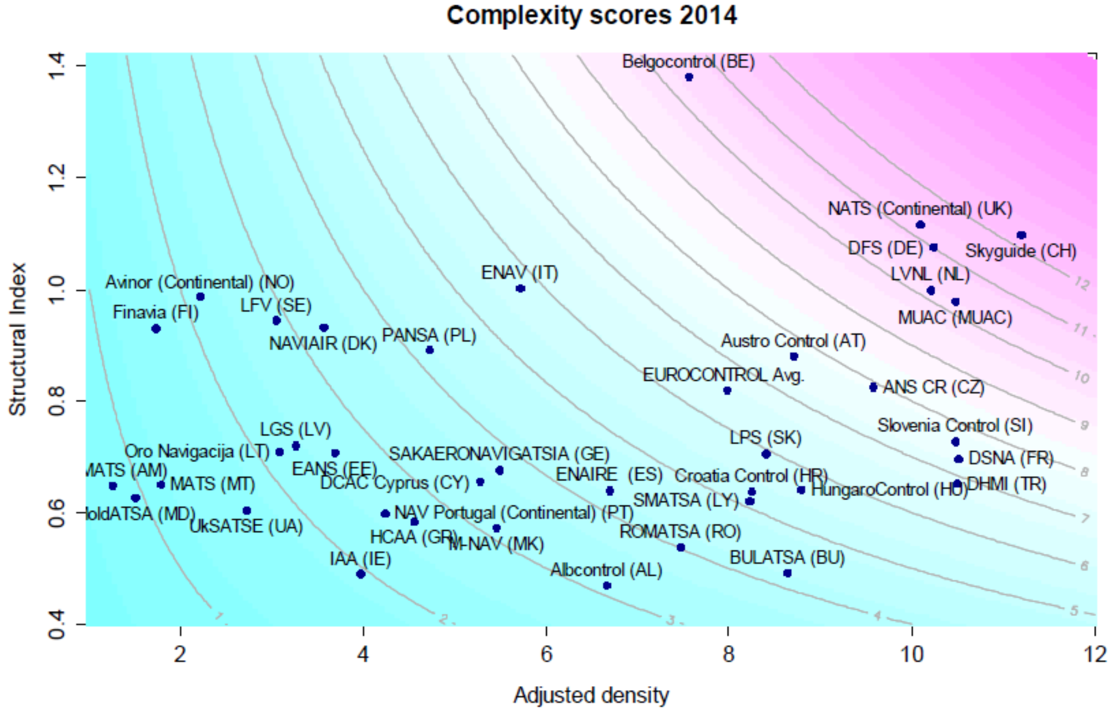


Figure 2-10: Structural complexity and adjusted density at ANSP level (2014)

In 2014, Skyguide traffic complexity score is ranked as the highest in Europe, followed by NATS, DFS, and Belgocontrol. A description of the methodology used to compute the complexity score and a table with the complexity scores can be found in Annex III on page 92 of this report.

Traffic characteristics in the US and in Europe

This section provides some key air traffic characteristics of the ATM system in the US and in Europe. The purpose is to provide some background information and to ensure comparability of traffic samples. As shown in Table 3-1, the total surface of continental airspace analysed in the report is similar for Europe and the US. However, the US controls approximately 57% more flights operating under Instrumental Flight Rules (IFR) 13 with less Air Traffic Controllers (ATCOs)14 and fewer en route and terminal facilities.

Table 3-1: US/Europe ATM key system figures at a glance (2013)

Calendar Year 2013	Europe[15]	USA[16]	US vs. Europe
Geographic Area (million km²)	11.5	10.4	≈ -10%
Nr. of civil en route Air Navigation Service Providers	37	1	
Number of Air Traffic Controllers (ATCOs in Ops.)	17 200	13 400[17]	≈ -22%
Number of OJT/developmental ATCOs	1 000	1 740	≈ +74%
Total ATCOs in OPS plus OJT/developmental	18 200	15 140	≈ -17%
Total staff	58 000	35 500	≈ -39%
Controlled flights (IFR) (million)	9.6	15.1	≈ +57%
Flight hours controlled (million)	14.3	22.4	≈ +57%
Relative density (flight hours per km²)	1.2	2.2	≈ x1.7
Share of flights to or from top 34 airports	67%	66%	
Share of General Aviation	3.9%	21%	
Average length of flight (within respective airspace)	551 NM	515 NM	≈ -7%
Number of en route centres	63	20	-43
Number of APP units (Europe) and terminal facilities (US)	260	163	-97
Number of airports with ATC services	425	516[18]	+91
Of which are slot controlled	> 90	4 [19]	
Source	EUROCONTROL	FAA/ATO	

15 EUROCONTROL States plus Estonia, excluding Oceanic areas, Georgia and Canary Islands. European staff numbers and facility count refer to 2011 which is the latest year available.

16 Area, flight hours and centre count refers to CONUS only.

17 This value reflects the CANSO reporting definition of a fully trained ATCO in OPS and includes supervisors. It is different than the total controller count from the FAA controller workforce plan which does not include supervisors.

The number of ATCOs in OPS does not include 1375 controllers reported for contract towers.

18 Total of 516 facilities of which 264 are FAA staffed and 252 Federal contract towers.

19 LGA, JFK, EWR, and DCA.

3.1.1 AIR TRAFFIC GROWTH

Figure 3.1 depicts the evolution of IFR traffic in the US and in Europe between 1999 and 2013.

There is a notable decoupling in 2004 when the traffic in Europe continued to grow while US traffic started to decline.

Whereas traffic in Europe grew by almost 17% between 1999 and 2013, the traffic in the US declined by 12% during the same period.

The effect of the economic crisis starting in 2008 is clearly visible on both sides of the Atlantic.

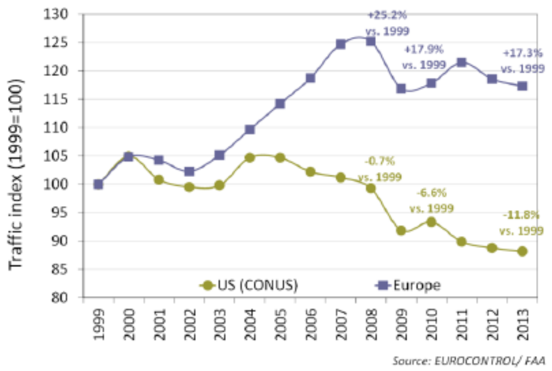


Figure 3.1: Evolution of IFR traffic in the US and in Europe

However, the system level averages mask contrasted growth rates within the US and Europe as illustrated in the map in Figure 3.2.

In Europe, much of the air traffic growth was driven by strong growth in the emerging markets in the East. The highest decrease compared to 2008 levels was observed in Ireland, Spain and the United Kingdom.

The US is a more homogenous and mature market which shows a different behaviour. Compared to 2008, traffic levels in the US declined in all centres, with a strong decline on the entire West coast. The traffic growth at the main airports in the US and Europe is shown in Figure 3.10 and Figure 3.11 on page 38 respectively.

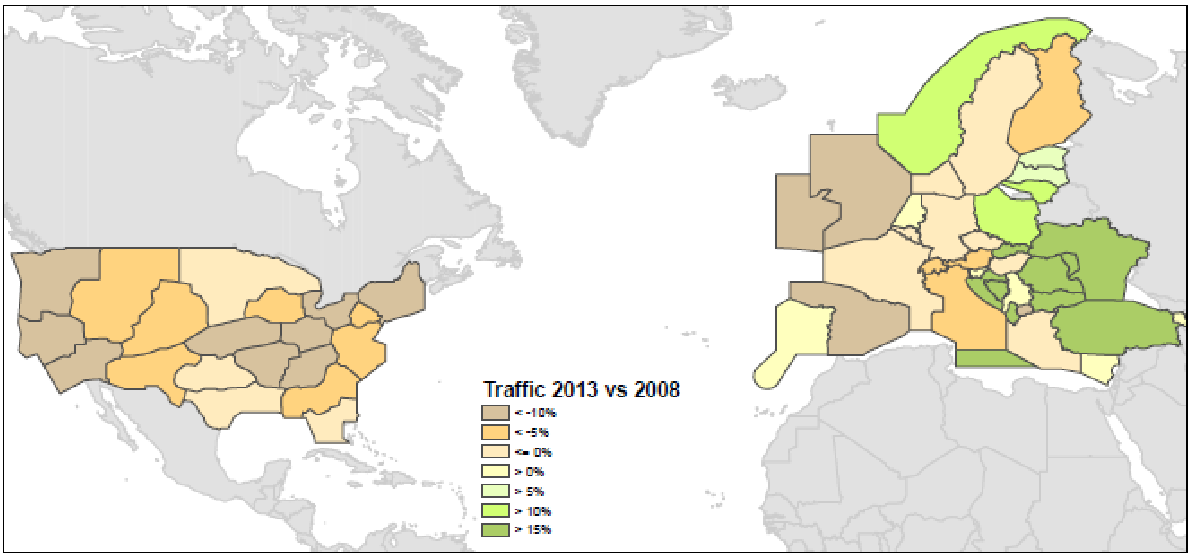


Figure 3.2: Evolution of IFR traffic in the US and in Europe (2013 vs. 2008)

3.1.2 AIR TRAFFIC DENSITY

Figure 3.3 shows the traffic density in US and European en route centres measured in annual flight hours per square kilometre for all altitudes in 2013. For Europe, the map is shown at State level because the display by en route centre would hide the centres in lower airspace.

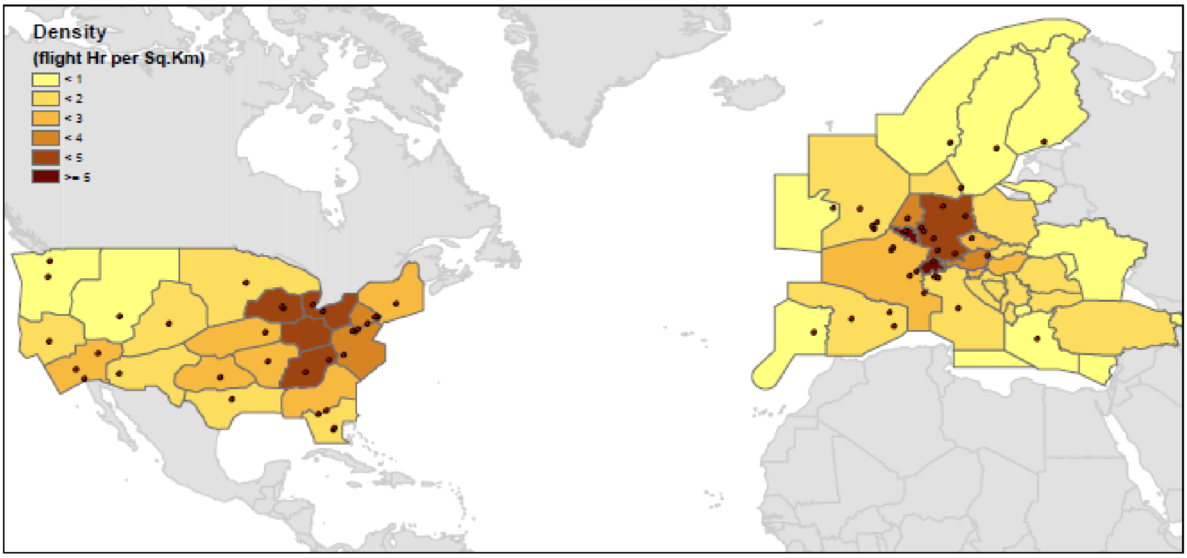


Figure 3.3: Traffic density in US and European en route centres (2013)

In Europe, the "core area" comprising of the Benelux States, Northeast France, Germany, and Switzerland is the densest and most complex airspace.

Similarly in the US, the centrally located centres of Cleveland (ZOB), Chicago (ZAU), Indianapolis (ZID), and Atlanta (ZTL) have flight hour densities of more than twice the CONUS-wide average.

The New York Centre (ZNY) appears less dense due to the inclusion of a portion of coastal/oceanic airspace. If this portion was excluded, ZNY would be the centre with the highest density in the US.

[…]

3.1.4 SEASONALITY

Seasonality and variability of air traffic demand can be a factor affecting ATM performance. If traffic is highly variable, resources may be underutilised during off-peak times but scarce at peak times. Different types of variability require different types of management practices to ensure that ATM can operate efficiently in the face of variable demand.

Figure 3.4 compares the seasonal variability (relative difference in traffic levels with respect to the yearly averages) and the "within week" variability.

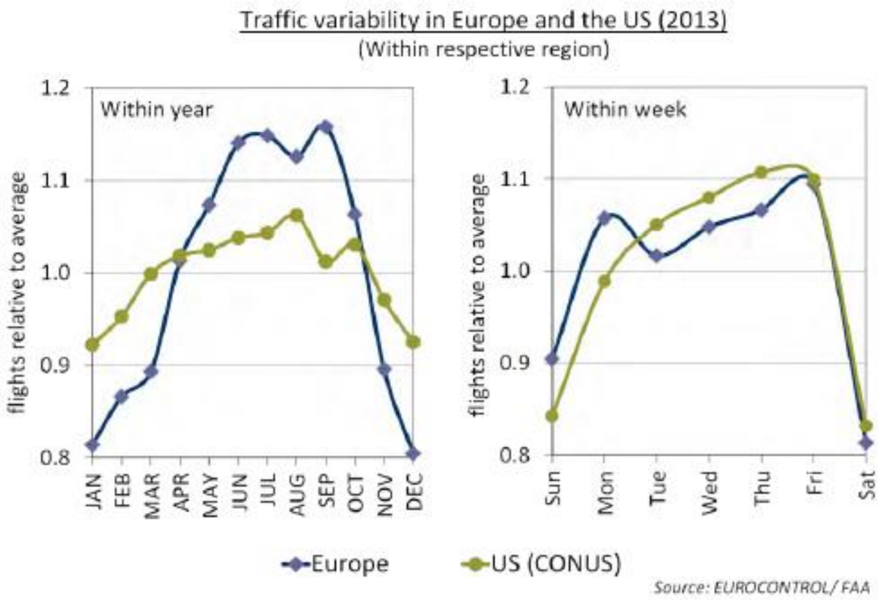


Figure 3.4: Seasonal traffic variability in the US and Europe (system level)

Whereas weekly traffic profiles in Europe and the US are similar (lowest level of traffic during weekends), the seasonal variation is higher in Europe. European traffic shows a clear peak during the summer months. Compared to average, traffic in Europe is in summer about 15% higher whereas in the US the seasonal variation is more moderate.

Figure 3.5 shows the seasonal traffic variability in the US and in Europe for 2013. In Europe, a very high level of seasonal variation is observed for the holiday destinations in South Eastern Europe where a comparatively low number of flights in winter contrast sharply with high demand in summer.

In the US, the overall seasonality is skewed by the high summer traffic in northern en route centres (Boston and Minneapolis) offsetting the high winter traffic of southern centres (Miami and Jacksonville) (see Figure 3.5)

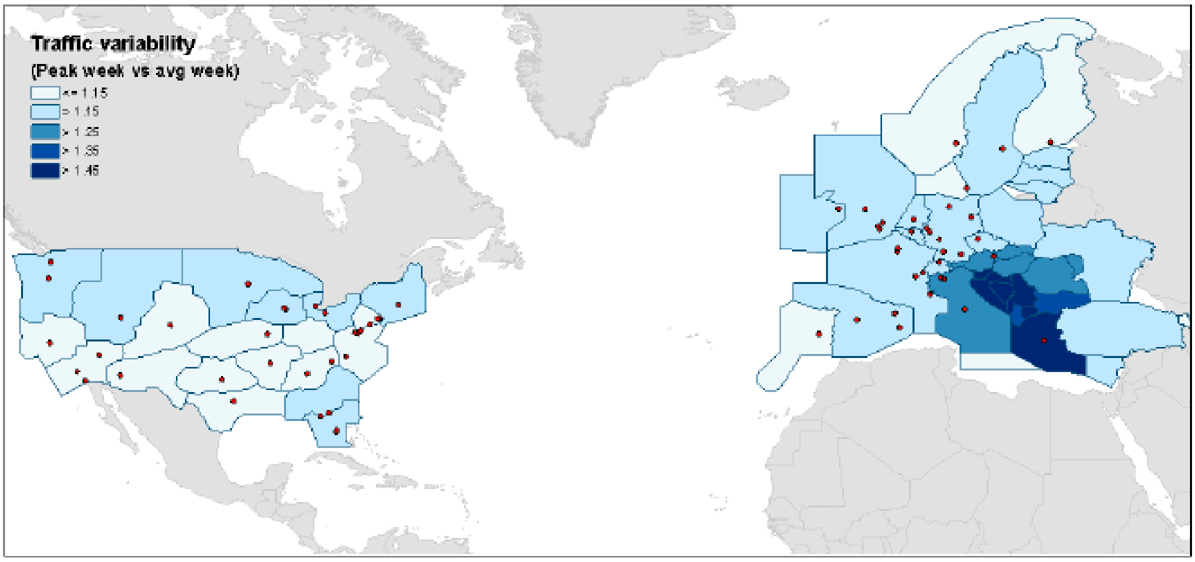


Figure 3.5: Seasonal traffic variability in US and European en route centres (2013)

3.1.5 *3.1.5 TRAFFIC MIX*

A notable difference between the US and Europe is the share of general aviation which accounts for 21% and 3.9% of total traffic in 2013, respectively (see Table 3-1 on page 28). This is confirmed by the distribution of physical aircraft classes in Figure 3.6 which shows a large share of smaller aircraft in the US for all IFR traffic (left side of Figure 3.6).

The samples are more comparable when only flights to and from the 34 main airports are analysed as this removes a large share of the smaller piston and turboprop aircraft (general aviation traffic), particularly in the US.

In order to improve comparability of data sets, the more detailed analyses in Chapters 4 and 4.4 are limited to controlled IFR flights either originating from or arriving to the main 34 US and European airports (see Annex I). Traffic to or from the main 34 airports in 2013 represents some 67% of all IFR flights in Europe and 66% in the US.

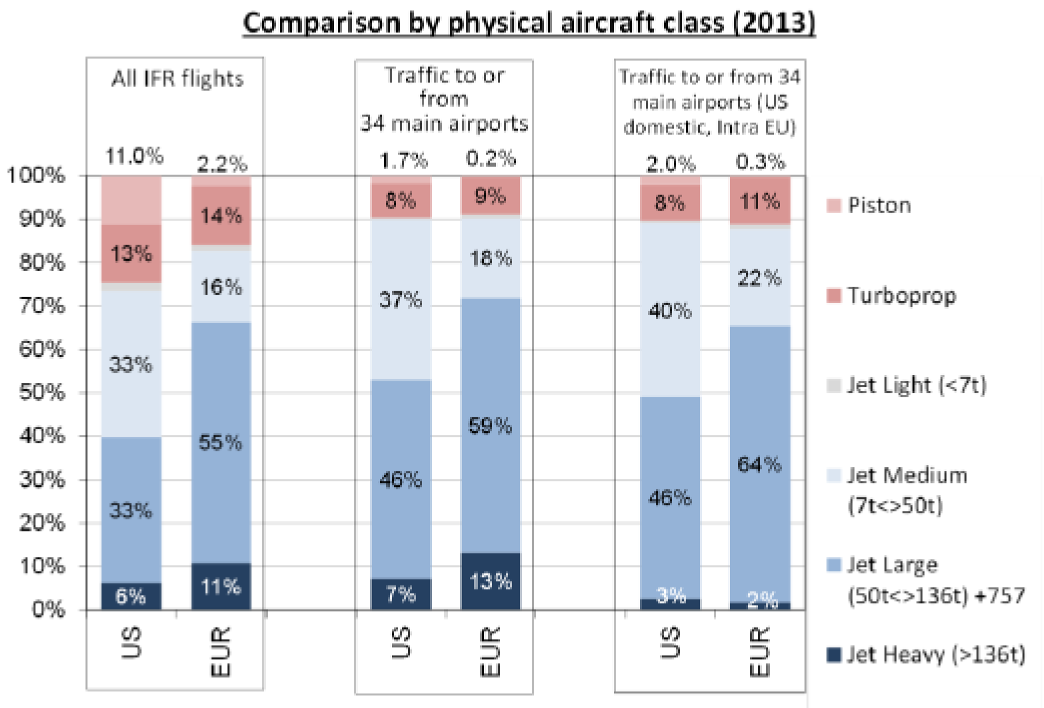


Figure 3.6: Comparison by physical aircraft class (2013)

Appendix B: Relevant extracts from the Eurocontrol ASARP study

Below are relevant extracts for the ASARP final project report (**Ref. [14]**).

ASARP – ACAS Safety Analysis post-RVSM Project

E.2.1. The ACAS Safety Analysis post-RVSM Project assessed whether the ACAS safety benefits anticipated prior to the introduction of RVSM operations are indeed achieved. [..]

E.2.2. The focus was on the evaluation of the safety benefits (in terms of reduced risk of mid-air collision) afforded by ACAS in the European RVSM airspace, and the identification of the main factors that influence this risk reduction.

Elements of ACAS safety analysis

2.2.1. General

2.2.1.1. ACAS is a last resort safety net whose ability to prevent near mid-air collisions may be affected by several factors including the efficacy of the ACAS logic itself under specific circumstances, but also the possible interaction between ACAS and other lines of defence against the risk of mid-air collision.

2.2.1.2. In controlled airspace, these other lines notably include clearances and instructions issued by ATC to ensure aircraft separation and even late controller intervention with avoidance instructions (when separation provision has failed). "In the event of an RA, pilots shall […] follow the RA even if there is a conflict between the RA and an ATC instruction to manoeuvre" [PANS-OPS]. Finally, the principle of "see-and-avoid" is very much a last line of defence against the risk of mid-air collision, and it is in no way a substitute for ATC or ACAS.

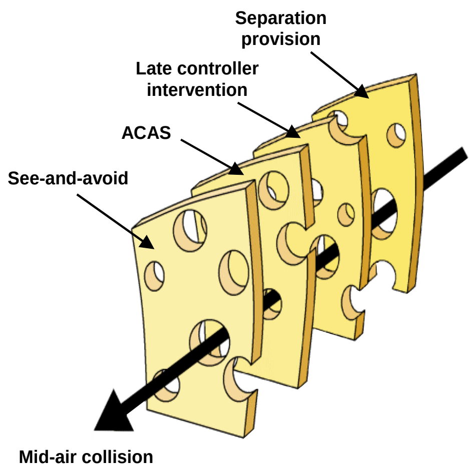


Figure 3: Lines of defence against mid-air collisions including ACAS

2.2.1.3. Figure 3 represents these lines of defence schematically. Any one line of defence can prevent a risk of collision which can only occur when all lines of defence fail (i.e. in the diagram, the holes line up).

2.2.2. Encounter characteristics in the considered airspace

2.2.2.1. Previous studies have shown that ACAS performance is very sensitive to the characteristics of the airspace. In other words, changes in 'encounter' types that may seem small can have a large effect on ACAS performance.

2.2.2.2. In the safety study presented here, the results are ultimately based on a large number of recent encounters extracted from En-Route radar data recordings for the period ranging from end January 2002 to July 2004, which represents two and a half years of RVSM operations in Europe.

2.2.2.3. As a consequence, it is again important to note that the safety results presented here can only be considered in the context of the European RVSM airspace, which is rather 'ACAS-friendly' with a high proportion of encounter geometries which are easily solved by ACAS (e.g. aircraft flying straight and level at constant speed).

2.2.3. Equipment characteristics and functioning

2.2.3.1. The level of ACAS equipage and the operating mode of ACAS are also factors that influence the safety benefits observed with the deployment of ACAS. If ACAS is unserviceable, is switched off, or is in standby-mode, then the aircraft is effectively unequipped. If ACAS is operated in TA-only mode, then it will indirectly provide some limited protection through the ability of TAs to prompt contact with the controller or aid visual acquisition. Maximum protection will be provided if ACAS is operated in full RA-mode.

2.2.3.2. The transponder equipage of aircraft is also of significance since this has an effect on ACAS surveillance and on the altitude reports that aircraft can provide (and on which the ACAS vertical tracking is based). Mode C equipped aircraft report altitude with a precision of 100-ft. Mode S equipped aircraft can report altitude with either 100-ft precision or with 25-ft precision. ACAS can use altitude in either reply format, but RAs issued on the basis of the more precise 25-ft altitude will generally be more effective.

2.2.3.3. The ACAS and transponder equipage level has been taken into account in the present safety study. It has been assumed that these systems always operate within their specifications.

2.2.4. Pilot behaviour in response to ACAS, controller and visual acquisition

2.2.4.1. The pilot behaviour is another key factor for the safety benefits delivered by ACAS and, in particular, the pilot response to the RAs issued by *the ACAS logic. Previous studies have demonstrated that the RAs that are generated should be followed, and followed promptly, for best benefits.*

2.2.4.2. In addition, the specific circumstance of a late controller intervention that would result in an instruction incompatible with the sense of a coordinated RA needs to be considered. In this case, the consequences of one pilot following the controller instruction while the other follows the RA matters significantly.

2.2.4.3. Finally, the possibility of the encounter being resolved by "see-and-avoid" needs to be considered. The probability of visual acquisition prompted by ACAS should be taken into account, along with the fact that visually acquiring a threat is no guarantee that a collision will be avoided.

2.2.4.4. All these environmental and human factors have been taken into account in the present safety study using best available evidence of their operational consequences and likelihood of occurrence.

2.2.5. Altimetry error

2.2.5.1. *The vertical miss distance, i.e. the vertical separation at 'Closest Point of Approach' (CPA), diagnosed by ACAS is the perceived separation – simply the difference in the tracked altitudes of the two aircraft.*

2.2.5.2. Altimetry error will inevitably be present in real aircraft systems. For any perceived vertical separation there is a finite probability that this separation will be negated by altimetry error and that a collision occurs. It is this probability that has to be calculated and summed to determine the overall risk in a set of encounters.

2.2.5.3. Altimetry errors, as observed in the European RVSM airspace, have been taken into account in the present safety study.

Appendix C: Relevant extracts from the Eurocontrol CAUSE study

Below are relevant extracts for the CAUSE Phase I study report (Ref. [25]

CAUSE – Collision Avoidance Requirements for Unmanned Aircraft Systems

In order to determine the ATM Collision Avoidance Requirements for UAS operating in non-segregated airspace EUROCONTROL have commissioned the CAUSE study, Phase 1. [..]

The study uses results from previous EUROCONTROL safety studies of ACAS to demonstrate that there is a need for UAS to have a collision avoidance capability comparable to that delivered by ACAS on manned aircraft. [..]

The study also investigates to what extent carriage of ACAS by UAS might deliver this capability and the issues involved. [..]

Requirements for UAS Collision Avoidance

UAS equipage with ACAS

The development and eventual mandating of ACAS was pursued in response to a perceived requirement that Commercial Air Traffic needed a collision avoidance capability (in the event that separation provision failed) superior to that offered by routine See & Avoid carried out by flight-crew by ACAS suitable for manned aircraft.

Since ACAS II is deemed to meet this requirement then the question naturally arises as to whether the same system can fulfil any similar requirement for UAS.

For various reasons the safety benefit resulting from the mandated equipage of manned aircraft is not necessarily immediately realisable when UAS are equipped with ACAS:

- *ACAS provides collision avoidance advice which is presented to the pilot who is required to implement the advised manoeuvre. On a UAS some means of presenting this advice to a remote pilot and/or having manoeuvres flown automatically by the UAS would be required;*
- *ACAS surveillance can be affected by the siting of the ACAS antennae. The shape of the UAS airframe and the potential proximity of various furniture could interfere with the optimal performance of ACAS surveillance;*

- *Aspects of the ACAS design assume deployment on civil fixed-wing aircraft. The performance of ACAS algorithms might be impaired by the routine flight dynamics of some UAS;*
- *ACAS collision avoidance manoeuvres require specific response times, vertical accelerations, and vertical rates. If these cannot be achieved by the UAS then the appropriateness of the ACAS advice is not guaranteed.*

These issues are discussed in more detail in Appendix D.

Conclusions and Recommendations

[...]

UAS equipage with ACAS II

Equipage with ACAS II has been demonstrated to deliver a safety benefit to manned aircraft that operate the system and comply with the RAs that it generates.

However, the safety benefit is not automatically guaranteed to UAS that choose to equip and operate the system:

- *Limitations of ACAS performance – ACAS is implicitly designed for operation on commercial civil fixed-wing aircraft. Limitations in ACAS hardware (particularly antennae and their siting) may become apparent when ACAS is deployed on a UAS airframe, and limitations in the ACAS software (particularly tracking algorithms) may become apparent if the UAS aerodynamic performance exceeds that expected from a commercial civil fixed-wing aircraft. These limitations will manifest themselves as degraded surveillance performance and lower reliability and quality of the tracking of targets.*
- *Limitations of UAS performance – the proven safety benefit of ACAS II deployed on manned aircraft is dependent on prompt and accurate compliance with the RAs that it generates. These RAs require a response within a specified time, at an acceleration of a specified strength, to achieve a specified vertical rate. If for any reason the UAS cannot achieve this standard response the efficacy of the RA can be compromised.*

UCAF interoperability with ACAS II

No matter what form a UAS collision avoidance function takes it is essential that it is interoperable with ACAS II and does not significantly degrade the safety benefit that ACAS II equipage delivers.

It is most likely that, for operational reasons, UAS will be required to equip with altitude reporting SSR transponders. Such equipage is essential if UAS are to be detected and tracked by ACAS.

In part the effectiveness of ACAS II is derived from the fact that when two ACAS II equipped aircraft encounter one another the sense of any avoidance manoeuvres is coordinated so that the two aircraft select compatible manoeuvres. To ensure this continued effectiveness UAS that encounter an ACAS II equipped aircraft need to, at least, respect the sense of any ACAS II

RA that is generated, and ideally participate in the coordination process by communicating the sense of their own avoidance manoeuvre to the ACAS on the other aircraft.

The primary purpose of SSR transponder equipage is to provide visibility of aircraft to ATC. Collision avoidance systems (such as ACAS) that detect other aircraft by active interrogations of their SSR transponders must limit the overall level of these interrogations so as not to unduly degrade the surveillance performed by ground-based SSR. ACAS achieves this by implementing specific interference limiting algorithms. It will be necessary for an UAS collision avoidance function that similarly interrogates SSR transponders to also ensure that no undue degradation of SSR surveillance occurs (e.g. by implementing its own interference limiting that achieves the same high-level performance targets of the ACAS interference limiting algorithms).

UAS Collision Avoidance Requirements

UAS Collision Avoidance Capability should equal or exceed that of manned aircraft in the same environment (known ATC environment or unknown ATC environment) and conditions (IMC or VMC50).

The performance of a UAS Collision Avoidance Function that does not coordinate the sense of avoidance manoeuvres with other aircraft (even when they are equipped with ACAS II or another UAS Collision Avoidance Function) should nevertheless equal or exceed the performance of ACAS II (which does coordinated the sense of avoidance manoeuvres where possible) in the same circumstance.

Appendix D: Encounter model and methodology

1. Overview of the methodology

The safety benefit afforded by the deployment of ACAS is usually expressed in terms of a 'risk ratio' that compares the risk of a 'Near Mid-Air Collision' (NMAC) with ACAS to that without ACAS.

ICAO has defined a set of target 'risk ratios' for different scenarios of aircraft equipage in a theoretical airspace described by a 'safety encounter model' (ICAO Annex 10 Volume IV, 2007). The framework initiated at the ICAO level when defining ACAS minimum performance has been further developed, and tuned to be operationally representative of the European airspace, in various EUROCONTROL projects especially in the ASARP, IAPA, AVAL and PASS projects.

The ASARP project delivered a comprehensive framework that includes a set of models replicating the environment in which ACAS is operated in Europe. These models consist essentially of a European safety encounter model that captures the properties of risk bearing encounters, models of pilot reaction in response to RAs, and a model of altimetry errors. Within the scope of the AVAL project the structure of the European safety encounter model was adapted to incorporate performance characteristics of Light Jet (LJ) and Very Light Jet (VLJ) aircraft. Contemporary radar data was then analysed to update the probability tables of this latest European safety encounter model

As shown in the following Figure, an ACAS simulator can use these models to assess ACAS performance in operationally realistic scenarios and determine the risk that remains when ACAS is being operated.

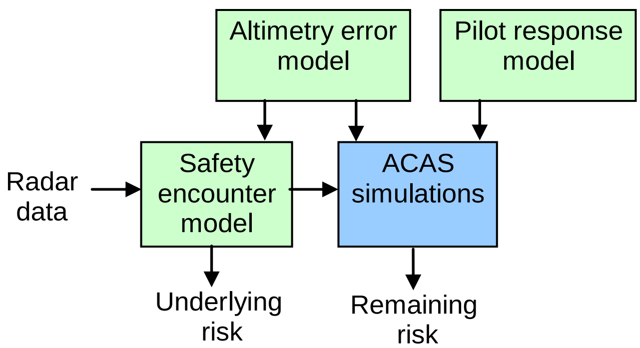


Figure 1: General framework for the evaluation of the safety benefits of ACAS

Within the scope of the IAPA project, the framework for the evaluation of the performances of ACAS was enriched with the delivery of a European ATM encounter model that captures the properties of encounters that occur in current day-to-day ATM operations in Europe. The IAPA ATM encounter model is a powerful tool for evaluating ATM changes and their potential interactions with ACAS.

Building on the IAPA project outcomes, the PASS project enabled the development of a set of models that constitutes a framework in which model-based simulations of STCA and TCAS operations can be conducted. An essential component of this framework is a European ATM safety-net related encounter model, i.e. the PASS ATM encounter model, designed to generate conflicts with a focus on losses of ATC separation in order to create situations with a potential for STCA or ACAS alerts. This encounter model for safety-net related occurrences builds upon the European ATM encounter model delivered by the IAPA project.

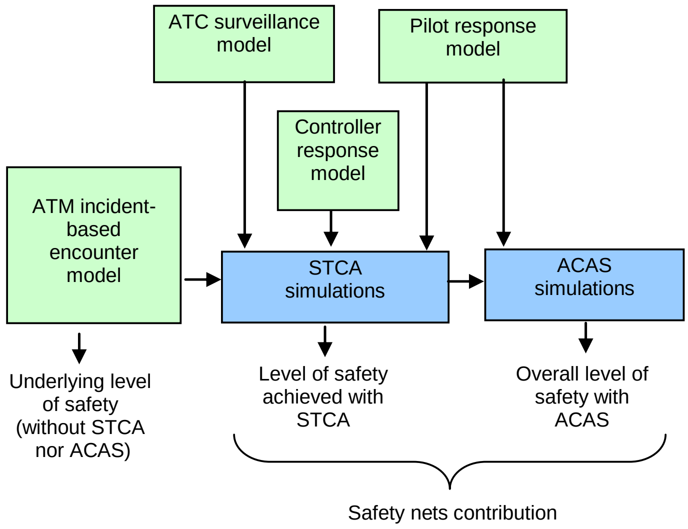


Figure 2: General framework for STCA & ACAS performance evaluation

When envisaging the validation of short-term ACAS improvements within SESAR Project 04.08.02 (i.e. AP/FD-TCAS and TCAP studies), the PASS ATM encounter model was identified as the more appropriate model to compute ACAS operational indicators since it includes more recent data characterising the European airspace . During these validation activities, it was observed that the PASS ATM encounter model could benefit from adaptations to cope with some limitations were damaging the operational realism of the ACAS simulations based on encounters generated using the PASS model.

The adapted ATM safety-net related encounter model, developed by Egis Avia, is designated for ACAS-only oriented studies and is considered operationally realistic (i.e. it reproduces the characteristics of ACAS encounters within the European airspace as observed through ACAS monitoring).

The figure below gives an overview of the various European encounter models, their different scope and use in ACAS safety and performance studies in Europe.

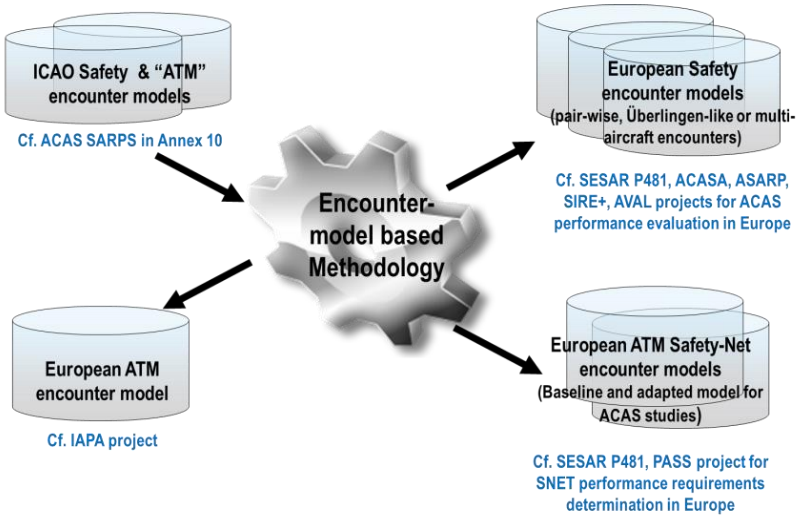


Figure 3: European encounter models used in ACAS studies in Europe

2. Other models supporting the encounter model-based methodology

As shown in the previous Figures, the validation of ACAS performance requires further models in addition to the encounter models described above.

The other relevant models used for ACAS simulations are as follows:

- Models of pilot response to RAs:
  - The standard pilot response model, which is defined in the ICAO ACAS SARPs, reflects the original TCAS II design assumption and corresponds to assumptions within the TCAS II logic
  - The typical pilot response model (developed by the ASARP project) which reproduces the wide range of pilots' behaviour identified in airborne data (from no response to aggressive); and
  - Automated response model, which replicates the AP/FD TCAS function as described in the MASPS for Flight Guidance System coupled to TCAS.
- Altimetry Error Models:
  - The standard Altimetry Error Model, as defined in the ICAO ACAS SARPs (which was developed in the early 1990s); and
  - The ASARP updated Altimetry Error Model, which takes into account the improved altimetry system performances of RVSM MASPS compliant aircraft flying in the European RVSM airspace.

The simulations conducted with the various sets of models then serve to compute a set of performance metrics that permit to assess ACAS performance on a given airspace for a given scenario.

3. Safety and operational metrics of CAS performance

The safety benefit afforded by ACAS is usually determined by comparing the risk of a Near-Mid Air Collision (NMAC) with ACAS to that without ACAS in a 'risk ratio':

$$\text{risk ratio} = \frac{\text{NMAC rate with ACAS}}{\text{NMAC rate without ACAS}}$$

It is important to note that risk ratio is a relative measure depending on the underlying risk without ACAS. This underlying risk will generally be different in different airspaces and which of two airspaces has the better level of safety when ACAS is deployed cannot be determined from the risk ratios alone. As well as resolving mid-air collisions, ACAS can also induce mid-air collisions that would not have occurred if ACAS had not been deployed. The total risk with ACAS can, therefore, be partitioned into two components: an unresolved risk and an induced risk. The efficacy of ACAS in resolving mid-air collisions is measured by the unresolved component of the risk ratio, whereas the induced component relates to the possibility that ACAS could induce a mid-air collision that would not otherwise occur.

More generally, the 'Vertical Miss Distance' (VMD) (i.e. the vertical separation at closest approach) is a key factor in determining the safety margins achieved when responding to ACAS RAs. The analysis of the VMD distributions with and without the effect of ACAS is therefore essential to assess the efficacy of the CAS logic, and its robustness to pilots' behaviour in response to RAs, in a given airspace.

The reduction in the risk of mid-air collision afforded by ACAS (for which Risk Ratio and the VMD distributions are two of the key metrics) is dependent upon pilot performance and acceptability of ACAS alerts. More timely and effective RAs will increase pilots' confidence in the system, favour prompt and adequate response to the RAs, and consequently reduce the risk of mid-air (or near-mid-air) collision in the airspace. Assessing the CAS logic performance from a pilot perspective in encounters likely to occur in the airspace is therefore essential. Key metrics include: the alert rates, the likelihood of RAs with altitude crossings, strengthening RAs, reversal RAs, RAs with sense selection incompatible with own vertical profile, etc.

Finally, from an overall ATM perspective, it is important that the behaviour of the CAS logic is shown to be compatible with the operations in the airspace. Key metrics to assess this include: the alert rates in encounters where safe vertical separation is ensured by ATC, the deviations induced by ACAS RAs (which should be limited to the minimum required to avoid mid-air collision so as to limit the risk of induced conflicts with third party aircraft in the vicinity).

These safety and operational metrics of ACAS performance have been used in past ACAS studies to assess the TCAS II performance in Europe. They have also recently been consolidated in the frame of the SESAR P04.08.01 project (dealing with TCAS II evolution) to establish a list of acceptability criteria for ACAS Xa performance in Europe [Ref. [37]].

EASA

European Union Aviation Safety Agency

European Union Aviation Safety Agency

Postal address
Postfach 10 12 53
50452 Cologne
Germany

Visiting address
Konrad-Adenauer-Ufer 3
50668 Cologne
Germany

Tel. +49 221 89990 - 000
Fax +49 221 89990 - 999
Mail info@easa.europa.eu
Web www.easa.europa.eu