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SESAR2020 V1 SA+ VALR

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Copyright Statement

CAPITO

PJ.11 CAPITO

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Abstract

This document provides the Validation report for PJ.11-A4: SA+ capability for V1. It shows results and conclusions of simulations about SA+/TSAA+ capability defined in Initial OSED document, in order to achieve V1 maturity level. Three fast time simulations / exercises have been performed within V1 phase of SA+ capability validation. Each exercise has been independent, performed by different solution partner (Honeywell, Thales, Leonardo) using different simulation platforms, and addressing different solution objective.

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1 Executive summary

This document provides first and initial validation results (relevant for V1 maturity phase) for **TSAA+** (enhanced **T**raffic **S**ituational **A**wareness system with **A**lerts) which have been evaluated with a sample of real European encounters. The report is complemented with results concluding TSAA performance on European encounters, since the TSAA system has been designed based on US encounters, and its performance in Europe has never been assessed.

The initial concept of TSAA+ functionality is described in the TSAA+ OSED (D6.1.070) published in May 2018.

This report summarizes results for three independent exercises, performed by different project partners (Honeywell, Thales, Leonardo). All three exercises were Fast Time Simulations (FTS) using different simulation platforms and addressing complementary validation objectives:

- Honeywell exercise (EXE-01) focused on evaluation and analysis of incremental benefits of TSAA+ compared to TSAA.
- Thales exercise (EXE-02) aimed to evaluate the operational suitability of SA+/TSAA+ system during mixed equipage encounters, however due to lack of significant data and assumption that was during evaluation shown to be inappropriate, the exercise finally introduced results showing NMAC probability improvements for TSAA.
- Leonardo exercise (EXE-03) aimed to evaluate the operational benefits of an already defined situation awareness and alerting system (TSAA) with typical European encounters.

All three exercises were using the same input: sample of European de-identified mixed equipage encounters (TCAS equipped / TCAS unequipped) that were provided by EUROCONTROL. This data sample required further post-processing which has been done by each partner, applying different filters, therefore actual number of used encounters may differ per exercise. Data were also complemented by additional inputs depending on the exercise/simulation needs.

Performed validations showed that:

- TSAA with "+" feature can introduce interesting operational benefits in European airspace, which will further be evaluated in V2 validation with pilot involvement.
- Even TSAA without "+" capability can in European airspace introduce promising safety benefits in terms of NMAC probability.
- And that the performance of TSAA without "+" functionality, in most of the cases meets the required thresholds, however, improved data set with better distinction of the encounters is needed for more significant results.

In addition, performed validation clarified pilot reaction assumptions, which will be further assessed in the next maturity phase. Detailed analysis of the existing TSAA standards identified inconsistencies in DO-348 which are already being coordinated with SC-186 experts to obtain clarifications, and it was observed that sample TSAA algorithm is not optimized for helicopter operations in close proximity (if the sample algorithm is implemented as is during helicopter operations, alerting performance may not meet operator expectations).

Even though these V1 simulation results should not be considered as definitive, and the concept will be further validated in the next phase, they **adequately conclude V1 phase and will be the basis for the V1 maturity assessment.**

2 Introduction

2.1 Purpose of the document

This document provides the Validation Report for PJ.11-A4: SA+ capability for V1. It describes the results of validation exercises defined in VALP document (D6.1.080) and how they have been conducted, and provides a set of relevant conclusions and recommendations.

Three fast time simulations / exercises have been performed within V1 phase of SA+ capability validation. Each exercise has been independent, performed by different solution partner using different simulation platform as described in the upcoming sections.

This validation report describes activities performed to fulfil following V1 objectives for SA+ capability:

- Evaluate the operational benefits of already defined situation awareness and alerting system (TSAA) with typical European encounters – addressed by Leonardo, EXE-PJ.11.A4-VALP-0003.
- Evaluate the operational suitability of SA+/TSAA+ system during mixed equipage encounters – addressed by Thales, EXE-PJ.11.A4-VALP-0002.
- Evaluate and analyse incremental benefits of TSAA+ on top of TSAA - addressed by Honeywell, EXE-PJ.11.A4-VALP-0001.

2.2 Intended readership

The intended audience for this document are members of PJ11-A4 solution and PJ11 members in general. At a higher programme level, the Content Integration project (PJ19) that is responsible for coordination and integration of solutions, as well as development of validation strategy with appropriate validation targets. In addition, GA/R/military airspace users (such as AOPA, or helicopters associations members), as main stakeholders, may have an interest in this document.

2.3 Background

The SESAR solution under the scope of this document is SA+, also referred as TSAA+. SA+ capability refers to enhancement of already standardized ADS-B IN Traffic Situational Awareness with Alerts **(TSAA)** application enhanced to use information about intruder RA (Resolution Advisory), and indicate it to Pilot. Such enhancement is referred as TSAA+ and its operational concept is built upon TSAA.

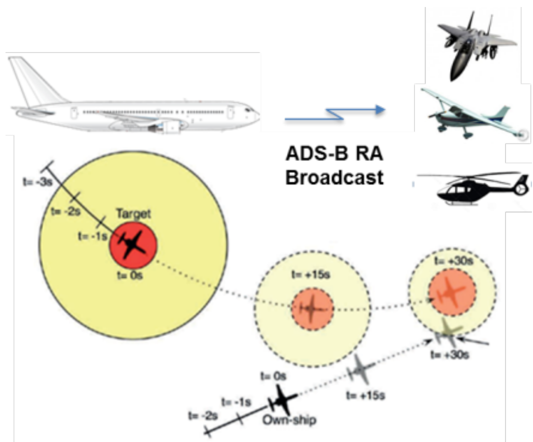

Figure 1: TSAA+ pictorial view

TSAA+ aims to address mixed equipped encounters, e.g. encounters involving TCAS-equipped and non-TCAS-equipped aircraft, and is intended for any civil or military, powered aircraft or rotorcraft which is not under TCAS II mandate.

SA+/TSAA+ capability has not been addressed in SESAR 1, and **its current maturity level is V0, aiming to reach V1 in 2018**. Initial analysis of TSAA alerting functions has been performed in the past within SESAR 9.47 project [12], using system and test vectors as defined in TSAA SPR [13] and MOPS [14].

SESAR 9.47 project [12] did the preliminary evaluation of future ACAS Xp performance, has compared the performance of GA-intended Traffic Situational Awareness with Alerts (TSAA) system and its alerting capabilities with ACAS Xa (primarily addressing CAT needs) model modified to use passive surveillance only; however without any modifications for GA. Selected TSAA-tailored and US-airspace test vectors of the MOPS were run through both TSAA and ACAS X models, focusing on evaluation of how the alerting system behaves when it IS EXPECTED to alert, and how it does behave when it IS NOT EXPECTED to alert (operational performance).

Nevertheless, TSAA application has been designed (and implementations are verified) against a set of test encounters which have been derived from the analysis of US airspace MAC and NMAC historical data, and its operational suitability and effectiveness in the European airspace is yet undetermined. It is now possible to take advantage of European recent radar track data and ACAS-X ongoing encounter modelling activities for assessing TSAA within European airspace environment from an operational point of view.

2.4 Structure of the document

Sections 1 and **2** are introductory sections describing purpose of this document and its background.

Section 3 describes validation context, defines TSAA+ capability in general, its mapping on PJ.11-A4 solution and provides traces to EATMA.

Section 4 introduces validation results from solution point of view.

Section 5 provides conclusions and recommendations for each exercise.

Section 6 lists reference documents.

Appendix A, B and C provide more details on Validation results.

Appendix D provides maturity assessment of solution.

Appendix E DO-348 performances metrics and TSAA evaluation for NAS.

Appendix F DO-348 performances Metrics and Success Criteria.

Appendix G Navigation source accuracies.

Appendix H Pseudo True Track degradation model.

Term	Definition	Source of the definition
Automatic dependent surveillance broadcast (ADS-B)	A means by which aircraft, aerodrome vehicles and other objects can automatically transmit and/or receive data such as identification, position and additional data, as appropriate, in a broadcast mode via a data link.	ICAO
General Aviation	General Aviation (GA) is defined by ICAO as "all civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire". This encompasses a wide range of activity: • Pilot training • Business aviation • Recreation including balloon, glider and model aircraft flying • Agriculture including crop spraying • Mail and newspaper deliveries • Transport of dangerously ill people and of urgently needed human organs, medical equipment and medicines • Monitoring ground traffic movements from the air • Civil search/rescue • Law enforcement including operations against smuggling • Aerial survey including photography for map making and pipeline and power cable patrols • Pollution control and fire fighting	PJ.11-A4

	• Flying displays and aircraft platforms: • Fixed wing • Rotary wing • Unconventional (e.g. balloons, airships, gliders, autogyro) In the context of PJ11-A4 "General Aviation" will indicate Fixed Wing platforms used for GA activities. This PJ11-A4 GA definition will include the EASA Safety Categories: "Aerial Work/Part SPO Aeroplanes" and "Non–Commercial Operations Aeroplanes".	
Rotorcraft (R)	In the context of PJ11-A4 with Rotorcrafts (or Helicopters) will indicate a rotary wing platform of any size (from Ultra-light to Medium, Heavy) used for GA, Commercial, Aerial Work, Customs, Police activities, including military helicopters as part of their operations in non-segregated airspaces.	PJ.11-A4
State aircraft	In the context of PJ11-A4 "State Aeroplanes" will indicate any Military, Police, Customs Fixed Wing platform flying in non-segregated airspace, excluding Transport Type aircrafts. Example of aeroplanes considered in this category are: military fast jets, military trainers, BizJet used e.g. for: police, custom, search & rescue, VIP transport, hospital transport, etc.	PJ.11-A4
Near Mid Air Collision	Near Mid Air Collision (NMAC) occurs when two aircraft come within 100 feet vertically and 500 feet horizontally	TCAS MOPS (DO-185)
Unequipped aircraft	An aircraft which is not equipped with any collision avoidance.	PJ.11-A4
Equipped aircraft	An aircraft equipped with TCAS II or potentially ACAS X system.	PJ.11-A4
Mixed encounters	In terms of this validation plan, mixed encounters refer to encounters involving two aircraft where one is equipped by ACAS and second is unequipped.	PJ.11-A4

Table 1: Glossary of terms

2.5 Acronyms and Terminology

Acronym	Definition
1090ES	Mode S Extended Squitter
A/C	Aircraft
ACAS	Airborne Collision Avoidance System
ACAS Xa	ACAS X – Active
ACAS Xp	ACAS X – Passive
ACE	Active Coordination Emulation
ADD	Architecture Definition Document
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-R	ADS-B Rebroadcast
AIRB	Basic Airborne Situation Awareness
AMC	Acceptable Means of Compliance
ASA	Aircraft Surveillance Applications
ASIAS	Aviation Safety Information Analysis and Sharing
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
AU	Airspace Users
AVAL	European encounter model based on 2007/2008 radar data
CA/CAS	Collision Avoidance (System)
CAT	Commercial Air Transport
CATI	Cockpit Annunciator for Traffic Information
CAZ	Collision Airspace Zone
CDTI	Cockpit Display of Traffic Information
CPA	Closest Point of Approach
DOD	Detailed Operational Description
EATMA	European ATM Architecture
E-ATMS	European Air Traffic Management System
E-OCVM	European Operational Concept Validation Methodology

Acronym	Definition
EASA	European Aviation Safety Agency
ECAC	European Civil Aviation Conference
EVAcq	Enhanced Visual Acquisition
FAA	Federal Aviation Administration
FLARM	Traffic and collision warning system for GA
GA/R	General Aviation (Fixed Wing) and Rotorcraft
GNSS	Global Navigation Satellite System
HAZ	Hazard Zone
HAZ’	No Hazard Zone
HMD	Horizontal Miss Distance
IA	Intersect Angle
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IRS	Interface Requirements Specification
LLEM	Lincoln Lab Encounter Model
LPAT	Low Power ADS-B Transceiver
INTEROP	Interoperability Requirements
MAC	Mid-Air Collision
MOPS	Minimum Operational Performance Standards
MTOM	Maximum Take-Off Mass
MTOW	Maximum Take-Off Weight
MTTA	Military Transport-Type Aircraft
NAS	National Airspace System
NAT	Nearby Airborne Traffic
NMAC	Near Mid-Air Collision
NTSB	National Transportation Safety Board
OPA	Operational Performance Assessment
PAZ	Protected Airspace Zone
PCAS	Portable Collision Avoidance System
PRs	Performance Requirements
RA	Resolution Advisory

Acronym	Definition
RHV	Relative Horizontal Velocity
RTCA	American Standardisation body that produces MOPS for TCAS
RVV	Relative Vertical Velocity
RWY	Runway
OFA	Operational Focus Areas
OSED	Operational Service and Environment Definition
SA	Situation Awareness
SA+	Enhanced Situation Awareness (TSAA+)
SBS	Surveillance and Broadcast Services
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SPR	Safety and Performance Requirements
SUA	Special Use Airspace
SUT	System Under Test
SVFT	Special Visual Flight Rules
TA	Traffic Advisory
TABS	Traffic Awareness Beacon system
TAD	Technical Architecture Description
TAS	Traffic Advisory System
TCA	Traffic Caution Alert
TCAS	Traffic Alert and Collision Avoidance System
TD	Traffic Display
TIS	Traffic Information Service
TIS-B	Traffic Information Services – Broadcast
TRAMS	TCAS RA Monitoring System
TS	Technical Specification
TSA	Traffic Situational Awareness

Acronym	Definition
TSAA	Traffic Situation Awareness with Alerts
TSAA+	Enhanced TSAA (refer to SA+)
VALP	Validation Plan
VALR	Validation Report
VALS	Validation Strategy
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VMD	Vertical Miss Distance
VP	Verification Plan
VR	Verification Report
VS	Verification Strategy
UAT	Universal Access Transceiver

Table 2: Acronyms and terminology

3 Context of the Validation

3.1 SESAR Solution PJ.11-A4 SA+ summary

The SESAR solution under the scope of this document is SA+, further referred as TSAA+. SA+ capability refers to enhancement of already standardized ADS-B IN Traffic Situational Awareness with Alerts **(TSAA)** application enhanced to use information about intruder RA (Resolution Advisory), and indicate it to Pilot. Such enhancement is referred as TSAA+ and its operational concept is built upon TSAA.

TSAA+ aims to address mixed equipped encounters, e.g. encounters involving TCAS-equipped and non-TCAS-equipped aircraft, which are one of the remaining sources of mid-air collision **(MAC)** risks [11]. TSAA+ is intended to provide timely alerts of qualified airborne traffic in the vicinity of ownship in order to increase flight traffic situation awareness, and if TCAS II-equipped traffic is issuing an RA (against ownship or any other traffic), then the information about RA will be passed to the flight crew. TSAA+ application is intended to reduce the risk of NMAC or MAC by aiding in visual acquisition, and to avoid TSAA+ pilot to manoeuvre against RA of TCAS II-equipped aircraft (e.g. idea is NOT to manoeuvre). In this case, for the V1 phase, TSAA+ pilot is expected not to react to SA alert, following RA reception.

The TSAA+ is intended for any civil or military, powered aircraft or rotorcraft which is not under TCAS II mandate. It is intended to operate in any airspace (controlled, uncontrolled or SUA) with various traffic density; in IMC or VMC; during IFR or VRF flights; during departure, en-route or approach operations when there is a potential of encounters with commercial, TCAS II-equipped aviation. TSAA+ will only be effective in an airspace where ADS-B Out equipment is installed and operational.

This SESAR solution is from the EATMA point of view addressed under PJ11-A4, Airborne Collision Avoidance for General Aviation and Rotorcraft – ACAS Xp, but since ACAS Xp and TSAA+ are two different capabilities, PJ11-A4 will be most likely split in the near future. For the time being, TSAA+ reference to EATMA and SESAR CONOPS is as defined in the tables below. Once final decision about the solution split is done, the solution description, OI step and enablers will be refined.

This table describes the SESAR Solution under the scope of this document, with reference to the applicable EATMA reference.

SESAR Solution ID	SESAR Solution Description	Master or Contributing (M or C)	Contribution to the SESAR Solution short description	OI Steps ref. (from EATMA)	Enablers ref. (from EATMA)

SESAR Solution PJ.11-A4 Airborne Collision Avoidance for General Aviation and Rotorcraft (ACAS Xp)[1]	Airborne Collision Avoidance for General Aviation and Rotorcraft - ACAS Xp provides Airborne Collision Avoidance to GA/RC, taking into account their limited capability to carry equipment and their operational specificities.	C	This VALR address SA+ capability only.	CM-0808-p Collision Avoidance for General Aviation and Rotorcraft (ACAS Xp)	AC-54a

Table 3: SESAR Solution(s) addressed in the Validation Report

3.2 Summary of the Validation Plan

3.2.1 Validation Plan Purpose

V1 validation activities for SA+/TSAA+ have been divided into three independent exercises performed by Honeywell, Thales and Leonardo aiming to fulfil the V1 validation objectives to:

- Evaluate the operational benefits of already defined situation awareness and alerting system (TSAA) with typical European encounters – addressed by Leonardo, EXE-PJ.11.A4-VALP-0003.
- Evaluate the operational suitability of SA/TSAA system during mixed equipage encounters – addressed by Thales, EXE-PJ.11.A4-VALP-0002.
- Evaluate and analyse incremental benefits of TSAA+ on top of TSAA - addressed by Honeywell, EXE-PJ.11.A4-VALP-0001.

EXE-PJ.11.A4-VALP-0001 has been performed by Honeywell in Brno (Czech Republic), EXE-PJ.11.A4-VALP-0002 has been performed by Thales in Gennevilliers (France) and EXE-PJ.11.A4-VALP-0003 has been performed by Leonardo in Genova (Italy). All three exercises have been performed as fast time simulations, with TSAA or TSAA+ implemented in the simulation platform. As an input, European de-identified mixed equipage encounters (equipped/unequipped) have been provided by EUROCONTROL.

3.2.2 Summary of Validation Objectives and success criteria

[1] Note, since PJ.11-A4 is currently addressing two different capabilities, they will most likely split in 2019 (once SA+ capability reach V1 maturity). Consequently – solution title, description, OI steps and enablers will be updated.

3.2.2.1 EXE-PJ.11.A4-VALP-0001

SESAR Solution Validation Objective	SESAR Solution Success criteria	Coverage and comments on the coverage of SESAR Solution Validation Objective in Exercise 001	Exercise Validation Objective	Exercise Success criteria
OBJ-PJ.11.A4-VALP-0003 *Evaluate and analyze incremental benefits of TSAA+ on top of TSAA.*	**CRT-PJ.11.A4-VALP-0003-001** *Scenarios with potentially increased risk of conflicting manoeuvring were identified.*	Fully covered	EX1-OBJ-PJ.11.A4-VALP-0001	CRT-PJ.11-A4-EX1-VALP-0001-0001
	CRT-PJ.11.A4-VALP-0003-002 *All identified scenarios were analysed.*	Fully covered	EX1-OBJ-PJ.11.A4-VALP-0002	CRT-PJ.11-A4-EX1-VALP-0002-0001

Table 4: Validation Objectives addressed in Validation Exercise 1

The V1 validation objectives & success criterions are rather theoretical and qualitative than quantitative at this stage.

Identifier	EX1-OBJ-PJ.11.A4-VALP-0001
Objective	To identify and analyse scenarios where the alerting of different type of systems may potentially increase risk of conflicting manoeuvring
Title	Risk of conflicting maneuvering
Category	<operational feasibility>
CRT-PJ.11-A4-EX1-VALP-0001-0001	Scenarios with potentially increased risk of conflicting manoeuvring were identified.

Identifier	EX1-OBJ-PJ.11.A4-VALP-0002
Objective	To evaluate in which portion of scenarios the availability of RA Broadcast could potentially help.

Title	RA information processing
Category	<operational feasibility>
CRT-PJ.11-A4-EX1-VALP-0002-0001	Ratio of scenarios where RA Broadcast could potentially help was estimated.

3.2.2.2 EXE-PJ.11.A4-VALP-0002

SESAR Solution Validation Objective	SESAR Solution Success criteria	Coverage and comments on the coverage of SESAR Solution Validation Objective in Exercise #2	Exercise Validation Objective	Exercise Success criteria
OBJ-PJ.11.A4-VALP-0002 *Evaluate the overall benefits of SA+/TSAA+ system during mixed equipage encounters.*	**CRT- PJ.11.A4-VALP-0002-001** *The probability of NMAC without and with TSAA+ was assessed for encounters including GA/R/Military.*	Fully covered[2]	EX2-OBJ-PJ.11.A4-VALP-0001	CRT-PJ.11-A4-EX2-VALP-0002-0001
			EX2-OBJ-PJ.11.A4-VALP-0003	CRT-PJ.11-A4-EX2-VALP-0003-0001
	CRT PJ.11.A4-VALP-0002-002 *Time/range to detect was assessed for encounters including GA/R/Military.*	Fully covered	EX2-OBJ-PJ.11.A4-VALP-0001	CRT-PJ.11-A4-EX2-VALP-0001-0002
			EX2-OBJ-PJ.11.A4-VALP-0003	CRT-PJ.11-A4-EX2-VALP-0003-0002

Table 5: Validation Objectives addressed in Validation Exercise 2

Identifier	EX2-OBJ-PJ.11.A4-VALP-0001
Objective	Evaluate the overall benefits of TSAA surveillance on board General Aviation

[2] Please refer to Appendix B regarding coverage of this solution objective.

	and Rotorcraft in fast-time simulation
Title	TSAA evaluation for General Aviation and Rotorcraft.
Category	<operational feasibility>
CRT-PJ.11-A4-EX2-VALP-0001-0001	The NMAC with TSAA is lower than NMAC without TSAA.
CRT-PJ.11-A4-EX2-VALP-0001-0002	Time/range to detect

Identifier	EX2-OBJ-PJ.11.A4-VALP-0002
Objective	Evaluate the overall benefits of TSAA surveillance on Military Aircraft in fast-time simulation.
Title	TSAA evaluation for Military Aircraft.
Category	<operational feasibility>
CRT-PJ.11-A4-EX2-VALP-0003-0001	The NMAC with TSAA is lower than NMAC without TSAA.
CRT-PJ.11-A4-EX2-VALP-0003-0002	Time/range to detect

3.2.2.3 EXE-PJ.11.A4-VALP-0003

SESAR Solution Validation Objective	SESAR Solution Success criteria	Coverage and comments on the coverage of SESAR Solution Validation Objective in Exercise 001	Exercise Validation Objective	Exercise Success criteria
OBJ-PJ.11.A4-VALP-0001 *Evaluate the operational benefits of already defined situation awareness and*	**CRT-PJ.11.A4-VALP-0001-001** *To check if the alerting of the TSAA installed on GA/R/Military is suitable for*	Fully covered	EX3-OBJ-PJ.11-A4-VALP-0001	CRT-PJ.11-A4-EX3-VALP-0001-0001

alerting system (TSAA) with typical European encounters.	*European encounter scenarios.*			
	CRT-PJ.11.A4-VALP-0001-002 *TSAA alerts according to DO-317B.*	Fully covered	EX3-OBJ-PJ.11-A4-VALP-0001	CRT-PJ.11-A4-EX3-VALP-0001-0002

Table 6: Validation Objectives addressed in Validation Exercise 3

The high-level validation objective of PJ.11-A4-EXE-03 was to evaluate the operational benefits of TSAA with typical European encounters.

Identifier	EX3-OBJ-PJ.11-A4-VALP-0001
Objective	Evaluate from an operational point of view TSAA algorithms on board GA/Rotorcraft/Military within EU airspace context
Title	TSAA evaluation for GA/Rotorcraft/Military within EU airspace context
Category	<operational feasibility>
CRT-PJ.11-A4-EX3-VALP-0001-0001	Missed Alert Percent [% of required alerts] < 5% (Missed alerts % includes late alerts and events when no alert is issued; a late alert is any required alert issued less than 12.5 seconds before CPA as indicated in DO-317B).
CRT-PJ.11-A4-EX3-VALP-0001-0002	Outlying Alert Percent [% of total alerts issued] < 5% (an Outlying alert is an alert which has been raised by the alerting system, even if the ownship and intruder remain always outside the non-hazard zone – HAZ).

Please note that there's a deviation with respect to VALP related to criteria defined above. Refer to section §3.3.2 for more details.

3.2.3 Validation Assumptions

Following table captures validation assumptions applicable to all exercises. Exercise-specific assumptions are listed per exercises in Appendix A, B and C.

Identifier	Title	Type of Assumption	Description	Justification	Flight Phase	KPA Impacted	Source	Value(s)	Owner	Impact on Assessment

ASS-PJ.11-A4-001	Scenarios availability	Traffic Characteristics	Preliminary encounter set will be provided by EUROCONTROL.	There is currently no Encounter Model for GA available.	N/A	N/A	EUROCONTROL	N/A	PJ.11	High
ASS-PJ.11-A4-002	ADS-B Only	Traffic Characteristics	No ADS-R or TIS-B data are considered as surveillance source.	This solution is addressing European airspace, and there is no ADS-R or TIS-B in Europe.	N/A	N/A	PJ.11-A4	N/A	PJ.11	Low
ASS-PJ.11-A4-003	Representativeness of traffic sample	Traffic Characteristics	Encounter set used will represent typical European environment.	The validation should assess TSAA+ performance in European environment.	N/A	N/A	Expert judgement	N/A	PJ.11	Medium

Table 7: Validation Assumptions overview

3.2.4 Validation Exercises List

[EXE]

Identifier	EXE-PJ.11.A4-VALP-0001
Title	V1 validation of SA+ capability by Honeywell
Description	Fast Time Simulation on Honeywell simulation platform (CASCARA) using SA+ capability model for evaluation during initial set of mixed-equipage encounters representative for European operations and involving GA/R.
Expected Achievements	Incremental benefits of TSAA+ on top of TSAA are evaluated and analysed.
V Phase	<V1>
Use Cases	N/A

Validation Technique	<Fast Time Simulation>
KPA/TA Addressed	<Safety>
Start Date	01/08/2017
End Date	30/10/2017
Validation Coordinator	Honeywell
Validation Platform	CASCARA
Validation Location	Brno, Czech Republic
Status	<completed>
Dependencies	V2 validation exercises (EXE-04)

[EXE]

Identifier	EXE-PJ.11.A4-VALP-0002
Title	V1 validation of SA capability by Thales
Description	SIMPLY simulation and evaluation of TSAA with typical European encounters.
Expected Achievements	Risk of collision with TCAS II intruder lower when ownship is TSAA equipped than not TSAA equipped.
V Phase	<V1>
Use Cases	N/A
Validation Technique	<Fast Time Simulation>
KPA/TA Addressed	<Safety>
Start Date	01/09/2017
End Date	29/12/2017
Validation Coordinator	Thales
Validation Platform	SIMPLY
Validation Location	Paris, France
Status	<completed>
Dependencies	No dependency.

[EXE]

Identifier	EXE-PJ.11.A4-VALP-0003
Title	V1 validation of TSAA alerting capability by Leonardo
Description	Validation that the TSAA alerting capability performs as expected also in typical European mixed encounter scenarios.
Expected Achievements	Evaluation of the operational performance of TSAA alerting capability (incorporated into SA+) with typical European mixed encounters (i.e. between GA/R/Mil and a TCAS equipped intruder).
V Phase	<V1>
Use Cases	N/A
Validation Technique	<Fast Time Simulations>
KPA/TA Addressed	<Safety>
Start Date	01/09/2017
End Date	29/12/2017
Validation Coordinator	Leonardo
Validation Platform	Leonardo's TSAA Simulator
Validation Location	Genova, Italy
Status	<completed>
Dependencies	N/A

3.3 Deviations

3.3.1 Deviations with respect to the SJU Project Handbook

This VALR is done in accordance to SJU Project Handbook and Validation Strategy. VALS however includes several typos that should be addressed by next VALS revision, and once solution is split, the VALS content should be updated accordingly. No major deviations.

3.3.2 Deviations with respect to the Validation Plan

For Honeywell:

1. The only deviation from planned activities is rewording of success criterion CRT-PJ.11-A4-EX1-VALP-0002-0001 into: "Ratio of scenarios where RA Broadcast could potentially help was estimated."

For Thales:

1. Validation objectives EX2-OBJ-PJ.11.A4-VALP-0001 and EX2-OBJ-PJ.11.A4-VALP-0002 are merged in one validation objective EX2-OBJ-PJ.11.A4-VALP-0001, since it was not possible to divide GA encounters from helicopter encounters at this stage.

2. Four new assumptions have been added (see table above) which have not been identified during VALP preparation.

3. Assumption New3 was during validation execution shown as inappropriate from operational point of view and might even have a negative impact on the probability of NMAC. It was concluded that such scenario rather describes baseline scenario, which represent today situation in which the ownship does not have an ADS-B In capability, not AIRB/EVAq applications nor TSAA and in which the intruder and ownship encounter tracks are identical to those recorded by SSR (provided by EUROCONTROL).

Above mentioned deviations caused that both exercise objectives and criterions CRT-PJ.11-A4-EX2-VALP-0001-0001 and CRT-PJ.11-A4-EX2-VALP-0003-0001 as defined in VALP have been modified to address NMAC probability improvements for TSAA (not TSAA+) when compared with baseline scenario (current situation).

For Leonardo:

Main deviations from planned activities are:

- No separate Performance evaluation for Airport and En-route operational scenarios: no data on airport proximity available in the encounter data set to discriminate airport from En-route environment encounters.

- No separate Performance evaluation for GA (Fixed wing) and Helicopters: no data to discriminate between Fixed wing GA and Helicopter encounters available in the encounter data set.[3]

- Performance evaluation on Military platforms with no sufficient statistical confidence level: not enough military encounters available (e.g. only 2 encounters classified as MUST ALERT Encounters)

In addition, Validation Objective success criteria, have been reformulated as follows:

[3] Clarification: Data set provided by EUROCONTROL was only divided between military and "others". Encounter were not divided into Helicopter and GA, and based on the data provided it was not possible to easily filter the tracks.

- CRT-PJ.11-A4-EX3-VALP-0001-0001: Missed Alert Percent [% of required alerts] < 5% (Missed alerts % includes late alerts and events when no alert is issued; a late alert is any required alert issued less than 12.5 seconds before CPA as indicated in DO-317B)
- CRT-PJ.11-A4-EX3-VALP-0001-0002: Outlying Alert Percent [% of total alerts issued] < 5% (an Outlying Alert is an alert which has been raised by the alerting system, even if the ownship and intruder remain always outside the non-hazard zone - HAZ').

4 SESAR Solution V1 Validation Results

4.1 Summary of SESAR Solution V1 Validation Results

SESAR Solution Validation Objective ID	SESAR Solution Validation Objective Title	SESAR Solution Success Criterion ID	SESAR Solution Success Criterion	SESAR Solution Validation Results	SESAR Solution Validation Objective Status
OBJ-PJ.11.A4-VALP-0003	Benefits of TSAA+ on top of TSAA	CRT-PJ.11.A4-VALP-0003-001	Scenarios with potentially increased risk of conflicting manoeuvring were identified.	Scenarios with potentially increased risk of conflicting manoeuvring are scenarios when: 1. Only TCAS alerted (so GA pilot is aware of RA issued nearby even before TSAA alert occur), 2. But also all the other situations when both TCAS and TSAA alerted regardless of the alert sequence, or corner case situation.	OK
		CRT-PJ.11.A4-VALP-0003-002	All identified scenarios were analysed	The above-identified scenarios where availability of RA broadcast can potentially help represents 78.4% from all scenarios where at least one system alerted. E.g. considering that even TSAA without "+" functionality can potentially help in 52.6% from all alerting scenarios, the benefit of "+" on top of TSAA is potential improvement	OK

				by 25.8%.	
OBJ-PJ.11.A4-VALP-0002	Initial operational benefits of TSAA+	CRT-PJ.11.A4-VALP-0002-001	The probability of NMAC without and with TSAA was assessed for encounters including GA/R/military	Note: Results provided are for TSAA, not TSAA+.[4] Phase 1 and 2: NMAC probability is reduced by TSAA using the baseline Pilot Model.	OK
		CRT-PJ.11.A4-VALP-0002-002	Time/range to detect was assessed for encounters including GA/R/military	Time to closest point of approach (CPA) in seconds and range (NM) between ownship & intruder at the moment of TSAA alert for GA and R is shown at the Figure 13 and Figure 14, and for military aircraft on Figure 17 and Figure 18.	OK
OBJ-PJ.11.A4-VALP-0001	TSAA operation with European encounters	CRT-PJ.11.A4-VALP-0001-001	Missed Alert Percent [% of required alerts] < 5%	for GA/R: 1.7%	OK
				for MIL: 0.0%	OK
		CRT-PJ.11.A4-VALP-0001-002	Outlying Alert Percent [% of total alerts issued] < 5%	for GA/R: 8.8%	NOK
				for MIL: 15.1%	NOK

Table 8: Summary of Validation Exercises Results

NOK results, and their potential root cause is further discussed in Appendix C.3.4 and C.3.53. Recommendations for the next steps needed in order to provide more significant results for these criterions are captured in 5.2.1.

[4] Refer to deviations with respect to VALP.

4.2 Detailed analysis of SESAR Solution Validation Results per Validation objective

4.2.1 OBJ-PJ.11.A4-VALP-0001 Results (Leonardo)

OBJ-PJ11.A4-VALP-0001 was to assess the TSAA operation with European encounters, or more explicitly to evaluate from an operational performance point of view, the TSAA algorithms on board GA Fixed Wing/Rotorcraft and Military aircrafts within EU airspace context.

Validation results obtained in this exercise are based on real de-identified mixed-equipage encounters (TCAS-equipped intruder with TCAS-unequipped ownship) in European airspace, collected from the three ANSPs by EUROCONTROL. Encounters have been post-processed by using two tools: one for close encounter identification (CFC) and the second for 1 Hz radar data interpolation, position smoothing and velocity vector (InCAS). These encounters have been used as Pseudo True Tracks for initial TSAA characterization, and subsequently the same tracks have been degraded for TSAA performance evaluation to consider the most likely scenario in EU (NACp=8, NACv=1).

While DO-348 (TSAA Safety and Performance Requirements) framework and metric for generic traffic alerting system performance have been adopted (e.g. encounter classification in MUST/MUST NOT/COULD ALERT), a different operational (and safety) criteria has been considered for EXE-03: while DO-348 has used TSAA Alerting rates (i.e. mean time between alerts) as the key Operational (and Safety) metric, using TAS performance in same environment as the acceptability threshold, in EXE-03, Missed Alert % (sum of Late and No Alert) and Outlying Alert % (Alert raised by TSAA in MUST NOT Alert encounters) were used as key performance parameters, and 5% as acceptability threshold5.

The encounter set did not distinguish between Rotorcraft and Fixed Wing GA to assess TSAA performance independently in the two scenarios. Furthermore, the encounters did not contain the information on the proximity to airports, so it was not possible to assess independently the Airport and En-Route encounter scenarios.

Out of 3838 encounters considered, 43 have been classified as MUST ALERT Encounters, 1208 as MUST NOT ALERT Encounters, and 2587 as COULD ALERT Encounters, depending on whether the minimum distance at CPA was inside or outside Hazard (HAZ) or Non-Hazard (HAZ') volumes, as defined in DO-348. The number of Military Encounters was limited (e.g. only 2 MUST ALERT Encounters), so results for military cannot be considered as significant.

Preliminary results of TSAA Performance indicate that:

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[5] Reported in an FAA study involving a group of pilots from the US and Europe and used by F. Kunzi in his TSAA foundational PhD Thesis

- **Missed Alerts % (sum of Late % and No Alerts %) are within the 5% threshold**, for both GA (fixed wing and rotorcraft), and Military encounters (~2% and ~0% respectively), when the intruder is a TCAS equipped aircraft;
- Outlying Alerts % are above the 5% threshold, for both GA (fixed wing and rotorcraft), and Military encounters (~9% and ~15% respectively), when the intruder is a TCAS equipped aircraft;
- both Missed Alerts (%) and Outlying Alerts (%) performance parameters, in the considered European encounter set, were smaller than the ones indicated in DO-348 for NAS encounters (Missed Alerts% ~ 40%÷60% and Outlying Alerts% ~ 28%÷67%)6
- Mean time to Alert was ~ 45 sec (with 20sec standard deviation)7, which is sensibly greater than the one indicated in DO-348 for NAS encounters (26÷30 sec depending on specific operational scenario).

Due to the characteristics of the encounter data set available, TSAA alert rates metrics (i.e. mean time between alerts) could not be measured in EXE-03 simulations, and comparison with DO-348 data could not be performed.

4.2.2 OBJ-PJ.11.A4-VALP-0002 Results (Thales)

OBJ-PJ.11.A4-VALP-0002 for V1 validation phase refers to initial evaluation of operational suitability of SA+/TSAA+ system during mixed equipage encounters. This objective has been initially assessed by evaluation of benefits of TSAA with "+" feature, e.g. providing pilot with RA information from another aircraft. The objective has been set up with a set of assumptions which were not fulfilled during the exercise execution.

Since **only 114 encounters out of 3622 (3.1%) raised RA before TSAA aircraft raises SA alert**, such a small number was considered insufficient for assessing the TSAA+ benefits. Also, it has been assumed that that TSAA+ pilot will, after the reception of RA information from intruder, **not modify originally planned trajectory** (e.g. no pilot model applied).

During validation execution, this assumption has been shown as inappropriate from operational point of view and might even have a negative impact on the probability of NMAC. It was concluded that such scenario rather describes **baseline scenario, which represent today situation** in which the ownship does not have an ADS-B In capability, not AIRB/EVAq applications nor TSAA and in which the intruder and ownship encounter tracks are identical to those recorded by SSR (provided by EUROCONTROL).

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[6] The range of values for DO-348 is due to different values obtained for the three operating scenario encounter set (Airport, Low En-Route, High En-Route)

[7] 45 sec mean time to alert value has been obtained by eliminating specific cases with very long Time to Alert (i.e. above 100s) which could be generated by anomalous encounters

Exercise objective was therefore modified to address NMAC probability improvements for TSAA when compared with baseline scenario representing today situation.

Results show that statistically over all significant encounters (with at least SA alert) pilot reaction to avoid aircraft collision in TSAA case reduces the probability of NMAC by up to 5.3% (GA/H encounters) in comparison to baseline scenario, e.g. no-TSAA case

That said, results have been strongly influenced by 2 factors:

- Low number of encounters for TSAA/TCAS simulations
- Simplified pilot reaction model

V1 exercise permits to have a baseline TSAA Pilot Model to be used as a basis for TSAA+ Pilot Reaction Model and perform TSAA+ safety assessment in V2, which should address quantitative safety criterions.

4.2.3 OBJ-PJ.11.A4-VALP-0003 Results (Honeywell)

OBJ-PJ.11.A4-VALP-0003 for V1 validation phase refers to evaluation and analysis of incremental benefits of TSAA+ on top of TSAA. This objective was fulfilled by identifying the scenarios where the alerting of different type of on-board systems on the conflicting aircraft can potentially increase risk incompatible manoeuvring and estimate the portion of scenarios where the availability of RA information from intruders (essential element of "+" capability) can potentially help.

A sample of 3622 mixed-equipage encounters from real European environment was used as an input to simulation involving TSAA (for unequipped trajectories) and TCAS II (for equipped trajectories) models. Such simulations showed that out of the cases where both systems alerted, in 47% it was TSAA which alerted first, in 32% TCAS TA was issued first, followed by TSAA alert, and in 14% TCAS TA was followed by TCAS RA and TSAA alert came at last.

It is assumed that TSAA with "+" feature, e.g. providing pilot with RA information from another aircraft, can potentially bring benefits in situations where:

- Only TCAS alerted (so GA pilot is aware of RA issued nearby even before TSAA alert occur),
- But also, all the other situations when both TCAS and TSAA alerted regardless of the alert sequence, or corner case situation.

Validation exercise results indicate that such situations represent 78.4% of all alerting scenarios[8]. Performed analysis however also envisage that even TSAA without "+" functionality has a potential to help in 52,6% of all alerting scenarios. Note, that this approach should be considered as a first approximation as probably some scenarios of this type would still evolve in RA and there may be some additional benefits related to "+" capability.

[8] By alerting scenario, scenario in which at least one system alerted is meant.

Based on obtained results, we can conclude that since TSAA+ can potentially bring benefits in 78.4% of all alerting scenarios, and TSAA without the "+" functionality has potential to help in 52,6% of all alerting scenarios, the incremental benefit of TSAA+ on top of TSAA is 25,8%.

These results shall be considered as initial as they are based on real but limited European data set, aiming to estimate opportunity for potential benefits. To estimate real safety benefits of the system, Human Factor study will be performed in V2 assessing pilot performance.

4.3 Confidence in Validation Results

4.3.1 Limitations of Validation Results

Validation results obtained in all exercises are based on real mixed-equipage encounters in European airspace, collected from three European ANSPs and provided by EUROCONTROL. Such a limited number of real European encounters is considered as sufficient for V1 validation phase, even though the number of analysed encounters itself is a limitation to be taken into account when interpreting the exercise results and conclusions.

Provided encounters were a mix of TMA and En-route environment encounters, but only Enroute HAZ/HAZ' volumes for encounter classification have been used, due to lack of information associated to encounters on vicinity to airports. Diversifying TMA and En-route scenarios, different HAZ/HAZ' volumes could be used, ending up possibly in different encounter classification (e.g. from Must Alert to Could Alert) and consequently TSAA/TSAA+ performance parameters results.

Provided encounters involved fixed wing aircraft and rotorcraft so it has not been possible to assess performance in fixed wing and rotorcraft independently.

The number of Military encounter was too limited to make a full assessment of TSAA/TSAA+ performance in Military platforms.

Validation results obtained for SA in EXE-PJ.11.A4-VALP-0002 were based on a limited number of real mixed-equipage encounters in European airspace, which can be considered as sufficient for V1 validation phase.

Moreover, validation results obtained for SA were based on a simplified (basic) pilot reaction model, which needs to be improved for V2 validation phase to take into consideration RA information.

4.3.1.1 Quality of Validation Results

The results provided per all exercises in Appendix A, Appendix B and Appendix C are based on TCAS II model, version 7.1 and TSAA model implemented according to TSAA sample algorithm in DO-317B. Assessment was performed in form of fast-time simulations, using three sets of real European de-identified radar tracks with 4 seconds update rate. Such encounters were interpolated to provide every second inputs for both models. Output data were post-processed to assess alerting results per encounter. Results classified as anomalies were manually analysed to define the cause.

In EXE-PJ.11.A4-VALP-0001, the accuracy of the classification based on alert times before the CPA is dependent on the method applied to define CPA position, which can be different for the two systems and method applied by evaluators.

SIMPLY simulator for EXE-PJ.11.A4-VALP-0002 has been developed in order to connect several aircrafts (modules) with their own anti collision system (i.e. TSAA and TCAS II) to a common software bus [15]. Aircraft connected can exchange information via this bus like in a real aerospace environment.

In EXE-PJ.11.A4-VALP-0002, pilot model was developed according to “Steering Behaviours For Autonomous Characters” document [16].

4.3.1.2 Significance of Validation Results

Exercise EXE-PJ.11.A4-VALP-0001 results are based on 3622 European encounters involving one TCAS-equipped and one unequipped aircraft. Encounters represent real situations recorded in central European airspace.

Exercise EXE-PJ.11.A4-VALP-0002 results were influenced by limited encounter set, but is considered as sufficient for V1 maturity phase since it showed promising benefits between encounters with TSAA equipped aircraft (with pilot reaction) and baseline scenario which refers to current situation in Europe when GA/R/MIL aircraft are not equipped with TSAA nor TSAA+. Results for Military aircrafts are not significant due to the very low number of encounters.

Exercise EXE-PJ.11.A4-VALP-0003 results are based on 3838 European encounters involving one TCAS-equipped and one unequipped aircraft. Unequipped aircraft were distinguished between GA (fixed wing and rotorcraft) and Military (fixed wing and rotorcraft), for a total of 3726 and 112 encounters respectively. Encounters represent real situations recorded in central European airspace. Out of the 3838 encounters 43 have been classified as Must Alert (MA), 1208 as Must Not Alert (MNA) and 2887 as Could Alert (CA), depending on the horizontal and vertical miss distance at CPA.

For V1 phase, analysis results for all exercises are qualitative.

5 Conclusions and recommendations

5.1 Conclusions

Validation results obtained in these three exercises (EXE-PJ.11.A4-VALP-0001, EXE-PJ.11.A4-VALP-0002, EXE-PJ.11.A4-VALP-0003) are based on real mixed-equipage encounters (TCAS equipped intruder with TCAS Unequipped ownship) in European airspace, collected from three European ANSPs and provided by EUROCONTROL.

EXE-PJ.11.A4-VALP-0001 had the objective to identify the scenarios where the alerting of different type of on-board systems on the conflicting aircraft can potentially increase risk incompatible manoeuvring and estimate the portion of scenarios where the availability of RA information from intruders (essential element of "+" capability) can potentially help.

A sample of 3622 mixed-equipage encounters from real European environment was used as an input to simulation involving TSAA (for unequipped trajectories) and TCAS II (for equipped trajectories) models. Such simulations showed that out of the cases where both systems alerted, in 47% it was TSAA which alerted first, in 32% TCAS TA was issued first, followed by TSAA alert, and in 14% TCAS TA was followed by TCAS RA and TSAA alert came at last.

It is assumed that TSAA with "+" feature, e.g. providing pilot with RA information from another aircraft, can potentially bring benefits in situations where:

- Only TCAS alerted (so GA pilot is aware of RA issued nearby even before TSAA alert occur),
- But also, all the other situations when both TCAS and TSAA alerted regardless of the alert sequence, or corner case situation.

Validation exercise results indicate that such situations represent 78.4% of all alerting scenarios[9]. Performed analysis however also envisage that even TSAA without "+" functionality has a potential to help in 52,6% of all alerting scenarios. Note, that this approach should be considered as a first approximation as probably some scenarios of this type would still evolve in RA and there may be some additional benefits related to "+" capability.

These results shall be considered as initial as they are based on real but limited European data set, aiming to estimate opportunity for potential benefits. To estimate real safety benefits of the system, Human Factor study will be performed in V2 assessing pilot performance.

EXE-PJ.11.A4-VALP-0002 had the objective to evaluate the benefits of TSAA with "+" feature, e.g. providing pilot with RA information from another aircraft. This objective has been set up with a set of assumptions which were not fulfilled during the exercise execution. Since **only 114 encounters out of 3622 (3.1%) raised RA before TSAA aircraft raises SA alert**, such a small number was considered insufficient for assessing the TSAA+ benefits. The objective was modified to address NMAC

[9] By alerting scenario, scenario in which at least one system alerted is meant.

probability improvements for TSAA when compared with baseline scenario which represent today situation in which the ownship does not have an ADS-B In capability, not AIRB/EVAq applications nor TSAA and in which the intruder and ownship encounter tracks are identical to those recorded by SSR (provided by EUROCONTROL).

In V1 phase a simplified pilot reaction model based on [16] has been used for simulations.

This model is based on Craig Reynold's paper "Steering Behaviours For Autonomous Characters" [16] at Sony. This paper presents a solution for one requirement of "autonomous characters" in animation and games: the ability to navigate around their world in a life-like and improvisational manner (for example seeking, fleeing, wandering, arriving, pursuing, evading, avoiding an obstacle, following a path, and so on). Steering behaviours is the name given by Craig Reynolds to his movement algorithms; they are not kinematic, but dynamic.

Dynamic movement takes account of the current motion of the character. A dynamic algorithm typically needs to know the current velocities of the character as well as its position. A dynamic algorithm outputs forces or accelerations with the aim of changing the velocity of the character. The term "Autonomous Characters" is used in many contexts and here it has been used for aircrafts.

The vehicle model used for TSAA aircraft is very simplistic and generic and based on a point mass approximation. This use of an oversimplified non-physical vehicle model is merely for convenience and intended to be "without loss of generality".

These results shall be considered as initial as they are based on real but limited European data set and a very simplified pilot reaction model, but described approach introduced very promising potential for benefits of TSAA+ and clarified next steps to be taken in order to be able to assess TSAA+ performance in next maturity phase.

Results show that statistically over all significant encounters (with at least SA alert) pilot reaction to avoid aircraft collision in TSAA case reduces the probability of NMAC by up to 5.3% (GA/H encounters) in comparison to baseline scenario, e.g. no-TSAA case.

That said, results have been strongly influenced by 2 factors:

- Low number of encounters for TSAA/TCAS simulations
- Very Simplified pilot reaction model

V1 exercise permits to have a baseline TSAA Pilot Model to be used as a basis for TSAA+ Pilot Reaction Model and perform TSAA+ safety assessment in V2, which should address quantitative safety criterions.

EXE-PJ.11.A4-VALP-0003 had the objective to evaluate from an operational performance point of view TSAA algorithms on board GA Fixed Wing/Rotorcraft and Military aircrafts within EU airspace context.

Results indicate that:

- Miss Alerts (Late and No Alerts) (%) are within the 5% threshold, for both the General Aviation (Fixed Wing and Rotary Wing aggregated, or GA_R) and Military (MIL) with TCAS-equipped aircraft encounters (~2% and ~0% respectively)

- Outlying Alerts (%) are above the 5% threshold for both GA_R and MIL mixed equipage encounters (~9% and ~15% respectively)
- both Miss Alerts (%) and Outlying Alerts (%) performance parameters in the considered European mixed encounter set have been measured to be smaller than the ones indicated in DO-348 for NAS encounters (Miss Alerts% ~ 40÷60% and Outlying Alerts% ~ 28÷67%, depending on specific scenario, being Airport, Low En-Route, High En-Route)
- Mean time to Alert has been measured to be ~ 45 sec in the considered encounter set (with 20sec standard deviation), which is sensibly greater than the one indicated by DO-348 for NAS encounters (cfr Table 36), also by eliminating specific cases with very long Time to Alert (i.e. above 100s) which could be generated by anomalous encounters.

Globally V1 exercises permits mainly to have qualitative assessment. For V2, which has to address safety criterions, quantitative assessment is necessary.

For more details refer to Appendix A, Appendix B and Appendix C.

5.1.1 Conclusions on SESAR Solution maturity

Refer to Appendix D.

5.1.2 Conclusions on concept clarification

SA+ concept, also referred as TSAA+, consist of already standardized ADS-B IN Traffic Situational Awareness with Alerts **(TSAA)** application enhanced to use information about intruder RA (Resolution Advisory), and indicate it to Pilot.

2017 edition of SESAR2020 CONOPS does not explicitly address TSAA+ (SA+) feature, but the solution description partially address what the concept of TSAA+ is (can be considered as initial). CONOPS update is anyway recommended.

Stakeholders were identified, discussed & documented in May 2017.

From conceptual point of view, it is recommended for TSAA+ operational feasibility to consider the TSAA operational feasibility in European context.

It would be interesting to assess feasibility of providing not only RA broadcast for GA/R/Military pilots, but also equipage status of intruder aircraft via BDS 1,0 (see Appendix I).

5.1.3 Conclusions on technical feasibility

Technical feasibility is not supposed to be an issue, e.g. was not assessed at this stage.

No architectural constraints have been identified.

5.1.4 Conclusions on performance assessments

This solution is addressing Safety and Human Performance KPA, and had no Validation Targets set for V1. V1 validation exercises permitted mainly to have qualitative assessment, which introduced adequate V1 outcomes to support V1 maturity assessment. Safety criterions, human performance and refined, rather quantitative assessment will be performed in V2.

5.2 Recommendations

5.2.1 Recommendations for next phase

Obtaining results with higher significance would require additional analysis using bigger data sample, ideally using GA encounter model (under development).

For the next maturity phase, it is recommended to:

- perform real time validation of the proposed solution including GA/R to assess the acceptability of the system and to refine benefits estimation which were addressed in this VALR,
- use bigger data sample for higher significance of the result analysis, in particular for what concerns Military encounters and other European geographical areas,
- address safety criterions defined in V1 Safety VALP for this solution,
- improve pilot model taking into account aircraft category manoeuvre capability,
- identify Helicopter encounters, in order to discriminate Fixed wing and Rotary wing within GA\R encounter set analysed in V1,
- eliminate anomalous encounters from the encounter set used for performance assessment, possibly using expert pilot judgement and additional information available to EUROCONTROL,
- discriminate Airport scenario encounters from en-route encounters, by means of visual inspection of flight patterns, possibly using expert pilot judgement and additional information available to EUROCONTROL,

5.2.2 Recommendations for updating ATM Master Plan Level 2

This SESAR solution is from the EATMA point of view addressed under PJ11-A4, Airborne Collision Avoidance for General Aviation and Rotorcraft – ACAS Xp, but since ACAS Xp and TSAA+ are two different capabilities, PJ11-A4 is likely to be split at the V1 SA+ gate.

In case of split, TSAA+ solution definition may be needed as well as solution definition at ATM Master Plan level. Suggested modifications for updating ATM Master Plan Level 2 and proposed solution allocation at EATMA level is as follows:

Solution name SOL: [suggested new PJ.11-A4b] – Improved Air Traffic Situational Awareness with Alerts for General Aviation, Rotorcraft and Military.

O/I:

- [suggested new CM-0808-sa] Improved Air Traffic Situational Awareness with Alerts for General Aviation, Rotorcraft and Military. *Description: Improved Situational Awareness with Alerts for General Aviation, Rotorcraft and Military, taking advantage of surveillance data from passive sources (ADS-B), improving compatibility with non-equipped aircraft.*

Enabler EN:

- A/C-54a (already existing and linked with PJ.11-A4) Enhanced Airborne Collision Avoidance (ACAS)

Operating Environments OE & Sub-Operating Environments: (suggested) TMA (High complexity, Low complexity, Medium Complexity) and En-Route (High complexity, Low complexity, Medium Complexity)

Deployment package DP: (suggested) Enhanced Safety Nets

Pilot Common Project; PCP Elements: N/A

Operational Hierarchy: (suggested) ENB01 CNS -> ENB01.01 CNS -> ENB01.01.05 Surveillance

Capability: Conflict Management -> Collision Avoidance -> Mid-Air Collision Avoidance

Key Feature: (suggested allocation) Advanced air traffic services and/or Enabling Aviation Infrastructure.

5.2.3 Recommendations on regulation and standardisation initiatives

Preliminary TSAA Safety and Performance Assessment of EXE03 on TSAA in European airspace have shown results which are quite different from the one described in DO-348. In particular for what concerns:

- Missed Alert %: EXE03 obtained values sensibly lower than those indicated in DO-348
- Outlying Alert %: EXE03 obtained values sensibly lower than those indicated in DO-348
- Mean Time to Alert: EXE03 obtained values sensibly higher than those indicated in DO-348

Having in mind that that EXE03 results considers only a subset of the master encounter sets used in DO-348, in particular:

- Only radar recordings of close encounters (few minutes before/after CPA)
- Only mixed encounters, in which ownship is a General Aviation (fixed and rotary wing) or Military aircraft (with no TCAS)
- Only central Europe airspace is represented
- Aggregate Airport and Enroute encounters performance (no information on airport proximity)

It would be useful to ask WG51/SC186 experts for clarification on the above mentioned discrepancies, as guidance for next Validation activities.

5.2.4 Recommendations for Future Research

It is recommended to assess feasibility of providing not only RA broadcast for pilots, but also equipage status of intruder aircraft. Such information may be beneficial in situations, when only TSAA alerted (5.8%). In case, only TSAA alert is issued, even information whether intruder is or is not equipped might be considered useful for GA pilot.

6 References

6.1 Applicable Documents

Content Integration

[1] B.04.01 D138 EATMA Guidance Material

[2] EATMA Community pages

[3] SESAR ATM Lexicon

Performance Management

[4] B.04.01 D108 SESAR 2020 Transition Performance Framework

[5] D4.2 PJ.19: Validation Targets (2017)

Validation

[6] Transition VALS SESAR 2020 - Consolidated deliverable with contribution from Operational Federating Projects

[7] European Operational Concept Validation Methodology (E-OCVM) - 3.0 [February 2010]

Safety

[8] SESAR, Safety Reference Material, Edition 4.0, April 2016

[9] SESAR, Guidance to Apply the Safety Reference Material, Edition 3.0, April 2016

6.2 Reference Documents

[10] ED-78A GUIDELINES FOR APPROVAL OF THE PROVISION AND USE OF AIR TRAFFIC SERVICES SUPPORTED BY DATA COMMUNICATIONS.[10]

[11] ATC-374, “Coordinating General Aviation Manoeuvres with TCAS Resolution Advisories”, MIT, 07/02/2011

[12] SESAR P09.47 D15, "Comparison study of TSAA and ACAS X performance", edition 00.02.00, 22/10/2015

10 The EUROCAE ED-78A has been used as an initial guidance material. ED-78A is useful, but is not an applicable document, because it mostly addresses the V4-V5 phases, whilst the SESAR R&D programme is focussed on development (V1-V2-V3, and because of its partial compliance with safety regulatory requirements).

[13] ED-232 / RTCA DO-348, “SAFETY, PERFORMANCE AND INTEROPERABILITY REQUIREMENTS DOCUMENT FOR TRAFFIC SITUATION AWARENESS WITH ALERTS (TSAA)”, 06/2014

[14] ED-194A / RTCA DO-317B, “Minimum Operations Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System”, 06/2014

[15] The IVY Software bus – a white paper – NT02-816, Stephane Chatty CENA, Centre d'Etudes de la Navigation Aérienne

[16] Steering Behaviors For Autonomous Characters, Craig W. Reynolds, Sony Computer Entertainment America

[17] DO-185B Minimum Operations Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II)

[18] TCAS-II Resolution Advisory Detection Algorithm Cesar Munoz, Anthony Narkawicz, James Chamberlain, NASA

[19] DEVELOPMENT OF A HIGH-PRECISION ADS-B BASED CONFLICT ALERTING SYSTEM FOR OPERATIONS IN THE AIRPORT ENVIRONMENT, Fabrice Kunzi (MIT), 2013

[20] SESAR Solution PJ.11-A4 Initial OSED (SA+), PJ.11-A4.V1.10

Appendix A Validation Exercise #01 Report (Honeywell)

This appendix concludes validation report for EXE-PJ.11-A4-VALP-0001, exercise performed by Honeywell.

A.1 Summary of the Validation Exercise #01 Plan

As in the VALP PJ.11-A4_V1_VALP_SA+ (T6.020).

A.1.1 Validation Exercise description, scope

This exercise was performed as FTS (Fast Time Simulation) on Honeywell simulation platform using SA capability model evaluated using initial set of mixed-equipage encounters representative for European operations and involving GA/R (provided by EUROCONTROL).

The primary objective was to identify and analyse scenarios where the alerting of different type of systems may potentially increase risk of conflicting manoeuvring. The second objective was to evaluate in how big portion of scenarios the availability of RA Broadcast could potentially help.

Simulations included encounters with one TSAA (+) equipped aircraft and one intruder equipped with TCAS II (validation scenario). Reference scenario was not applicable for this type of exercise.

Validation approach is depicted at Figure 2. Radar data tracks received from EUROCONTROL (8090) were initially filtered (discarded encounters where both aircrafts displayed both status: “EQUIPPD”, “GANOTCS”) to eliminate equipped-equipped encounters caused by incorrect initial correlation of the tracks. Such filter eliminated 55.2% of the encounters, leaving a sample of 3622 encounters. Next steps were then to modify raw data to fit the two platforms described below and to interpolate the data to get the every second data.

Two platforms were used to perform this exercise: First, CASCARA (**C**ollision **A**voidance **S**imulation **C**omponents **A**nd **R**untime **A**nalysis) simulation platform was used to simulate TCAS II-equipped intruder. CASCARA is extensible modular simulation platform developed by Honeywell to support simulation of various ACAS Xa/p/u/… builds. It supports range of I/O data types and execution modes for development, testing and analysis. Second, development TSAA simulation platform was used to simulate non-TCAS-equipped ownship.

Once the encounters were processed by both models, the alerting performance of TCAS II and TSAA was compared, introducing a result that could have been divided into several different groups.

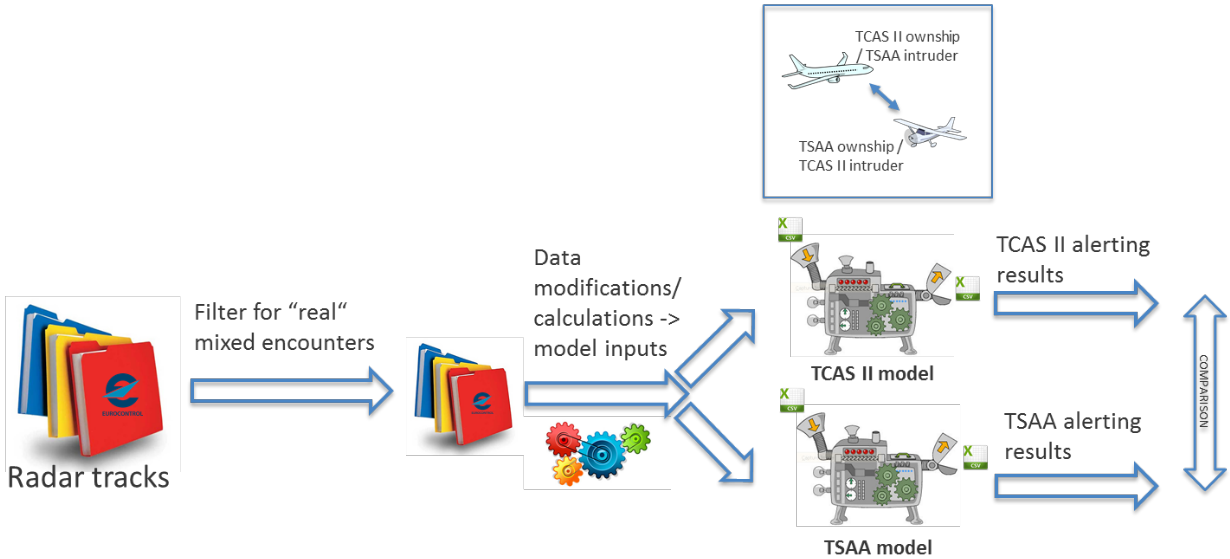


Figure 2: EXE#1 validation approach

A.1.2 Summary of Validation Exercise #01 Validation Objectives and success criteria

The V1 validation objectives & success criterions are rather theoretical and qualitative than quantitative at this stage.

Identifier	EX1-OBJ-PJ.11.A4-VALP-0001
Objective	To identify and analyse scenarios where the alerting of different type of systems may potentially increase risk of conflicting manoeuvring
Title	Risk of conflicting maneuvering
Category	<operational feasibility>
CRT-PJ.11-A4-EX1-VALP-0001-0001	Scenarios with potentially increased risk of conflicting manoeuvring were identified.

Identifier	EX1-OBJ-PJ.11.A4-VALP-0002
Objective	To evaluate in which portion of scenarios the availability of RA Broadcast could potentially help.
Title	RA information processing
Category	<operational feasibility>
CRT-PJ.11-A4-	~~All scenarios identified in previous objective were analysed.~~ Ratio of scenarios

EX1-VALP-0002-0001	where RA Broadcast could potentially help was estimated.

A.1.3 Summary of Validation Exercise #01 Validation scenarios

The validation scenario (solution scenario) are based on real mixed equipped encounters detected in core European airspace with one aircraft without TCAS II. For validation, these encounters were simulated with a non-cooperative aircraft being equipped by TSAA+.

Reference scenario was not applicable in this case, since the objective of this exercise was to identify and analyse scenarios where the alerting of different type of systems may potentially increase risk of conflicting manoeuvring, not to compare actual behaviour of the aircraft with and without TSAA+ (such objectives being considered for V2).

A.1.4 Summary of Validation Exercise #01 Validation Assumptions

Apart from general validation assumptions listed in section 3.2.3. Following exercise-related assumptions were identified.

Identifier	Title	Type of Assumption	Description	Justification	Flight Phase	KPA Impacted	Source	Value(s)	Owner	Impact on Assessment
ASS-PJ.11-A4-005	Ownship types	Traffic Characteristics	Preliminary encounter set will consist of encounters including GA and R encountering TCAS II equipped intruders.	Honeywell is not addressing military aspects.	N/A	N/A	HONEYWELL	N/A	HONEYWELL	Low
ASS-PJ.11-A4-006	One intruder only	Traffic Characteristics	Simulations will include only one intruder.	We will only simulate conflict of two aircraft.	N/A	N/A	HONEYWELL	N/A	HONEYWELL	Low

Table 9: Validation Assumptions overview for EXE#01

A.2 Deviation from the planned activities

The only deviation from planned activities is rewording of success criterion CRT-PJ.11-A4-EX1-VALP-0002-0001 into: “Ratio of scenarios where RA Broadcast could potentially help was estimated.”

A.3 Validation Exercise #01 Results

A.3.1 Summary of Validation Exercise #01 Results

Validation Exercise #01 Validation Objective ID	Validation Exercise #01 Validation Objective Title	Validation Exercise #01 Success Criterion ID	Validation Exercise #01 Success Criterion	Sub-operating environment	Exercise #01 Validation Results	Validation Exercise #01 Validation Objective Status
EX1-OBJ-PJ.11.A4-VALP-0001	Risk of conflicting maneuvering	CRT-PJ.11-A4-EX1-VALP-0001-0001	Scenarios with potentially increased risk of conflicting manoeuvring were identified.	En-Route, TMA – various from high to low complexity	Scenarios with potentially increased risk of conflicting manoeuvring are scenarios when: 1. Only TCAS alerted (so GA pilot is aware of RA issued nearby even before TSAA alert occur), 2. But also all the other situations when both TCAS and TSAA alerted regardless of the alert sequence, or corner case situation.	OK
EX1-OBJ-PJ.11.A4-VALP-0002	RA information processing	CRT-PJ.11-A4-EX1-VALP-0002-0001	Portion of scenarios where RA Broadcast could potentially help was estimated.	En-Route, TMA – various from high to low complexity	The above-identified scenarios where availability of RA broadcast can potentially help represents 78.4% from all scenarios where at least one system alerted.	OK

Table 10: Validation Results for Exercise 1

A.3.2 Analysis of Exercise 1 Results per Validation objective

Approach to analysis

EUROCONTROL has provided 3 sets of radar tracks each one of them describing the encounter between two aircraft. Provided data sets were filtered by EUROCONTROL to include TCAS-equipped and non-equipped aircraft. The total numbers of encounters provided by EURCONTROL for 3 ANSPs:

	ANSP1	ANSP3	ANSP6
N° total encounters	992	3473	3625

Table 11: Number of encounters

Each file (.eu1) contains the following information: *time stamp, flight ID, squawk number, X position [NM], Y position [NM], altitude [ft] and status*. The information about each aircraft is given by alternating rows. The time stamp indicates the time moment when the flight information was recorded and is given every 4 seconds. X and Y positions are distances respect to an unspecified origin whose location is not necessary for the successful outcome of the exercise. Finally, the possible statuses that an aircraft can assume are: TCAS=*EQUIPPD* and/or non-equipped=*GANOTCS*.

Initial analysis of provided encounters showed that encounters does not necessarily include only mixed encounters, therefore an additional filter was applied. To obtain only mixed-encounters from the initial set of data, and to take only TCAS-equipped and (GA) non-equipped aircraft into consideration, filtering was achieved by making sure that each aircraft assumes just one status (*EQUIPPD* or *GANOTCS*) during the encounter and that they are different from one another (ex: AC1 status=*EQUIPPD* vs. AC2=*GANOTCS*). Therefore, the following number of mixed encounters has been identified and used for analysis:

	ANSP1	ANSP3	ANSP6
N° mixed encounters	354	1023	2245

Table 12: Number of mixed encounters

Such data has then been post-processed to generate the input files needed for TCAS and TSAA simulation. The following steps were therefore applied:

1. Remove inconsistent information: some files do not display an alternating pattern of the rows (probably missing data). Standalone rows have been thus removed to restore the alternating rows format.

2. Interpolation: since the flight information is given every 4 seconds, as mention in the first paragraph, an interpolation has been applied to estimate the flight data every 1 second.

3. Extracting additional information: other quantities such as latitude, longitude, ground speed, vertical rate, East-West and North-South speed have been calculated.

4. Generate input files: the data for each aircraft has been reshaped to fit the input file format for TCAS and TSAA simulation.

TCAS simulation was performed by using the TCAS II, version 7.1 module integrated in a Honeywell encounter-based simulator named CASCARA. This simulator provides one platform for simulation of various ACASes (e.g., TCAS II or different versions of ACAS X) and can be also connected to systems running on different platforms. Results have been analyzed to identify the number of encounters which raised traffic advisory (TA) and/or resolution advisory (RA). The encounters have been categorized based on the type and number of alerts raised:

	ANSP1	ANSP3	ANSP6
Only TA (no RA)	222	678	1455
Only RA (no TA)	0	0	0
TA or TA&RA	328	858	1932
TA and RA with Anomalies	106	180	477
TA and RA without Anomalies	104	170	453

Table 13: TCAS alerts combinations

Ten TCAS outputs have shown some anomaly behaviour due to the time when TA and/or RA have been raised respect to the Closest Point of Approach (CPA). Specifically, an anomaly is identified in case RA and/or TA and/or SA are raised after the CPA. Here is presented a figure summarizing possible combinations according to which an anomaly behaviour is determined:

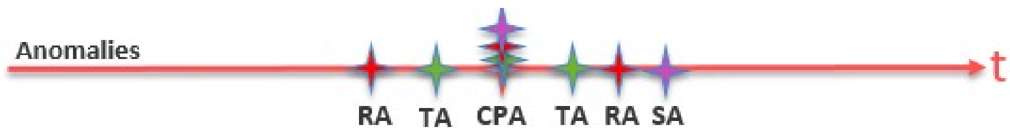


Figure 3: Anomalies

A table resuming the anomalies for each ANSP is given below:

	ANSP1	ANSP3	ANSP6
RA > TA > CPA	-	1	-
CPA > TA or CPA > RA	1	2	12
CPA > TA or CPA > RA and RA > TA	1	4	3
RA = CPA	-	3	9
SA = CPA	-	-	1

Table 14: List of anomalies

Additional analysis showed that possible reasons which can be associated to these anomalies are the following:

- The global CPA is selected instead of the local one at which the alerts are raised.
- Missing/jumping[11] data may cause the wrong calculation of the CPA, thus positioning TA and/or RA after or at the same time of the closest point of approach. Here a figure presenting such behaviour is shown:

[11] Missing data: information about aircrafts is not given every 4 seconds as from file format. Jumping data: information about aircrafts is given every 4 seconds but positional coordinates are not consistent thus causing extreme displacements.

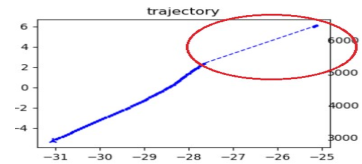


Figure 4: Jumping data

- Differences in CPA calculation between the implemented approach (time at which slant range is minimum) and TCAS/TSAA estimation.
- Insufficient flight data before CPA may just be enough to raise RA but not TA.
- Near collision situations which may raise RA before CPA followed by TA, would require more detailed analysis which are out of the scope of this validation exercise. A possible explanation could be related to the presence of helicopter data which could cause unexpected behaviour during TCAS and TSAA simulations.

Even though the anomalies are rather realistic, and most probably caused by simulation limitations, they did not fall into any of the four categories (described below) which were further analysed in order to evaluate the added value of the TSAA "+" feature, and therefore were excluded from next steps of analysis.

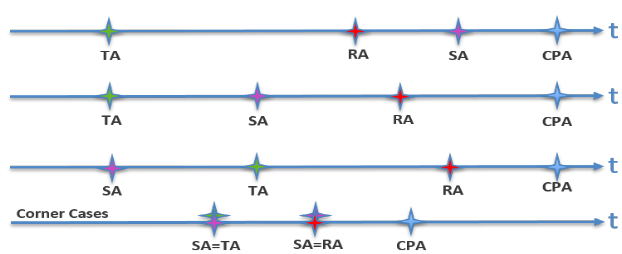
In the next step, TSAA simulations were performed to investigate how many Situational Awareness (SA) alerts have been raised throughout the encounters.

	ANSP1	ANSP3	ANSP6
N° TSAA alerted	92	113	398

Table 15: Number of encounters with TSAA alert

TCAS and TSAA results were then compared in order to determine which flights have raised TA, RA and SA alerts during an encounter (to obtain encounters in which both systems alerted). The goal of such analysis is to obtain a statistical distribution of the alert times before the CPA. Based on the time when alerts were issued, 4 categories were used to interpret the data:

A. TA > RA > SA > CPA
B. TA > SA > RA > CPA
C. SA > TA > RA > CPA
D. SA==TA > CPA or SA == RA > CPA



OBJ-PJ.11.A4-VALP-0003 Results

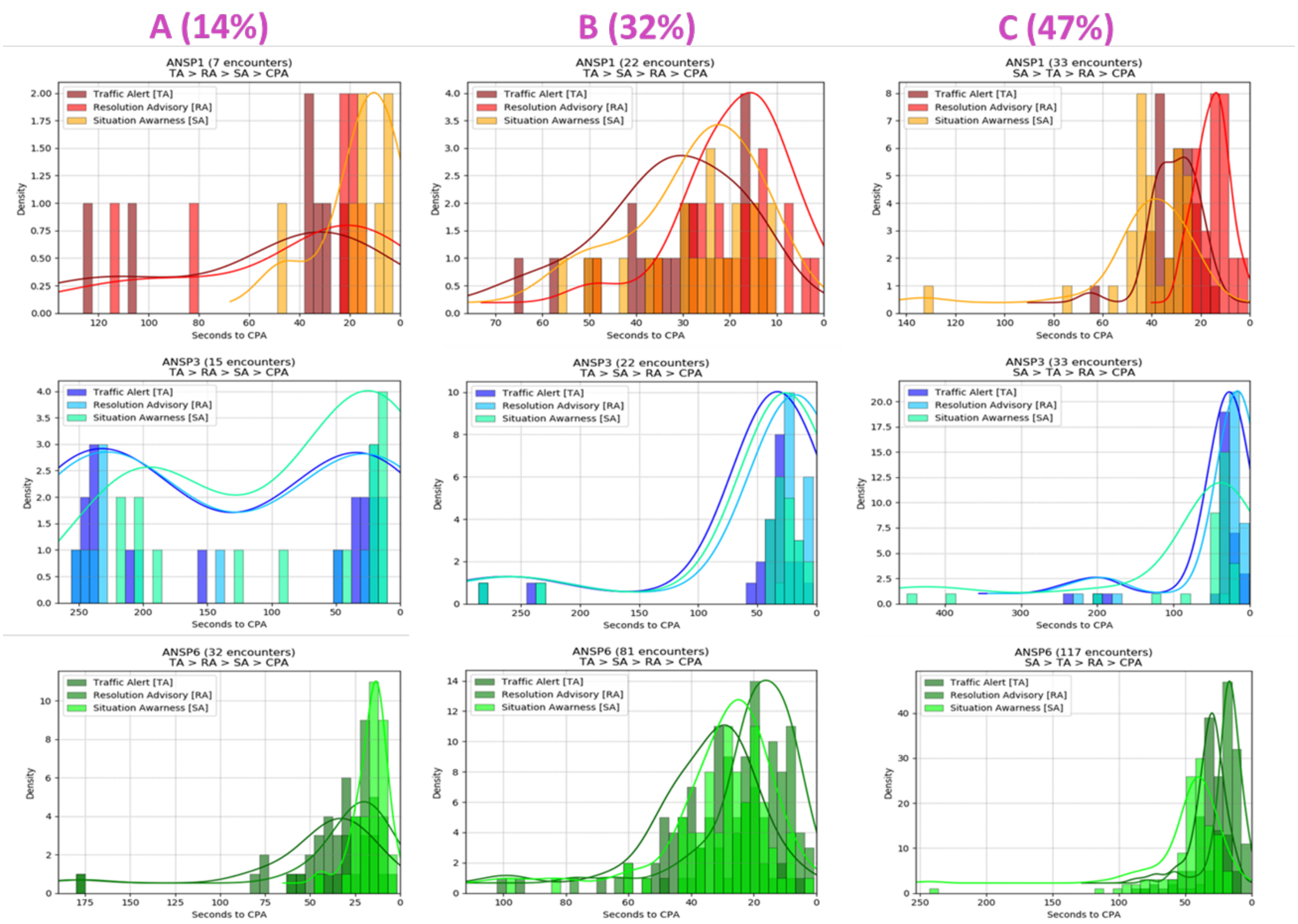
OBJ-PJ.11.A4-VALP-0003 for V1 validation phase refers to evaluation and analysis of incremental benefits of TSAA+ on top of TSAA. Following table summarizes alerting results for different data sets.

	Ansp1				Ansp3				Ansp6			
N° of encounters by Eurocontrol	992				3473				3625			
N° of mixed encounters	354				1023				2245			
TSAA [SA] | TCAS [TA-RA] Analysis		TSAA		TCAS		TSAA		TCAS		TSAA		TCAS
	Paz: True / Caz: False	70	only TA alerts	222	Paz: True / Caz: False	86	only TA alerts	678	Paz: True / Caz: False	318	only TA alerts	1455
	Paz: False / Caz: True	0	only RA alerts	0	Paz: False / Caz: True:	0	only RA alerts	0	Paz: False / Caz: True:	0	only RA alerts	0
	Paz: True / Caz: True	22	TA and RA alerts	106	Paz: True / Caz	27	TA and RA alerts	180	Paz: True / Caz	80	TA and RA alerts	477
	SA alerts	92	TA and RA and no anomalies	104	SA alerts	113	TA and RA and no anomalies	170	SA alerts	398	TA and RA and no anomalies	453
N° of encounters rising SA (TSAA), TA and RA (TCAS) without anomalies	67				76				244			

Figure 5: Overview of encounter alerts

Out of all mixed encounters, 73,2% of encounters did not issue any alert, in 10,2% of cases only TCAS alerted, and in 5,8% of cases only TSAA alerted. Both systems alerted in 10,8% of encounters, e.g. 387 mixed-encounters were post processed and divided into A, B, C or D groups for further analysis with the distribution as depicted below.

In most of the cases (47%) where both systems alerted, it was the TSAA which alerted first, followed by TCAS TA and RA. In 32% of the cases, first a TCAS TA was issued, followed by TSAA alert and then



TCAS RA. Only in 14% of analysed scenarios first the TCAS TA and RA was issued and then TSAA system alerted. Corner cases where TA or RA was issues at the same time as TSAA alert represent 7% of the analysed scenarios.

Results per exercise objectives

EX1-OBJ-PJ.11.A4-VALP-0001: ***To identify and analyse scenarios where the alerting of different type of systems may potentially increase risk of conflicting manoeuvring.***

The goal of TSAA+ is to increase pilot situational awareness of threats and so to assist the pilot in when and where to look out the cockpit to acquire the approaching aircraft; to increase the performance of the detection and support the decision making as regards a making a successful sense and avoid manoeuvre; and to reduce the failure of TCAS RA with GA involvement due to GA pilot misunderstanding of the TCAS equipped aircraft intentions. Based on that, it is clear that TSAA with "+" feature showing RA information from another aircraft, can introduce significant benefits in situations where:

- Only TCAS alerted (so GA pilot is aware of RA issued nearby even before TSAA alert occur),
- But also, all the other situations when both TCAS and TSAA alerted regardless of the alert sequence, or corner case situation.

In the TA-SA-RA (group B) or SA-TA-RA (group C) cases, GA pilot is having an alert on TCAS-equipped aircraft earlier than TCAS RA is issued and gives GA pilot a chance to solve potential conflict early enough to even avoid TCAS to issue an RA. The same is true also for scenarios where only TSAA alerted. Such situations can be considered as **TSAA-only benefit**, regardless of "+" functionality being implemented or not, and they represent 52.6% of all alerting scenarios (where at least one system alerted). This approach should be considered as a first approximation as probably some scenarios of this type would still evolve in RA and there may be some benefits related to "+" capability.

EX1-OBJ-PJ.11.A4-VALP-0002: ***To evaluate in which portion of scenarios the availability of RA broadcast could potentially help.***

The above-identified scenarios where availability of RA broadcast can potentially help represents 21% from whole data sample, what represents 78.4% from all scenarios where at least one system alerted.

A.3.4 Confidence in Results of Validation Exercise 1

1. Level of significance/limitations of Validation Exercise Results

Validation results obtained in this exercise are based on real mixed-equipage encounters in European airspace, collected from three European ANSPs and provided by EUROCONTROL. Such a limited number of real European encounters is considered as sufficient for V1 validation phase, even though the number of analysed encounters itself is limitation to be taken into account when interpreting the exercise results and conclusions.

Provided encounters were a mix of TMA and en-route environment encounters involving fixed wing aircraft and rotorcraft.

2. Quality of Validation Exercises Results

The results provided in this appendix are based on TCAS II model, version 7.1 and TSAA model implemented according to TSAA sample algorithm in DO-317B. Assessment was performed in form of fast-time simulations, using three sets of real European de-identified radar tracks with 4 second update rate. Such encounters were interpolated to provide every second inputs for both models. Output data were post-processed to assess alerting results per encounter. Results classified as anomalies were manually analysed to define the cause.

The accuracy of the classification based on alert times before the CPA is dependent on the method applied to define CPA position, which can be different for the two systems and method applied by evaluators.

3. Significance of Validation Exercises Results

Exercise results are based on 3622 European encounters involving one TCAS-equipped and one unequipped aircraft. Encounters represent real situations recorded in central European airspace. To obtain the results, expert judgement was applied.

A.3.5 Conclusions

EXE01 had the objective to identify the scenarios where the alerting of different type of on-board systems on the conflicting aircraft can potentially increase risk incompatible manoeuvring and estimate the portion of scenarios where the availability of RA information from intruders (essential element of "+" capability) can potentially help.

A sample of 3622 mixed-equipage encounters from real European environment was used as an input to simulation involving TSAA (for unequipped trajectories) and TCAS II (for equipped trajectories) models. Such simulations showed that out of the cases where both systems alerted, in 47% it was TSAA which alerted first, in 32% TCAS TA was issued first, followed by TSAA alert, and in 14% TCAS TA was followed by TCAS RA and TSAA alert came at last.

It is assumed that TSAA with "+" feature, e.g. providing pilot with RA information from another aircraft, can potentially bring benefits in situations where:

- Only TCAS alerted (so GA pilot is aware of RA issued nearby even before TSAA alert occur),
- But also, all the other situations when both TCAS and TSAA alerted regardless of the alert sequence, or corner case situation.

Validation exercise results indicate that such situations represent 78.4% of all alerting scenarios[12]. Performed analysis however also envisage that even TSAA without "+" functionality has a potential to help in 52,6% of all alerting scenarios. Note, that this approach should be considered as a first approximation as probably some scenarios of this type would still evolve in RA and there may be some additional benefits related to "+" capability.

These results shall be considered as initial as they are based on real but limited European data set, aiming to estimate opportunity for potential benefits. To estimate real safety benefits of the system, Human Factor study will be performed in V2 assessing pilot performance.

1. Conclusions on concept clarification

From conceptual point of view, it is recommended to assess feasibility of providing not only RA broadcast for GA pilots, but also equipage status of intruder aircraft. Such information may be beneficial in situations, when only TSAA alerted (5.8%). In case, only TSAA alert is issued, even information whether intruder is or is not equipped might be considered useful for GA pilot.

2. Conclusions on technical feasibility

Technical feasibility is not supposed to be an issue, e.g. was not assessed at this stage.

3. Conclusions on performance assessments

N/A. No performance assessment was performed at this stage.

A.3.6 Recommendations

Obtaining results with higher significance would require additional analysis using bigger data sample, ideally using GA encounter model (under development).

For the next maturity phase, it is recommended to:

- address safety criterions defined in V1 Safety VALP for this solution, and
- perform real time validation of the proposed solution including GA pilots to assess the acceptability of the system and to refine benefits estimation which were addressed in this VALR.

From conceptual point of view, it is recommended to assess feasibility of providing not only RA broadcast for GA pilots, but also equipage status of intruder aircraft.

[12] By alerting scenario, scenario in which at least one system alerted is meant.

Appendix B Validation Exercise #02 Report (Thales)

This appendix concludes validation report for EXE-PJ.11-A4-VALP-0002, exercise performed by Thales.

B.1 Summary of the Validation Exercise #02 Plan

As in the VALP PJ.11-A4_V1_VALP_SA+ (T6.020).

Deviations from VALP are captured in section B.2.

B.1.1 Validation Exercise description, scope

This exercise was performed as FTS (Fast Time Simulation) on Thales simulation platform SIMPLY using TSAA capability model according to [13] and TCAS II capability model according to [17].

Simulations in exercise used initial set of mixed-equipage encounters representative for European operations and involving Global Aviation Aircraft, Rotorcraft and Military Aircraft (provided by EUROCONTROL).

The objective was to assess qualitatively, the benefits of TCAS II information broadcast ("+") on TSAA-equipped aircraft, in terms of probability of near mid-air collision (NMAC).

Radar data tracks received from EUROCONTROL (8384) were initially filtered (discarded encounters where both aircrafts displayed both status: "EQUIPPD", "GANOTCS") to eliminate equipped-equipped encounters caused by incorrect initial correlation of the tracks. Such filter eliminated 53,3% of the encounters, leaving a sample of 3916 encounters.

Radar data was sampled every 4 seconds and interpolation has been done using InCAS software provided by EUROCONTROL to get the every second data.

Simulations included one TSAA equipped aircraft and one intruder equipped with TCAS II, and they were performed in 2 phases.

The objective of the phase 1 was to assess the benefits of RA broadcasting to TSAA+ aircraft. However, performed timing analysis of TCAS RA on intruder (TSAA/TSAA+ equipped aircraft) showed that due to too variable order of arrival of RA and SA alerts, the number of significant encounters is insufficient for assessing the intended objective.

Thales therefore suggested to proceed to the next phase of validation considering also the assumption of BDS 1.0 broadcasting (see Appendix I) by TCAS equipped aircraft, what allowed to take into account all the encounters with SA alerts regardless the order of arrival. This means that the assessment has been done with two set of encounters:

- In phase 1, encounters with RA reception by TSAA aircraft before SA alert were selected.
- In phase 2, all encounters.

Following scenarios have been applied in the validation:

1. TCAS II-equipped intruder vs. TSAA equipped ownship with modification of original ownship trajectory by pilot reaction (using preliminary pilot reaction model described below) as soon as SA alert is raised,

2. TCAS II-equipped intruder vs. TSAA+ equipped aircraft with the assumption, that TSAA+ pilot will, after the reception of RA information from intruder, **not modify originally planned trajectory** (e.g. no pilot model applied). **During validation execution, this assumption has been shown as inappropriate from operational point of view and might even have a negative impact on the probability of NMAC.** It was concluded that such scenario rather describes **baseline scenario, which represent today situation** in which the ownship does not have an ADS-B In capability, not AIRB/EVAq applications nor TSAA and in which the intruder and ownship encounter tracks are identical to those recorded by SSR (provided by EUROCONTROL).

Pilot reaction model for steering decisions in V1 phase is based on Craig Reynold's paper "Steering Behaviours For Autonomous Characters" [16] at Sony. This paper presents a solution for one requirement of "autonomous characters" in animation and games: the ability to navigate around their world in a life-like and improvisational manner (for example seeking, fleeing, wandering, arriving, pursuing, evading, avoiding an obstacle, following a path, and so on). Steering behaviours is the name given by Craig Reynolds to his movement algorithms; they are not kinematic, but dynamic.
Dynamic movement takes account of the current motion of the character. A dynamic algorithm typically needs to know the current velocities of the character as well as its position. A dynamic algorithm outputs forces or accelerations with the aim of changing the velocity of the character. The term "Autonomous Characters" is used in many contexts and here it has been used for aircrafts.
The behaviour of an autonomous character can be better understood by dividing it into three layers: *action selection, steering,* and *locomotion (*Figure 6).

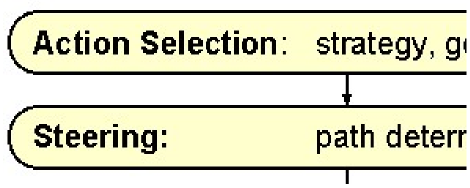


Figure 6: A hierarchy of motion behaviours

The first layer (Action Selection) corresponds to the main objective of TSAA system: Collision Avoidance.

The second layer (Steering) corresponds to the pilot maneuver to satisfy the main objective.

The third layer (Locomotion) corresponds to the TSAA equipped aircraft, and is parameterized by a single steering force vector. The pilot tries to avoid the incoming threat by implementing a flee manoeuver (Figure 7) and adopting a stable altitude.

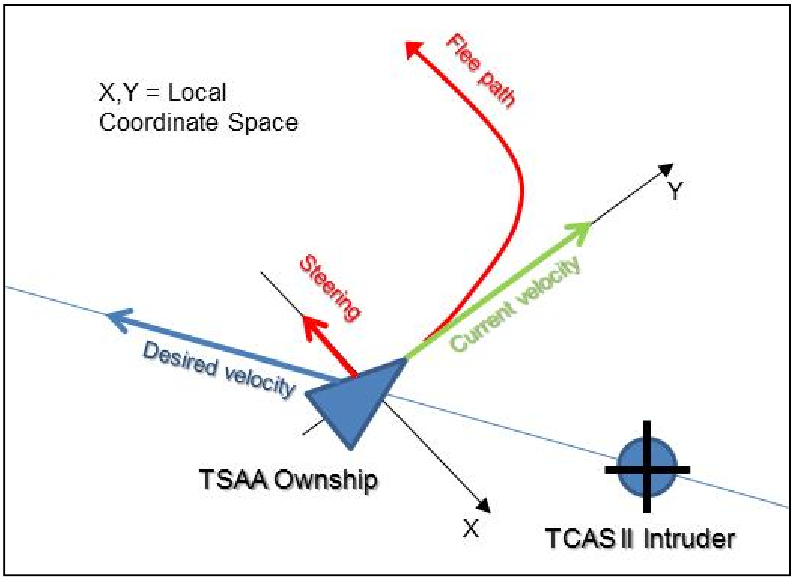


Figure 7: flee maneuver

This locomotion model is based on a simple idealized *vehicle.* The vehicle model described here is very simplistic and generic and based on a point mass approximation. This use of an oversimplified non-physical vehicle model is merely for convenience and intended to be "without loss of generality".

A point mass is defined by a *position* property and a *mass* property. In addition, the simple vehicle model includes a *velocity* property. The velocity is modified by applying forces. Because this is a vehicle, these forces are generally self-applied, and hence limited.

Finally, the simple vehicle model includes an *orientation*, which taken together with the vehicle's position form a velocity-aligned local coordinate space to which a geometric model of the vehicle can be attached.

At each simulation step, behaviourally determined steering forces are applied to the vehicle's point mass. This produces acceleration equal to the steering force divided by the vehicle's mass. That acceleration is added to the old velocity to produce a new velocity. Finally, the velocity is added to the old position

For V1 phase acceleration and speed are clipped to their maximum allowed values:

- 0.2g for horizontal movement,
- 0.2g for vertical movement,
- 120kt for speed.

Pilot reaction delay is 5 seconds.

In figures below there is an example of pilot reaction with SIMPLY in *ansp1_2015-08-05_00170_D* encounter.

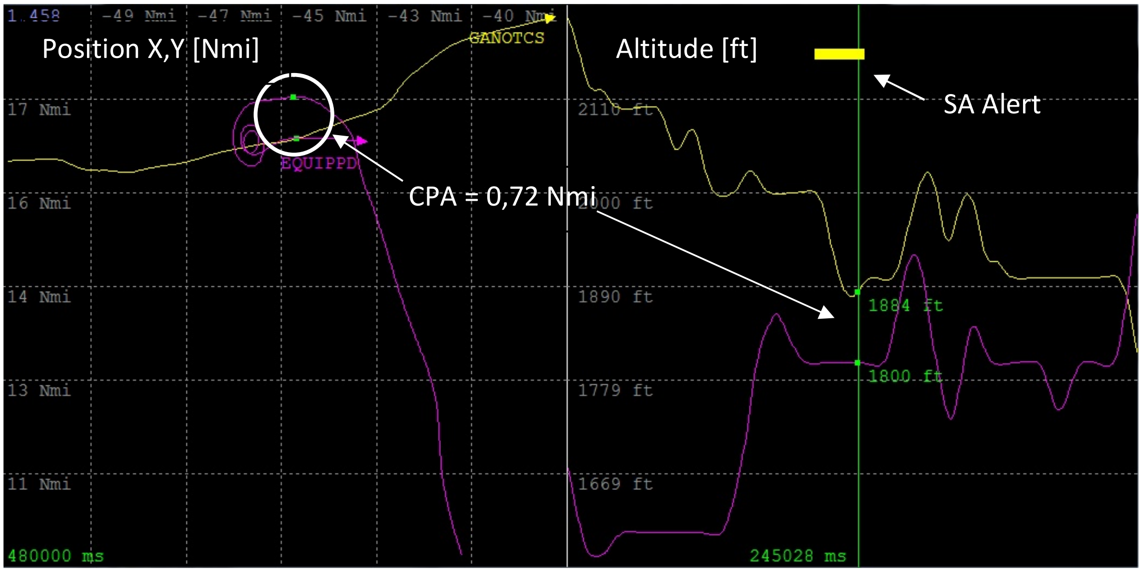


Figure 8: CPA without pilot reaction at SA alert

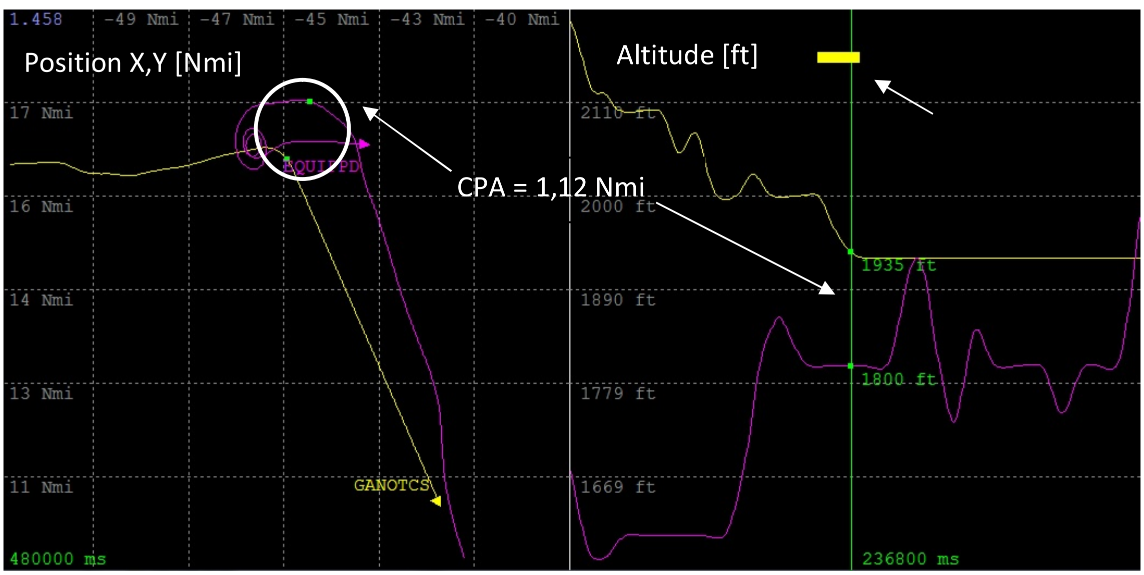


Figure 9: CPA with pilot reaction at SA alert

B.1.2 Summary of Validation Exercise #02 Validation Objectives and success criteria

Identifier	EX2-OBJ-PJ.11.A4-VALP-0001
Objective	Evaluate the overall benefits of TSAA surveillance on board General Aviation and Rotorcraft in fast-time simulation.
Title	TSAA evaluation for General Aviation and Rotorcraft.

Category	<operational feasibility>
CRT-PJ.11-A4-EX2-VALP-0001-0001	The NMAC with TSAA is lower than NMAC without TSAA.
CRT-PJ.11-A4-EX2-VALP-0001-0002	Time/range to detect

Identifier	EX2-OBJ-PJ.11.A4-VALP-0003
Objective	Evaluate the overall benefits of TSAA surveillance on Military Aircraft in fast-time simulation
Title	TSAA evaluation for Military Aircraft.
Category	<operational feasibility>
CRT-PJ.11-A4-EX2-VALP-0003-0001	The NMAC with TSAA is lower than NMAC without TSAA.
CRT-PJ.11-A4-EX2-VALP-0003-0002	Time/range to detect

B.1.3 Summary of Validation Exercise #02 Validation scenarios

Following scenarios have been applied in the validation:

- TCAS II-equipped intruder vs. TSAA-equipped ownship with modification of original ownship trajectory by pilot reaction (using preliminary pilot reaction model described below) as soon as SA alert is raised,

- TCAS II-equipped intruder vs. TSAA+ equipped aircraft with the assumption, that TSAA+ pilot will, after the reception of RA information from intruder, **not modify originally planned trajectory** (e.g. no pilot model applied). **During validation execution, this assumption has been shown as inappropriate from operational point of view and might even have a negative impact on the probability of NMAC.** It was concluded that such scenario rather describes **baseline scenario, which represent today situation** in which the ownship does not have an ADS-B In capability, not AIRB/EVAq applications nor TSAA and in which the intruder and ownship encounter tracks are identical to those recorded by SSR (provided by EUROCONTROL).

B.1.4 Summary of Validation Exercise #02 Validation Assumptions

Apart from general validation assumptions listed in section 3.2.3, following exercise-related assumptions were identified.

Identifier	Title	Type of Assumption	Description	Justification	Flight Phase	KPA Impacted	Source	Value(s)	Owner	Impact on Assessment
ASS-PJ.11-A4-007	Pilot behaviour	Aircraft Equipage	Pilot behaviour is not repetitive for the same situation.	Pilot behaviour is based on visual acquisition and time to react. Thus, the pilot behaviour depends on this factor, and it is not repetitive.	N/A	Environment	Expert judgement	N/A	N/A	Low
ASS-PJ.11-A4-008	Encounter Model	Simulation	Simulations will be limited to 2 aircraft: 1 ownship and 1 intruder.	Validation with more than 2 aircraft will be performed in V2.	N/A	Environment	Expert judgement	N/A	N/A	Low
New1	Ownship types	Traffic Characteristics	Results of simulations including GA and R are not separated.	Encounters including GA and R and provided by EUROCONTROL are not separated.	N/A	N/A	THALES	N/A	THALES	Low

New2	Ownship types	Simulation	In initial pilot reaction model speed and acceleration of ownship are clipped to their maximum allowed values resp. 120kt and 0,2g (horizontal and vertical). Reaction delay is fixed to 5s.	Initial Pilot reaction model for V1	N/A	Environment	THALES	Maximum speed 120kt Maximum horizontal and vertical acceleration 0,2g Reaction delay 5s	THALES	High
New3	Pilot behaviour	Simulation	For V1 TSAA+ pilot doesn't modify original trajectory following RA from TCAS intruder	Initial Pilot reaction model for V1	N/A	N/A	THALES	N/A	THALES	High
New4	Data significance	Traffic Characteristics	Data provided for V1 evaluation will be significant enough to assess the intended objective, e.g. NMAC probability for TSAA+	To be able to evaluate probabilit y of NMAC, large – significant data set is required.	N/A	Safety	Expert judgement	500.000	THALES	High

Table 16: Validation Assumptions overview

B.2 Deviation from the planned activities

With respect to exercise as described in VALP, following deviations were made during validation execution:

- Validation objectives EX2-OBJ-PJ.11.A4-VALP-0001 and EX2-OBJ-PJ.11.A4-VALP-0002 are merged in one validation objective EX2-OBJ-PJ.11.A4-VALP-0001, since it was not possible to divide GA encounters from helicopter encounters at this stage.
- Four new assumptions have been added (see table above) which have not been identified during VALP preparation.
- Assumption New3 was during validation execution shown as inappropriate from operational point of view and might even have a negative impact on the probability of NMAC. It was concluded that such scenario rather describes baseline scenario, which represent today situation in which the ownship does not have an ADS-B In capability, not AIRB/EVAq

applications nor TSAA and in which the intruder and ownship encounter tracks are identical to those recorded by SSR (provided by EUROCONTROL).

Above mentioned deviations caused that both exercise objectives and criterions CRT-PJ.11-A4-EX2-VALP-0001-0001 and CRT-PJ.11-A4-EX2-VALP-0003-0001 as defined in VALP have been modified to address NMAC probability improvements for TSAA when compared with baseline scenario (current situation).

B.3 Validation Exercise #02 Results

B.3.1 Summary of Validation Exercise #02 Results

Validation Exercise #01 Validation Objective ID	Validation Exercise #01 Validation Objective Title	Validation Exercise #01 Success Criterion ID	Validation Exercise #01 Success Criterion	Sub-operating environment	Exercise #01 Validation Results	Validation Exercise #01 Validation Objective Status
EX2-OBJ-PJ.11.A4-VALP-0001	TSAA evaluation for General Aviation and Rotorcraft	CRT-PJ.11-A4-EX2-VALP-0001-0002	Time/range to detect was assessed for encounters including General Aviation and Rotorcraft	En-Route, TMA – various from high to low complexity	Time to closest point of approach (CPA) in seconds and range (NM) between ownship & intruder at the moment of TSAA alert for GA and R is shown at the Figure 13 and Figure 14.	OK
		CRT-PJ.11-A4-EX2-VALP-0001-0001	The NMAC with TSAA is lower than NMAC without TSAA	En-Route, TMA – various from high to low complexity	NMAC probability is reduced by TSAA using the baseline Pilot Model	OK
EX2-OBJ-PJ.11.A4-VALP-0003	TSAA evaluation for Military Aircraft	CRT-PJ.11-A4-EX2-VALP-0003-0002	Time/range to detect was assessed for encounters including Military Aircraft	En-Route, TMA – various from high to low complexity	Time to closest point of approach (CPA) in seconds and range (NM) between ownship & intruder at the moment of TSAA alert for military aircraft is show at Figure 17 and Figure 18.	OK

		CRT-PJ.11-A4-EX2-VALP-0003-0001	The NMAC with TSAA is lower than NMAC without TSAA	En-Route, TMA – various from high to low complexity	Note: Results provided are for TSAA, not TSAA+.[13] NMAC probability is reduced by TSAA using the baseline Pilot Model. **Results are not significant due to very low number of encounters!**	OK

Table 17: Validation Results for Exercise 1

B.3.2 Analysis of Exercise 2 Results per Validation objective

EUROCONTROL has provided 3 sets of radar tracks each one of them describing the encounter between two aircraft. Provided data sets were filtered by EUROCONTROL to include TCAS-equipped and non-equipped aircraft. The total numbers of encounters provided by EURCONTROL for 3 ANSPs:

	ANSP1	ANSP3	ANSP6
N° total encounters	976	3561	3823

Table 18: Number of encounters

Each file (.eu1) contains the following information: *time stamp, flight ID, squawk number, X position [NM], Y position [NM], altitude [ft] and status*. The information about each aircraft is given by alternating rows. The time stamp indicates the time moment when the flight information was recorded and is given every 4 seconds. X and Y positions are distances respect to an unspecified origin whose location is not necessary for the successful outcome of the exercise. Finally, the possible statuses that an aircraft can assume are: TCAS=*EQUIPPD* and/or non-equipped=*GANOTCS*.

Initial analysis of provided encounters showed that encounters does not necessarily include only mixed encounters, therefore an additional filter was applied. To obtain only mixed-encounters from the initial set of data, and to take only TCAS-equipped and (GA) non-equipped aircraft into consideration, filtering was achieved by making sure that each aircraft assumes just one status (*EQUIPPD* or *GANOTCS*) during the encounter and that they are different from one another (ex: AC1 status=*EQUIPPD* vs. AC2=*GANOTCS*). Therefore, the following number of mixed encounters has been identified and used for analysis:

	ANSP1	ANSP3	ANSP6
N° mixed encounters	362	1111	2443

Table 19: Number of mixed encounters

[13] Refer to deviations with respect to VALP.

Such data has been post processed to InCAS software in order to have second by second position, velocity and acceleration interpolating.

1. OBJ-PJ.11.A4-VALP-0002 Results

OBJ-PJ.11.A4-VALP-0002 for V1 validation phase refers to evaluation of operational suitability of SA+/TSAA+ system during mixed equipage encounters. According to the TCAS MOPS [17], Near Mid Air Collision (NMAC) occurs when two aircraft come within 100 feet vertically and 500 feet horizontally.

Out of 3916 mixed encounters, 72,4% of encounters did not issue any alert, in 15,6% of cases only TCAS alerted, and in 5,7% of cases only TSAA alerted, and in 6,3% of cases both alerted.

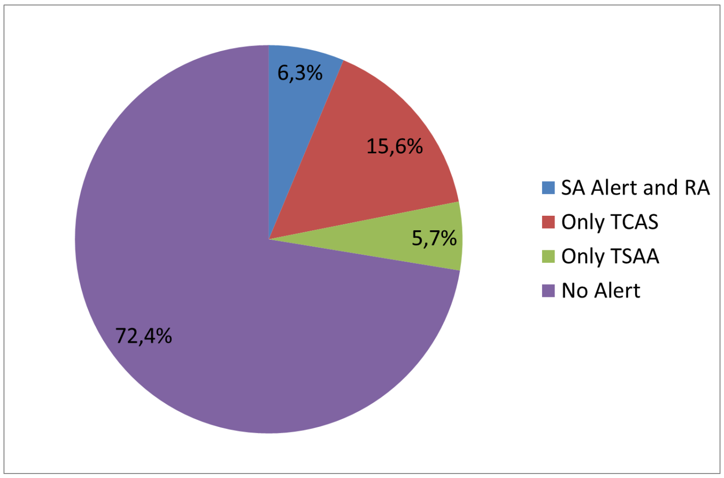


Figure 10: Type of encounter

Low number of significant encounters in which TCAS II aircraft rises RA before TSAA aircraft raises SA alert was considered insufficient for assessing the TSAA+ benefits. Thales suggested to proceed to the next phase of validation considering also the assumption of BDS 1.0 broadcasting by TCAS equipped aircraft, what allowed to take into account all the encounters with SA alerts regardless the order of arrival.

EX2-OBJ-PJ.11.A4-VALP-0001: *Evaluate the overall benefits of TSAA surveillance on board General Aviation and Rotorcraft in fast-time simulation.*

Simulations were performed for General Aviation and Rotorcrafts encounters in order to compute the NMAC probability.

In the phase 1 of simulations 114 encounters on 3622 or 3,1% were found where RA was detected before SA alert.

NMAC probability was computed in Figure 11.

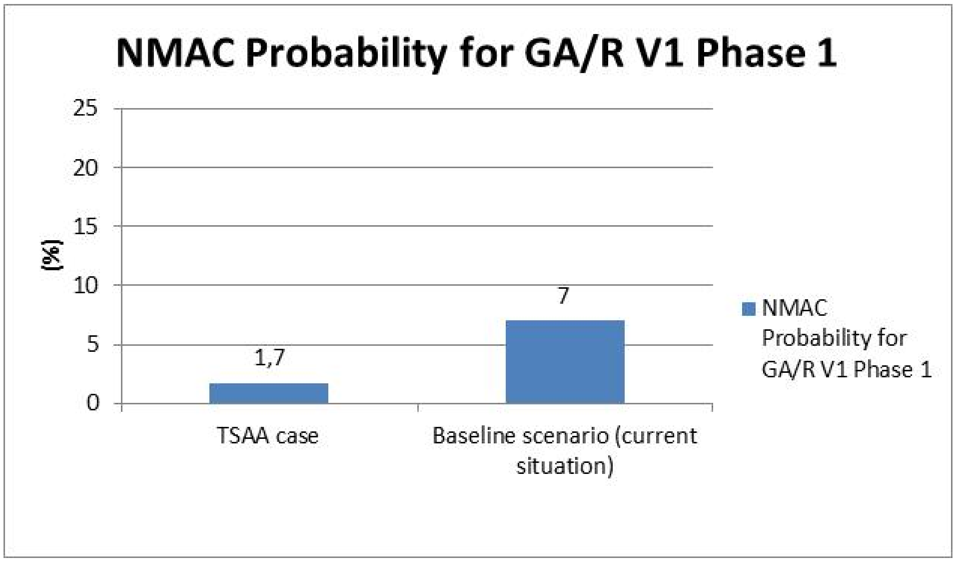


Figure 11: NMAC Probability for GA/R Phase 1

In the phase 2 of simulations 454 encounters with SA alerts on 3622 or 12,5% were found and the NMAC probability was computed in Figure 12.

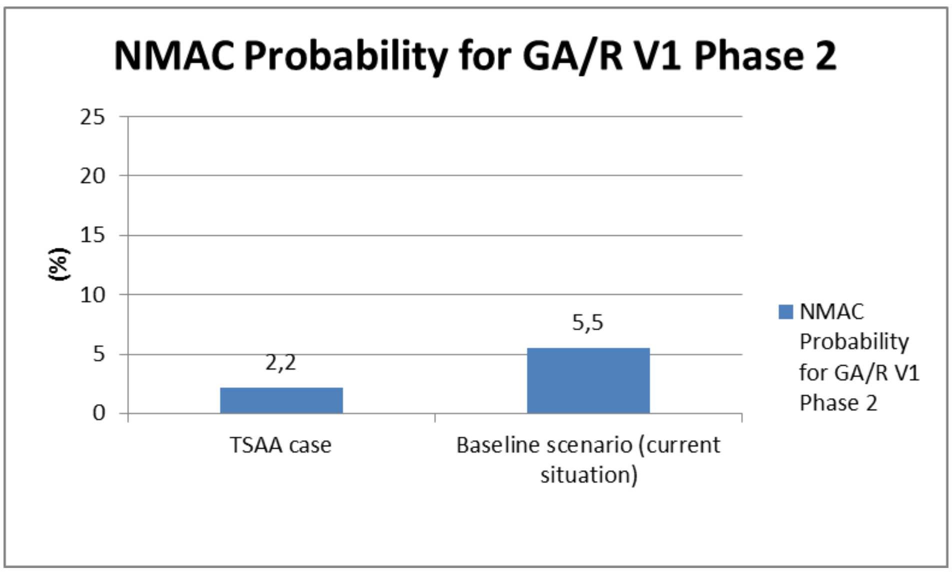


Figure 12: NMAC Probability for GA/R Phase 2

Baseline scenario depicted in Figures 11 and 12 referring to current situation when no GA/H is equipped with TSAA/TSAA+, also reflects results for TSAA+ under assumption New4 which has been shown as inappropriate, and will be refined for V2 validation.

These initial results show that NMAC probability for TSAA is lower than in baseline scenario (e.g. current situation when GA/R/MIL aircraft are not equipped with TSAA not TSAA+).

Pilot model needs to be improved for V2 phase taking into account aircraft category manoeuvre capability and TSAA+ pilot reaction following RA. Furthermore, also the Intruder track should be modified to take into account ownship manoeuvring.

Time / range to detect assessment for GA/R

The results concern Time to closest point of approach (CPA) and range (NM) ownship/intruder at the moment of TSAA alert. Only mixed encounters with TSAA alert were taken into account.

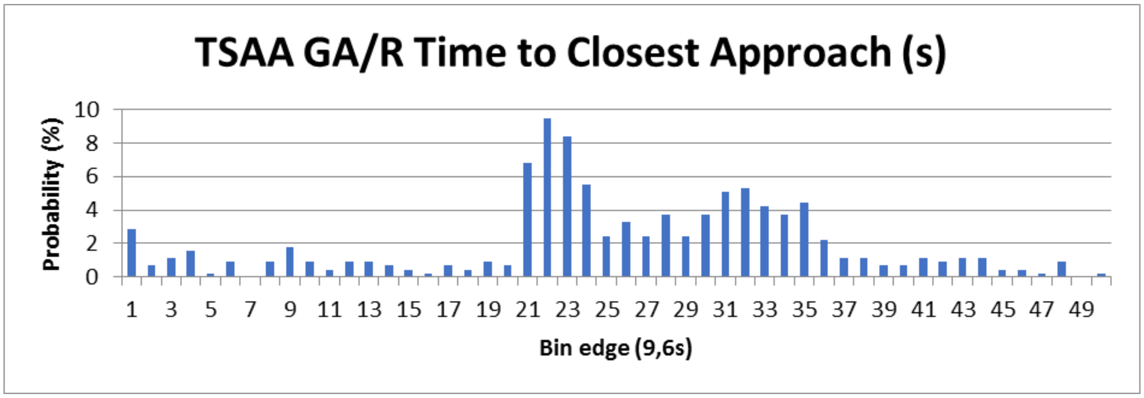


Figure 13: TSAA GA/R Time to Closest Approach (s)

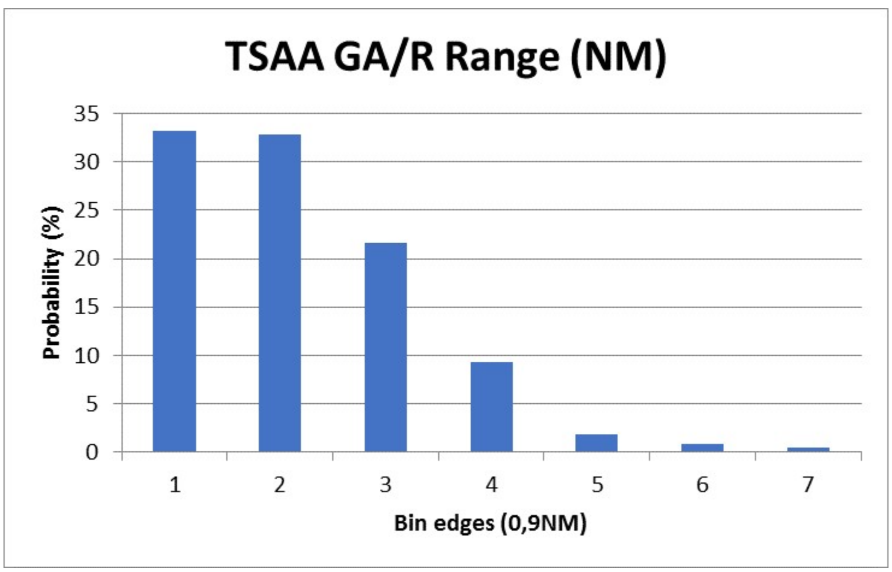


Figure 14: TSAA GA/R Range (NM)

EX2-OBJ-PJ.11.A4-VALP-0003: *Evaluate the overall benefits of TSAA surveillance on Military Aircraft in fast-time simulation*

Simulations were performed for Military encounters in order to compute the NMAC probability.

In the phase 1 of simulations 5 military encounters on 294 or 1,7% were found where RA was detected before SA alert.

NMAC probability was computed with and without pilot reaction to SA alert in Figure 15.

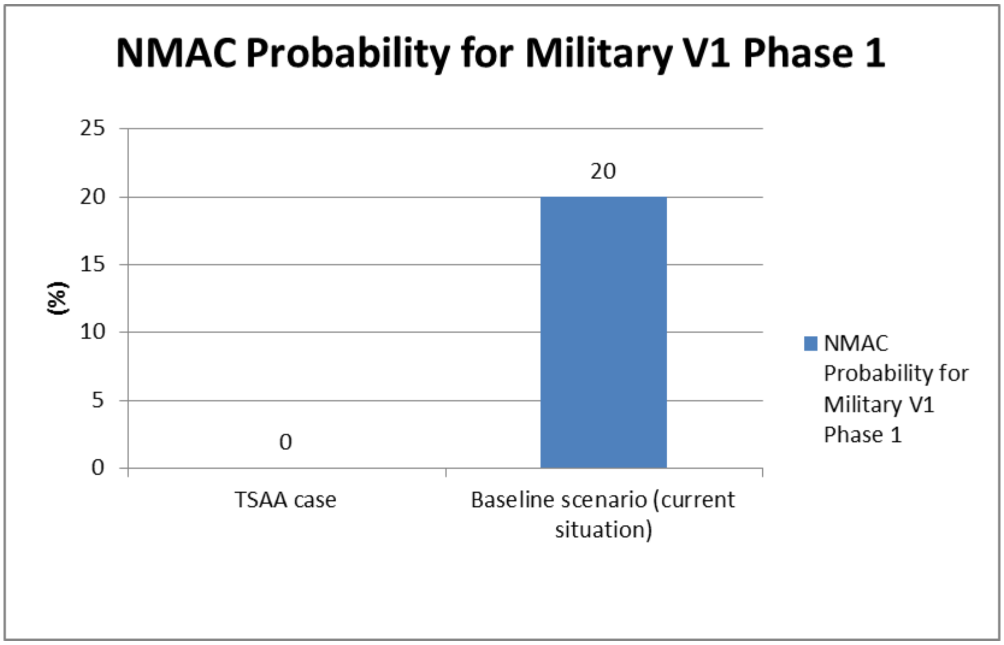


Figure 15: NMAC Probability for Military Phase 1

In the phase 2 of simulations 16 military encounters with SA alerts on 294 or 5,4% were found and the NMAC probability in the two cases described above is in Figure 16.

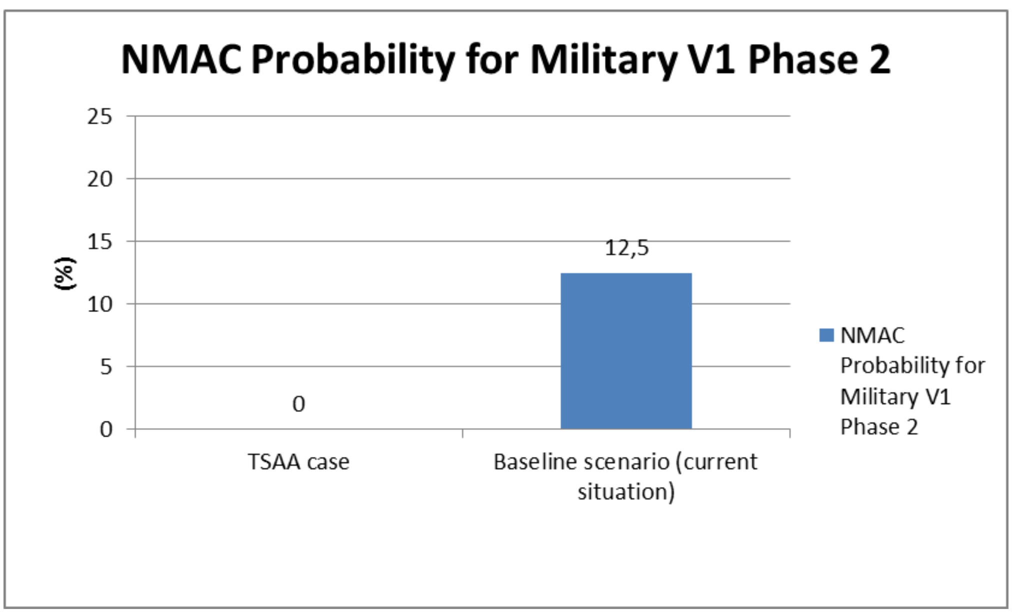


Figure 16: NMAC Probability for Military Phase 2

Even though the results for Military aircrafts are not considered as significant due to the very low number of encounters, they show potential safety improvement of TSAA over baseline scenario (e.g. current situation).

Baseline scenario depicted in Figures 13 and 14 referring to current situation when no MIL is equipped with TSAA/TSAA+, also reflects results for TSAA+ under assumption New4 which has been shown as inappropriate, and will be refined for V2 validation.

Time / range to detect assessment for military

The results concern Time to closest point of approach (CPA) and range (NM) ownship/intruder at the moment of TSAA alert. Only mixed encounters with TSAA alert were taken into account.

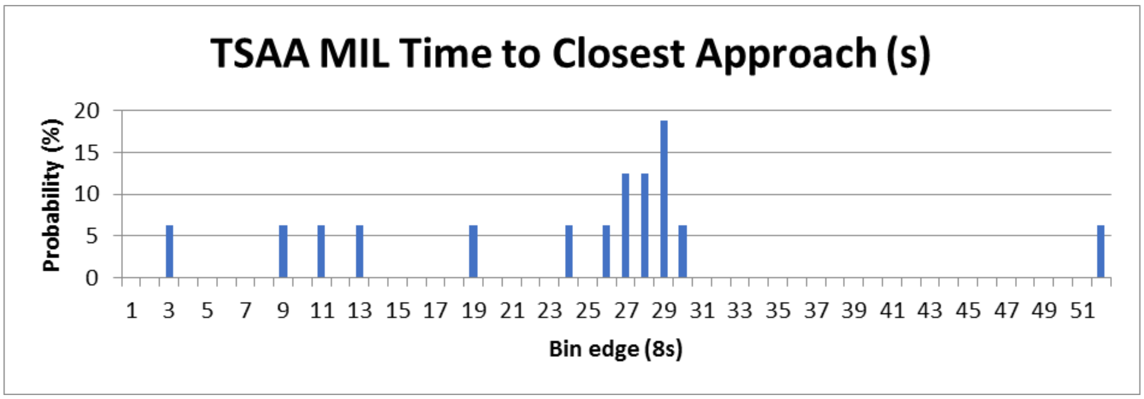


Figure 17: TSAA MIL Time to Closest Approach (s)

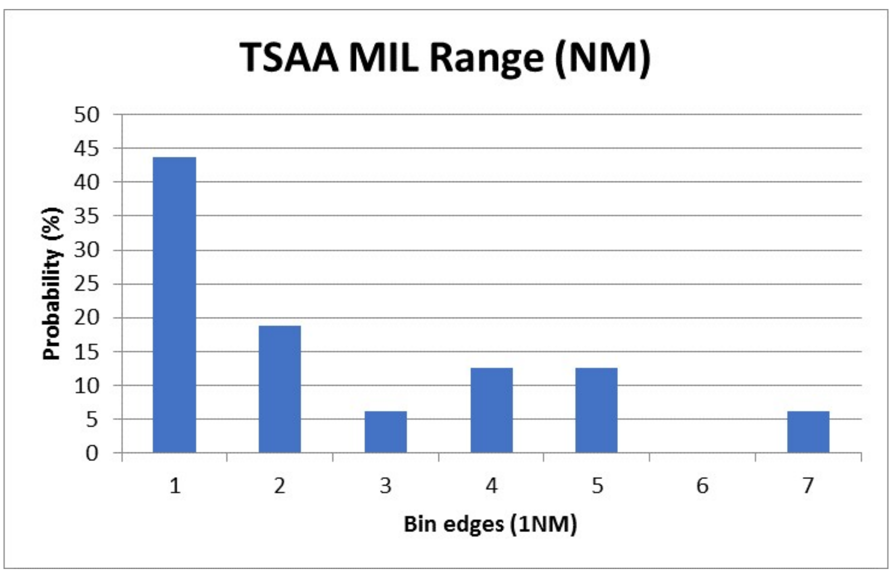


Figure 18: TSAA MIL Range (NM)

B.3.3 Unexpected Behaviours/Results

Most of all mixed encounters (i.e. 72,4%) did not raise any alert and thus they are not significant for analysis.

Regarding the encounters in which both aircraft raise an alert (RA and SA alert) it has been observed that 3% of SA alerts were raised before RAs. In this case, it can be reasonably assumed for next phase of validation that RA information would not be taken into account by TSAA aircraft because the pilot at RA reception has already started the manoeuvre to avoid collision, with no coordination with TCAS II aircraft, and risks to increase the probability of NMAC. For this reason, will Thales in the V2 validation also evaluate the scenario in which TCAS II capability information (BDS 1.0) is sent by TCAS II aircraft via ADS-B messages in order to TSAA aircraft to detect TCAS II aircraft before any manoeuvre.

B.3.4 Confidence in Results of Validation Exercise 2

1. Level of significance/limitations of Validation Exercise Results

Validation results obtained for TSAA in this exercise were based on a limited number of real mixed-equipage encounters in European airspace, which can be considered as sufficient for V1 validation phase.

Moreover, validation results obtained for SA were based on a simplified (basic) pilot reaction model, which needs to be improved for V2 validation phase to take into consideration RA information.

For V1 validation results are considered sufficient to compare the results between encounters with TSAA equipped aircraft (with pilot reaction) and baseline scenario which refers to current situation in Europe when GA/R/MIL aircraft are not equipped with TSAA nor TSAA+.

2. Quality of Validation Exercises Results

SIMPLY simulator has been developed in order to connect several aircrafts (modules) with their own anti-collision system (i.e. TSAA and TCAS II [18]) to a common software bus [15]. Aircraft connected can exchange information via this bus like in a real aerospace environment.

Four seconds sampled input data from EUROCONTROL to SIMPLY has been interpolated second by second.

Pilot model was developed according to “Steering Behaviours For Autonomous Characters” document [16] and needs to be enhanced for next validation phase.

3. Significance of Validation Exercises Results

The significance of validation exercises results was influenced by limited encounter set, but is considered as sufficient for V1 maturity phase since it showed promising benefits between encounters with TSAA equipped aircraft (with pilot reaction) and baseline scenario which refers to current situation in Europe when GA/R/MIL aircraft are not equipped with TSAA nor TSAA+.

These results permit to have a quantitative assessment of a TSAA Pilot Model to permit to perform TSAA+ benefit assessment in terms of safety improvement.

Results for Military aircrafts are not significant due to the very low number of encounters.

B.3.5 Conclusions

EXE-PJ.11.A4-VALP-0002 had the objective to evaluate the benefits of TSAA with "+" feature, e.g. providing pilot with RA information from another aircraft. This objective has been set up with a set of assumptions which were not fulfilled during the exercise execution. Since **only 114 encounters out of 3622 (3.1%) raised RA before TSAA aircraft raises SA alert**, such a small number was considered insufficient for assessing the TSAA+ benefits. The objective was modified to address NMAC probability improvements for TSAA when compared with baseline scenario which represent today situation in which the ownship does not have an ADS-B In capability, not AIRB/EVAq applications nor TSAA and in which the intruder and ownship encounter tracks are identical to those recorded by SSR (provided by EUROCONTROL).

These results shall be considered as initial as they are based on real but limited European data set and a very simplified pilot reaction model, but described approach introduced very promising potential for benefits of TSAA and clarified next steps to be taken in order to be able to assess TSAA+ performance in next maturity phase.

Results show that statistically over all significant encounters (with at least SA alert) pilot reaction to avoid aircraft collision in TSAA case reduces the probability of NMAC by up to 5.3% (GA/H encounters) in comparison to baseline scenario, e.g. no-TSAA case

That said, results have been strongly influenced by 2 factors:

- Low number of encounters for TSAA/TCAS simulations
- Simplified pilot reaction model

V1 exercise permits to have a baseline TSAA Pilot Model to be used as a basis for TSAA+ Pilot Reaction Model and perform TSAA+ safety assessment in V2, which should address quantitative safety criterions.

1. Conclusions on concept clarification

It would be interesting to assess feasibility of providing not only RA broadcast for GA/R/Military pilots, but also equipage status of intruder aircraft via BDS 1,0.

2. Conclusions on technical feasibility

Technical feasibility is not supposed to be an issue, e.g. was not assessed at this stage.

3. Conclusions on performance assessments

N/A. No performance assessment was performed at this stage.

B.3.6 Recommendations

V1 exercise permits to have a baseline Pilot Model which has been characterised in terms of TSAA safety performance (NMAC reduction probability). For V2, which has to address safety criterions, such Pilot Model will be used as baseline for the TSAA+ Pilot Reaction model necessary for TSAA+ safety benefit quantitative assessment.

To reach this objective, it will be necessary to increase the number of significant encounters and be able to classify them according aircraft category (helicopter, GA, military).

Pilot model needs to be improved according to aircraft category manoeuvre capability and for RA reaction capability.

It is also necessary to define what kind of information/alert the TSAA pilot has to be shown in case of TCAS status detection (RA, BDS 1.0,…) and to define the pilot related behaviour.

Appendix C Validation Exercise #03 Report (Leonardo)

This appendix concludes validation report for EXE-PJ.11-A4-VALP-0003.

C.1 Summary of the Validation Exercise #03 Plan

This exercise has been performed by Leonardo in order to evaluate the behaviour of currently defined Traffic Situation Awareness and Alerting (i.e. TSAA) using European representative encounters for GA Fixed Wing/Rotorcraft and military (as provided by EUROCONTROL). The objective were:

Evaluate from an Operational Performance Point of View TSAA algorithms on-board General Aviation Fixed Wing/Rotorcraft and Military within the EU airspace context.

C.1.1 Validation Exercise description, scope

This exercise was performed as FTS (Fast Time Simulation) on Leonardo simulation platform using TSAA capability model developed in accordance to DO-317B evaluated using initial set of mixed-equipage encounters, as recorded by surveillance SSR radar, representative for European operations (as provided by EUROCONTROL).

TSAA application has been tuned and validated considering NAS airspace close encounters, for this reason Leonardo's EXE03 primary scope has been to evaluate TSAA Operational Performance in the EU airspace context utilizing typical European encounters.

DO-348 «TSAA Safety and Performance Requirement» (SPR), has defined a methodology, performance metrics and acceptability criteria to evaluate a generic traffic alerting system, in order to demonstrate TSAA operational and safety objectives. Leonardo has adopted the DO-348 methodology and metrics to evaluate EU TSAA Operational Performance, but with a different approach on acceptability criterias.

Simulations included ownship TSAA equipped aircraft and one intruder equipped with TCAS II. Ownship aircrafts included two set of encounters: one involving Fixed Wing General Aviation or Rotorcrafts (GA_R) as ownship and another involving Military aircrafts not equipping TCAS (MIL).

Validation approach is depicted in Figure 2. A total of 3838 validated encounters (or Pseudo True Tracks Encounters - PTTE), of which 3726 are GA/R and only 112 are MIL encounters.

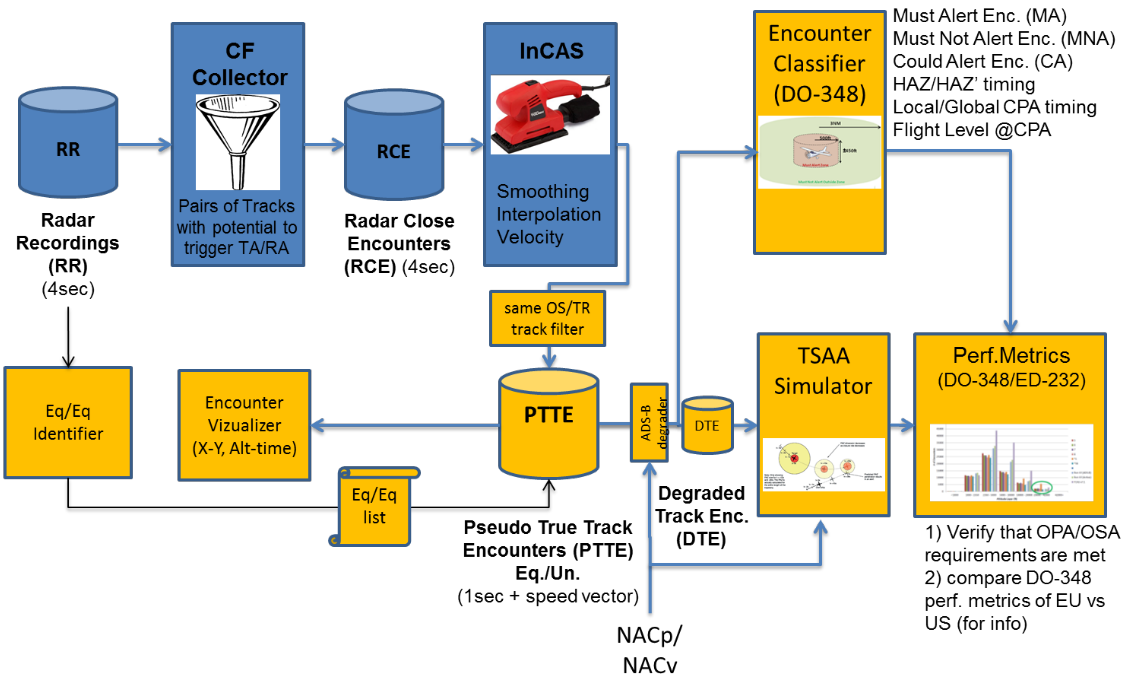


Figure 1: EXE#3 validation approach

Leonardo evaluation platforms for this exercise comprised 5 main modules:

1. ***Encounter Visualizer (ENVIS)***: this tool allow to visualize each encounter, using X-Y horizontal position, Altitude vs time and 3-D of both ownship and intruder.

2. ***Encounter Classifier (ENCLASS):*** this tool allows to classify each encounter as Must Alert (MA), Must Not Alert (MNA) and Could Alert (CA), in relation to hazard volumes (HAZ and HAZ') defined by FAA with the involvement of a pilot group (see Appendix F). In addition this tool provides HAZ/HAZ' enter/exit time, local/global CPA time and ownship's flight level (used as input for TSAA alerting thresholds).

3. ***Encounter Degrader (ENDEG):*** used to degrade (Pseudo) True Tracks with statistical errors on position, velocity, latency to take into consideration different position and velocity data quality parameters (e.g. NACp, NACv). Different degraders have been used for ownship and intruder data (see Appendix H).

4. ***TSAA Simulator (TSAASIM)***: this tool has been developed considering DO-317B exemplar tracker and TSAA algorithm, including TSAA algorithm configuration parameters as per DO-317B Table T-3.

5. ***Traffic Alerting System Performance Evaluator (TASPE)***: this tool, on the basis of Encounter Classifier and TSAA Simulator outputs, establishes and counts in accordance with DO-348 methodology: Total Raised Alerts, Required Alerts, Repeated Required Alerts, Permissible Alerts, Repeated Permissible Alerts and Outlying Alerts, necessary to calculate key performance parameters such as Missed Alert % and Outlying Alert %.

Once the encounters were processed by the above described models, the alerting performance of TSAA was compared with recognised acceptability thresholds and equivalent data contained in DO-348 describing the TSAA simulated performance for the NAS encounter set.

C.1.2 Summary of Validation Exercise #03 Validation Objectives and success criteria

The validation objective of PJ.11-A4-EXE-03 is to evaluate the operational benefits of TSAA with typical European encounters.

DO-348 «TSAA Safety and Performance Requirement» (SPR), has defined a methodolgy and performance metrics to evaluate a generic traffic alerting system, as summarized in Appendix E of this document. DO-348 has used as the primary safety objective (Safety Requirement SR-1): ***"The TSAA application shall alert less frequently than existing certified alerting systems that are designed to operate in the same operational environments."*** and used TAS (Traffic Alerting System, a GA equivalent for TCAS I) as existing certified alerting system. No other acceptability criterias have been used. In particular for what concerns number of encounters in which an alert is considered necessary but have no TSAA Caution Alert or have late alters (Missed Alert%) and number of encounters in which an alert in issued by TSAA where it is not considered necessary (Outlying Alerts%).

Leonardo has instead used as overarching acceptability criterias the two above, using as thresholds those which has been indicated by an FAA study on TSAA, and used in F. Kunzi PhD Thesis ([19])

Table below recalls VALP Objective with updated Success Criterias.

Identifier	EX3-OBJ-PJ.11-A4-VALP-0001
Objective	Evaluate from an operational performance point of view TSAA algorithms on board GA/Rotorcraft/Military within EU airspace context
Title	TSAA performance evaluation for GA/Rotorcraft and Military within EU airspace context
Category	<Operational feasibility>
CRT-PJ.11-A4-EX3-VALP-0001-0001	**Missed Alert Percent** [% of required alerts] < 5% (Missed alerts % includes late alerts and events when no alert is issued; a late alert is any required alert issued less than 12.5 seconds before CPA as indicated in DO-317B)
CRT-PJ.11-A4-EX3-VALP-0001-0002	**Outlying Alert Percent** [% of total alerts issued] < 5% (an Outlying Alert is an alert which has been raised by the alerting system, even if the ownship and intruder remain always outside the non hazard zone - HAZ')

Table 20: EXE03 Objective and Success Criterias

C.1.3 Summary of Validation Exercise #03 Validation scenarios

Due to the nature of the validation activity there is no reference scenario, as TSAA is today not used in Europe, unless in very limited aircrafts. The solution scenarios instead considered:

- operational environment
- encounter types
- aircrafts navigation/surveillance accuracies

Operational environment

Depending on the Operational environment, different traffic densities, separation minima and pilot/ATC operational procedures are expected.

DO-348/DO317B has specified and characterized TSAA in three different operational environments, relevant for the NAS airspace:

- Airport Environment: within 5 nm of an airport, below 3000 ft AGL.
- Low En Route: at or Below 10,000 ft MSL.
- High En Route: above 10,000 ft MSL.

It should be noted indeed that 10.000 feet is the altitude corresponding in NAS to the transition to the mandated transponder and ADS-B airspace, which does not have an equivalent in Europe.

EXE03 criteria to associate an encounter to an operational environment, has been the altitude and distance from airport of the ownship at the Closest Point of Approach (CPA).

Unfortunately the information provided by Eurocontrol on the encounters did not contain the information on the proximity to airports, nor absolute coordinates, so it was not possible distinguish between Low En-Route and Airport encounters.

For the above reason EXE03 used Hazard and No Hazard volumes defined for Low/High En-Route scenarios, distinguishing between Low and High depending on the ownship altitude at CPA.

Encounter type

A total of 8389 radar tracks of close encounters (Radar Close Encounters - RCE) were received from EUROCONTROL, as output of Eurocontrol “CF Collector” tool, whose scope is to select pairs of SSR radar tracks with potential to trigger a TCAS TA/RA. Of these RCE, 8095 involved a General Aviation Fixed Wing or Rotorcraft as ownship (GA/R) and 294 involved a Military aircraft as ownship (MIL).

As radar tacks had 4 sec granularity and did not have velocity vector data, another Eurocontrol tool has been used (InCas) to interpolate and smooth position data to 1 sec, and finally derive a velocity data. The outputs of InCas has been used as pseudo true tracks and the paired tracks associated in a close encounter as Pseudo True Track Encounters (PTTE).

These PTTE went through a Validation process (corrected some of the InCas output files which had Ownship and Intruder data swapped; discarded encounters where both aircrafts displayed status either "EQUIPPD" or "GANOTCS" or "MILNOTCS") to eliminate equipped-equipped encounters caused by incorrect initial correlation of the tracks. Such filter eliminated 4551 encounters (54.2% of the initial RCE), leaving a sample of 3838 encounters (3726 GA/R and 112 MIL encounters).

One important step for the performance assessment is the classification of encounters (independent from the alerting algorithm) in light of how these are considered hazardous or not, hence would require an alert to be issued or not.

DO-348 methodology consists in defining two cylindrical volumes around an aircraft, HAZ and HAZ', defined as Hazad zone and no Hazard zone. If in an encounter the intruder aircraft enters the HAZ volume around the ownship, it is desirable that an Alert is issued. If an intruder aircraft never enters the no-Hazard (HAZ') cylinder, it is desirable that no alert is issued. If the intruder enters the HAZ', but never enter the HAZ volume, than it is considered permissible that the system raise an Alert.

FAA, based on input of a group of pilots with different skill and seniority, has defined the size of these two volumes in different operational scenarios, as follows:

	Hazard Zone (HAZ)		**No-Hazard Zone (HAZ')**	
	Radius	**+/- Vertical**	**Radius**	**+/- Vertical**
Airport Environment (within 5 NM of airport, < 3000 ft AGL)	500 ft	200 ft	1/2 NM	500 ft
Low En Route (< 10,000 ft MSL)	500 ft	450 ft	2 NM	850 ft
High En Route (> 10,000 ft MSL)	500 ft	450 ft	3 NM	850 ft

Table 1: DO-348 HAZ/HAZ' volumes

EXE03 has adopted the same methodology for classifying encounters and used same HAZ/HAZ' volumes sizes, so that encounters have been classified in Must Alert, Must Not Alert and Could Alert encounters as follows:

- **Must Alert Encounter**: an encounter for which there exists at least one instant in which the Intruder falls within Hazard Zone (HAZ)
- **Must Not Alert Encounter**: an encounter for which at all times the Intruder falls outside the Non Hazard Zone (HAZ')
- **Could Alert Encounter:** are all other encounters which do not fall within the two previous categories

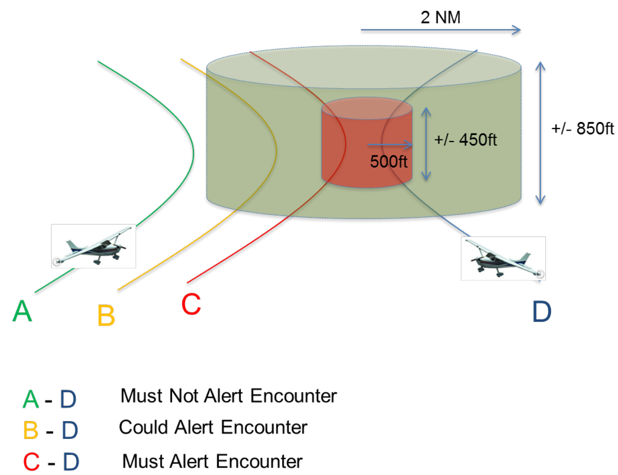


Figure 19: encounter classification concept (Low en-route HAZ/HAZ' case)

As stated in previous section on Operational Scenarios, Regarding lack of vicinity of encounters with respect to airport, we used in the encounter classification only the En-Route volumes, distinguishing only between Low and High En-Route on the basis of ownship altitude at CPA.

Table below shows the number of validated encounters per ANSP and classified as Must Alert, Must Not Alert and Could Alert.

	Close Encounters			Validated encounters			Encounter Classification (Enroute HAZ/HAZ' volumes)								
	(from ECTRL)			true Uneq/Eq			MUST ALERT			MUST NOT ALERT			COULD ALERT		
	TOT	GA/R	MIL	TOT	GA/R	MIL	TOT	GA/R	MIL	TOT	GA/R	MIL	TOT	GA/R	MIL
ANSP 1	1002	994	8	380	378	2	10	10	0	64	64	0	306	304	2
ANSP 3	3562	3474	88	1063	1046	17	18	16	2	512	502	10	533	528	5
ANSP 6	3825	3627	198	2395	2302	93	15	15	0	632	601	31	1748	1686	62
TOT	8389	8095	294	3838	3726	112	43	41	2	1208	1167	41	2587	2518	69
				46%			1%			31%			67%		

Table 2: Validated Encounters and their classification

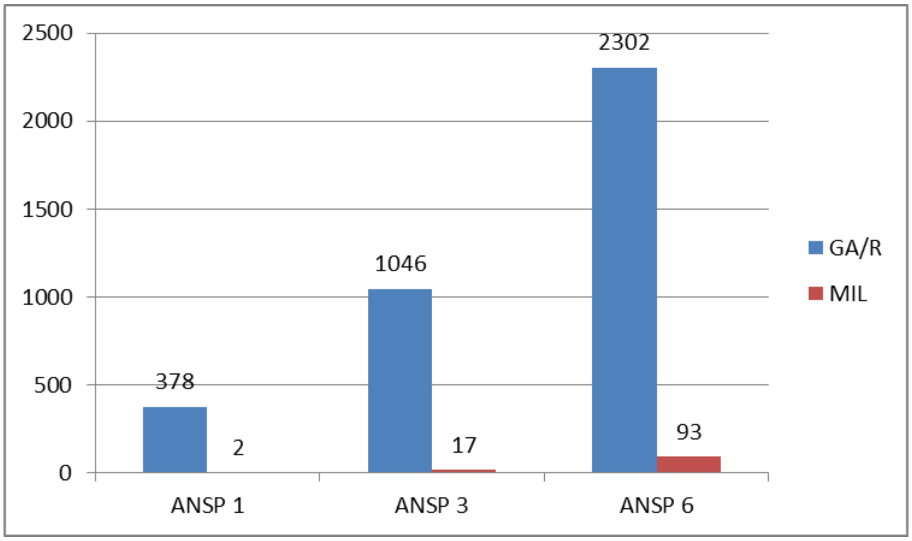


Figure 20: Validated Mixed Encounters per ANSP and ownship category

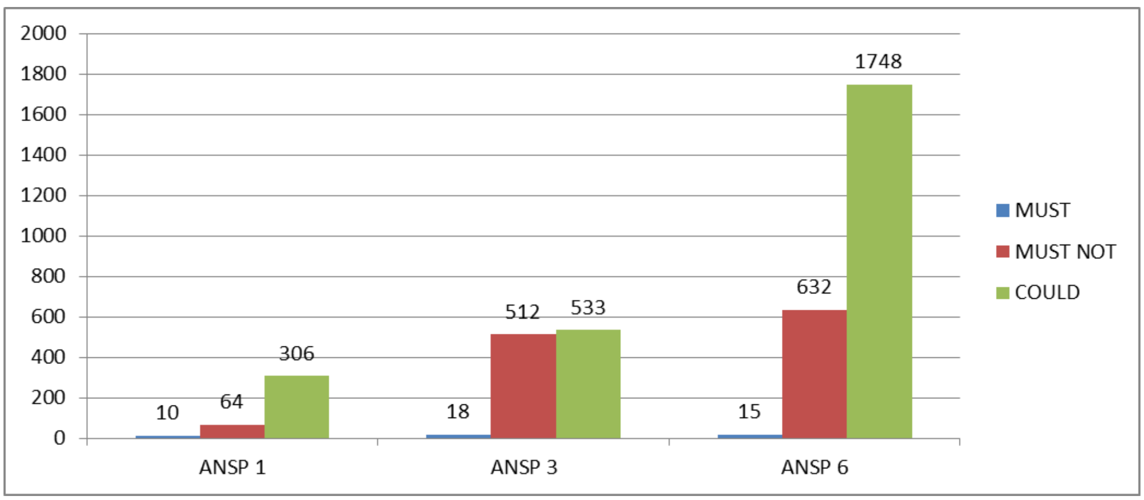


Figure 21: Encounter type per ANSP

In Figure 21 it can be seen that for ANSP3, contrary to the other two ANSP's, there are almost same number of MUST NOT Alert encounters and Could Alert encounters.

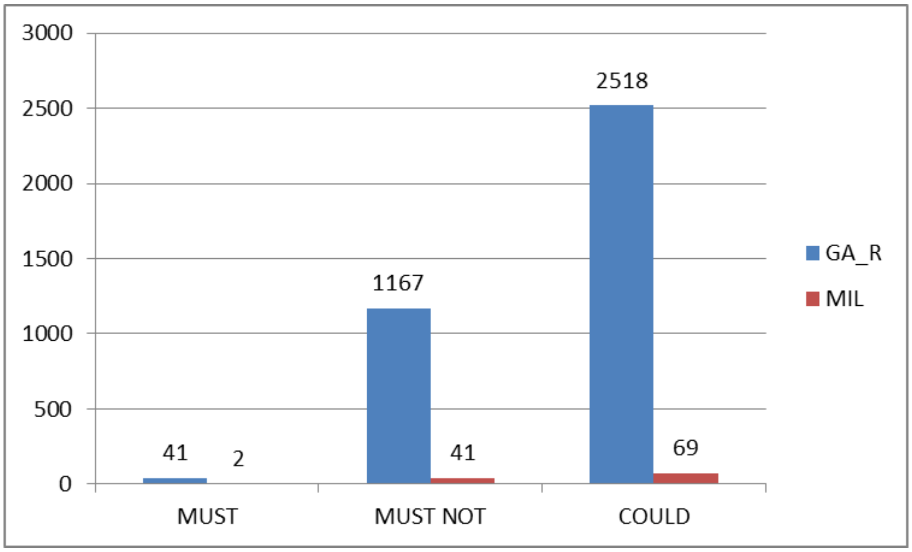


Figure 22: Encounter type per aircraft category

Anomalous encounters

During simulation results post processing analysis, 18 encounters (12 classified as Must Alert and 6 Could Alert) have been identified by Leonardo as anomalous as having almost identical tracks for ownship and intruder, either in X-Y plane or in the Altitude-Time plane. These encounters are suspect of being split tracks or intentional proximity (e.g. aircrafts in formation flights).

In addition, Eurocontrol has identified 77 encounters (6 Must Alert and 71 Could Alert) as suspect of being split tracks, both unequipped, both MIL, intentional proximity, or other SUR anomalies.

As these arrived at the end of simulation campaign, escaping the semi-automatic pre-screening by CFC tool, and more could come later as analysis progress, it was decided at solution level not to re-run simulations (with consequent delays) and leave for V2 phase possible exclusion of these encounters.

Navigation source accuracies (NACp/NACv)

EC Regulation 1207/2011 (and subsequent amendments) mandate in Europe that IFR/GAT aircrafts with MTOW >5700Kg or max true airspeed >250 knots are equipped with ADS-B Out capability after 2020.

EASA CS-ACNS (BOOK 2 — Subpart D – Surveillance (SUR) - Appendix H - Part 3 – ADS-B Out Minimum Horizontal Position and Velocity Data Requirements – Table 20) provides a summary of the minimum horizontal position data requirements as specified in the defining ADS-B-RAD Safety and Performance Requirements/Interoperability document (ED-161), as follows:

- Position Accuracy (NACp):
  - NACp<=185.2 m (0.1NM) (i.e. NACp>=7) for both 3 NM and 5 NM separation

- Velocity Accuracy (NACv):
    - NACv<=10 m/s (i.e. NACv>=1)

DO-317B Table 2-4 specify the required minimum performance of state and velocity data, as derived from DO-348 (TSAA Safety and Performance Requirement) which also specify the minimum accuracies required for traffic to qualify for Traffic Caution Alerts. In particular the DO-348 has determined that for traffic aircraft to qualify for TSAA alerting:

- Horizontal Position Uncertainty (95%): 926m / 0.5 NM (NACp >= 5)
- Vertical Position Uncertainty (95%): < 45m[14]

Required minimum Velocity accuracies:

- Horizontal Velocity Uncertainty (95%): < 10m/s / 20 Knots (NACv >= 1)
- Vertical Velocity Uncertainty (95%): no requirement

Considering that FAA requires for ADS-B minimum accuracies of NACp>=8 and NACv>=1, there are at least three relevant scenarios for the mixed encounters of EXE03, as indicated in Table 21.

Case	Ownship	Intruder	Rationale
1	NACp=5 NACv=1	NACp=7 NACv=1	this scenario considers EU mandate for Equipped aircrafts, and minimum requirement for TSAA alerting i.a.w. DO.317B
2	NACp=5 NACv=1	NACp=8 NACv=1	this scenario considers FAA mandate for Equipped aircraft, and minimum requirement for TSAA alerting i.a.w. DO.317B
3	NACp=8 NACv=1	NACp=8 NACv=1	This scenario represent the nominal condition in EU

Table 21: position and velocity accuracy scenarios

Considerations and assumptions:

[14] DO-348 states: the Altitude Accuracy must be 45 m at 95% probability or better (valid pressure altitude or Geometric Vertical Accuracy (GVA) ≥ 2)

- TCAS equipped aircrafts are also ADS-B equipped: the TCAS and ADS-B mandates are slightly different (TCAS II is mandated for aircrafts with MTOW>5700kg or more than 19 passengers, while ADS-B is mandated for aircrafts with MTOW >5700Kg or max true airspeed >250 knots)
- European aircrafts will have a GNSS system compatible with FAA mandate (i.e. NACp>=8 instead of NACp>=7)
- "GA grade" GPS receivers are normally compatible with NACp >=8 and NACv>=1 (see Appendix G)

Considering the above, scenario 3 was selected for EXE03 to be the most relevant.

TSAA algorithm configuration parameters

The same TSAA algorithm configuration parameters used in DO-348 simulations and indicated in DO-317B for the exemplar algorithm have been used in EXE03 simulations, as indicated in Table 22.

TABLE T-3: ALGORITHM INTERNAL PARAMETERS THAT DEFI

Algorithm Parameter	Variable	Setting	Purp
Look-ahead Time (s)	*tlook*	35	Leng
Trajectory Discretization (s)	*dt*	1	How gene
Turn Rate Filter (#)	*q*	5	How angle calcu
Vertical Rate Filter (#)	*r*	11	How used
CAZ Radius (ft)	*rCAZ*	500	Radi
CAZ Height (ft)	*vCAZ*	±200	Heig
Min. PAZ Radius (ft)	*rPAZmin*	750	Minir buffe
Min. PAZ Height (ft)	*vPAZmin*	±450	Minir buffe
Hor. PAZ Scaling (s)	*tauPAZr*	8	How scale with
Vert. PAZ Scaling (s)	*tauPAZv*	2	How scale

Table 22: TSAA Algorithm internal parameters

C.1.4 Summary of Validation Exercise #03 Validation Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Flight Phase	KPA Impacted	Source	Value(s)	Owner	Impact on Assessment
ASS-PJ.11-A4-SA-009	Traffic alert update	Aircraft Equipage/Technology	Single TSAA Traffic Caution Alert should be provided per threatening encounter.	Automatic updates of traffic alert when the encounter persists or degrades are optional for TSAA	ALL	N/A	DO-317B	N/A	PJ.11	Low
ASS-PJ.11-A4-SA-010	ADS-B Out capable aircraft densities	Regulatory Framework	TCAS Equipped A/C will be assumed as the ADS-B Out current mandated A/C	No detailed information about A/C densities made available by EUROCONTROL	ALL	N/A	Expert Opinion	N/A	PJ.11	Low
ASS-PJ.11-A4-006	One intruder only	Traffic Characteristics	Simulations will include only one intruder.	We will only simulate conflict of two aircraft.	N/A	N/A	HON	N/A	HON	Low
New	Airport Environment	Environment Characteristics	All encounters will be classified with En-Route HAZ/HAZ'	Encounter data set does not contain information on airport proximity	TMA	N/A	DO-348	N/A	LDO	TDB

Table 23: Validation Assumptions overview

C.2 Deviation from the planned activities

Main deviations from planned activities are:

- <u>No separate Performance evaluation for Airport and Enroute operational scenarios</u>: no data on airport proximity available in the encounter data set to discriminate airport from en-route environment encounters.
- <u>No separate Performance evaluation for GA (Fixed wing) and Helicopters</u>: no data to discriminate between Fixed wing GA and Helicopter encounters available in the encounter data set.[15]
- <u>Performance evaluation on Military platforms with no sufficient statistical confidence level</u>: not enough military encounters available (e.g. only 2 encounters classified as MUST ALERT Encounters)

In addition Validation Objective success criteria have been reformulated as follows:

- CRT-PJ.11-A4-EX3-VALP-0001-0001: Missed Alert Percent [% of required alerts] < 5% (Missed alerts % includes late alerts and events when no alert is issued; a late alert is any required alert issued less than 12.5 seconds before CPA as indicated in DO-317B)
- CRT-PJ.11-A4-EX3-VALP-0001-0002: Outlying Alert Percent [% of total alerts issued] < 5% (an Outlying Alert is an alert which has been raised by the alerting system, even if the ownship and intruder remain always outside the non hazard zone - HAZ').

C.3 Validation Exercise #03 Results

C.3.1 Summary of Validation Exercise #03 Results

Validation Exercise #03 Validation Objective ID	Validation Exercise #03 Validation Objective Title	Validation Exercise #03 Success Criterion ID	Validation Exercise #03 Success Criterion	Sub-operating environment	Exercise #03 Validation Results	Validation Exercise #01 Validation Objective Status
EX3-OBJ-PJ.11.A4-VALP-0001	TSAA perf. evaluation for GA/Rotorcraft and Military within EU	CRT-PJ.11-A4-EX3-VALP-0001-0001	**Missed Alert Percent** [% of required alerts] <	**GA_R**	1.7%	OK
				MIL	0.0%	OK

[15] Clarification: Data set provided by EUROCONTROL was only divided between military and "others". Encounter were not divided into Helicopter and GA, and based on the data provided it was not possible to easily filter the tracks.

	airspace		5%			
		CRT-PJ.11-A4-EX3-VALP-0001-0002	**Outlying Alert Percent** [% of total alerts issued] < 5%	**GA_R**	8,8%	NOK
				MIL	15,1%	NOK

Table 24: Validation Results for Exercise 1

NOK results, and their potential root cause is further discussed in Appendix C.3.4 and C.3.53. Recommendations for the next steps needed in order to provide more significant results for these criterions are captured in 5.2.1.

C.3.2 Analysis of Exercise 3 Results per Validation objective

Approach

In EXE03 we initially evaluated TSAA performance using the Pseudo True Track Encounter data, i.e. the data derived from Radar Tracks (4 sec), interpolated, smoothed and from which a velocity vector has been derived. This provided a baseline on TSAA performance, to better appreciate the effect of track degradation. As part of Encounter Classification activity, also the HAZ and HAZ' penetration time, together with global and local CPA(s) time have been identified.

The PTTE encounters have then been used as input for the TSAA Simulator (TSAASIM): this allowed to calculate for each encounter the TSAA PAZ and CAZ volumes penetration time together with TSAA Alerts.

On the basis of previous data calculated for each encounter, the following counters have been calculated:

 # HAZ penetr.: the count of HAZ penetration events (considering En-Route thresholds, Low or High depending on Ownship altitude at CPA)

 # HAZ penetr. within time Alert : the count of HAZ penetration events which had at least one TSAA Alert associated issued with correct timing (i.a.w. DO-348 an Alert active 60 sec before HAZ penetration or 10 sec after would be considered associated to that HAZ penetration period)

 # HAZ penetr. with Late Alert: the count of HAZ penetration events which had at least one TSAA Alert associated, but this alert is issued less than 12.5 sec before the (local) CPA

 # HAZ penetr. with No Alert: the count of HAZ penetrations events with no associated TSAA Alert issued.

Skipped Alerts [#]: is the number of HAZ penetration events in which CPA is less than 12.5 sec from the start of the track, hence it should not be considered for the Late Alert count and Mean CPA Time.

Cumulative CPA Time [sec]: is the sum of all time periods in seconds between an issued Alert and the CPA. It is used to calculate Mean Time to CPA performance parameter.

Total Raised Alerts [#]: is the total number of issued TSAA Alerts

Required Alerts [#]: is the portion of the total number of TSAA issued Alerts, which are due as the encounter has penetrated the HAZ volume (if more than one is raised remaining always within same HAZ period, then only the first is counted)

Repeated Required Alerts [#]: in case more than one alert is issued remaining always within same HAZ period, it is total number of issued Alerts in the HAZ penetration period minus one

Permissible Alerts [#]: is the portion of the total number of issued Alerts which are permissible, i.e. when the intruder has entered an HAZ' volume but not the HAZ volume (if more than one alert is issued in the period, then only the first is counted)

Repeated Permissible Alerts [#]: in case more than one alert is issued in same period, it is total number of issued Alerts in the HAZ' penetration period minus one

Outlying Alerts [#]: is the portion of the total issued Alerts, which are not due as the intruder never entered an HAZ' volume.

As an example in the following are provided the output data for a specific encounter (global encounter ID: 3120, ansp6_2016-03-22_00241, classified as Must Alert encounter, involving a GA-R as ownship).

Figure 23 provides X-Y plane (above, X=distance(NM), Y= distance(NM)) and Altitude-Time (below, X=time(s) Y= Altitude(feet)) views of the encounter.

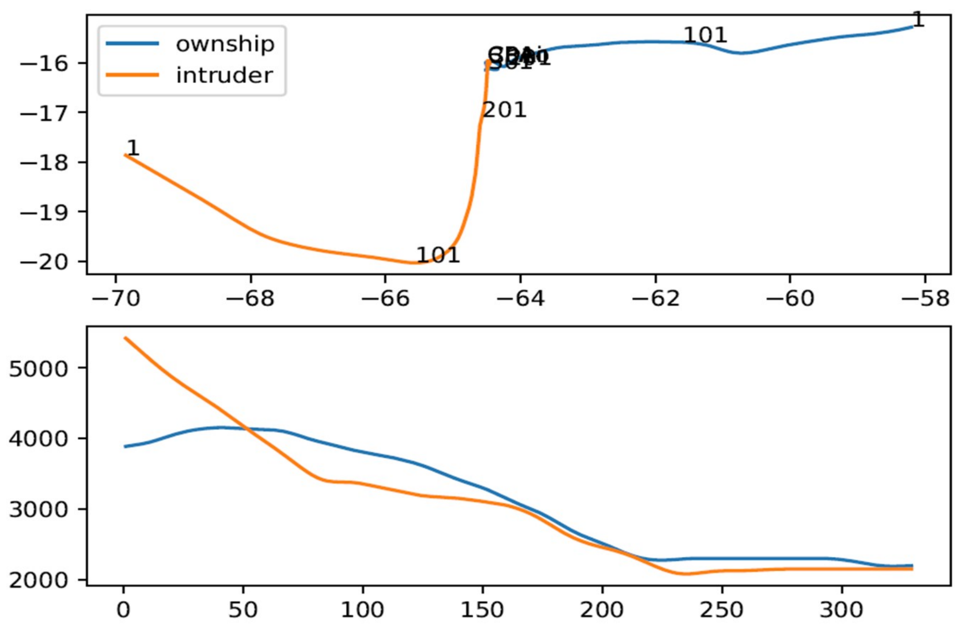


Figure 23: exemplar encounter X-Y plane (above) and Altitude-time (below) views

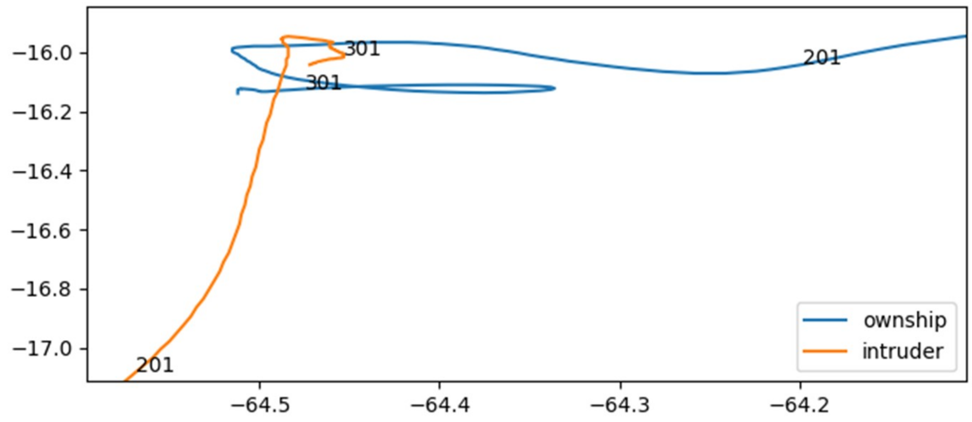
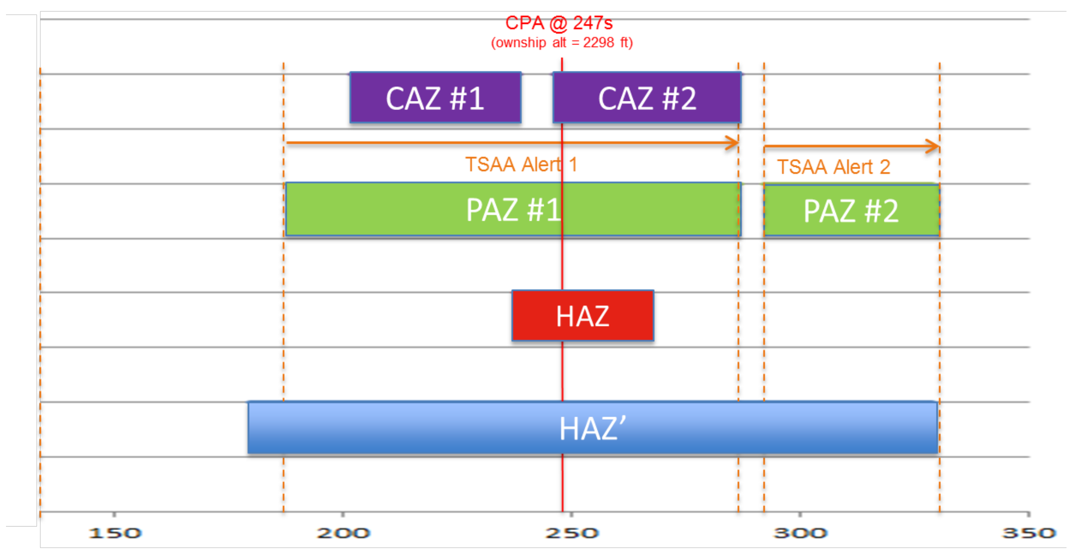


Figure 24: exemplar encounter X-Y plane detail around CPA

Figure 25 instead provides a pictorial view of HAZ/HAZ' and PAZ/CAZ volumes penetrations time, together with TSAA alerts durations and CPA timings.



# HAZ penetr.	# HAZ penetr. with *in time Alert*	# HAZ penetr. with *Late Alert*	# HAZ penetr. with *No Alert*	Total Raised Alr	Req Alr	Rep Req Alr	Perm Alr	Rep Perm Alr	Outlying Alr
1	1	0	0	2	1	0	1	0	0

Figure 25: HAZ/HAZ' and TSAA PAZ/CAZ volumes penetration timing example (ansp3_2015-09-28_01106)

This encounter is characterized as follows:

- Encounter Duration 330 s
- One HAZ' penetration event: from 181 to 329 s
- One HAZ penetration event: from 239 to 265 s

- Two PAZ penetration events: from 188 to 287 s, and from 292 s until end of the encounter track
- Two CAZ penetration events: from 202 to 239 s, and from 246 to 287 s
- One CPA: the Global (and local) CPA at 247 s, with an ownship altitude of 2298 ft

On the basis of the previous counters the following Performance Metrics have been calculated, as defined, in accordance to DO-348, as follows:

Outlying Alerts %: is the percentage of Outlying Alerts of total alerts issued

Missed Alerts %: is the sum of late alerts and events when no alert is issued, over the total of required alerts (a late alert is any required alert issued less than 12.5 seconds before CPA as indicated in DO-317B)

Repeat Alerts %: is the sum of all Repeated Alerts (required+permissible) over the Total Raised Alerts

Mean Time to Alert [sec]: is the average time between TSAA Alert and the CPA, calculated as the Cumulative CPA Time [sec] divided by sum of OK Alerts + Late Alerts

Results - Pseudo True Tracks Encounters

Table 25 shows results of TSAA Simulations utilizing Pseudo True Tracks Encounters. As said previously these have been used as a reference, to analyze degraded encounters results, to understand where effects are due to degradation or not.

Name	# HAZ penetr.	# HAZ penetr. with *in time Alert*	# HAZ penetr. with *Late Alert*	# HAZ penetr. with *No Alert*	Skipped	Total Raised Alr	Req Alr	Rep Req Alr	Perm Alr	Rep Perm Alr	Outlying Alr
ANSP6 GA_R	15	14	1	0	0	368	15	0	335	12	6
ANSP6 MIL	0	0	0	0	0	9	0	0	7	0	2
ANSP3 GA_R	36	35	1	0	0	118	25	17	68	4	4
ANSP3 MIL	3	3	0	0	0	8	2	0	4	0	2
ANSP1 GA_R	10	9	1	0	0	100	10	0	88	0	2
ANSP1 MIL	0	0	0	0	0	1	0	0	1	0	0
TOT	64	61	3	0	0	604	52	17	503	16	16
GA_R	**61**	**58**	**3**	0	0	**586**	**50**	**17**	**491**	**16**	**12**
MIL	**3**	**3**	0	0	0	**18**	**2**	**0**	**12**	**0**	**4**

Table 25: Alert count per type and per ANSP – Pseudo True Tracks Encounters (for reference only)

Table 26 provides the TSAA Performance Metrics PTTE results .

	Aggregate			ANSP6		ANSP3		ANSP1	
	GA_R	MIL		GA/R	MIL	GA/R	MIL	GA/R	MIL
Outlying Alert %	2,0%	22,2%		2%	22%	3%	25%	2%	0%
Missed Alert %	4,9%	0,0%		7%	NA	3%	0%	10%	NA
No Alert %	0,0%	0,0%		0%	NA	0%	0%	0%	NA
Late Alert %	4,9%	0,0%		7%	NA	3%	0%	10%	NA
Repeat Alert %	5%	0%		3%	0%	18%	0%	0%	0%

Table 26: TSAA Performance Metrics – Pseudo True Tracks Encounters (for reference only)

Results with Degraded Encounters

When running the simulations to determine the minimum Performance Requirements, randomized navigation and surveillance errors are added to encounter tracks. The model used for Pseudo True Tracks degradation in EXE03 simulation is described in Appendix H.

As described in C.1.3, EXE03 used NACp=8 (<92 m @95%) and NACv=1 (<10 m/s @95%) for both ownship and intruder position and velocity accuracies. The rationale behind this choice is that, as will be better understood later, TSAA performance data highly depend on the quality of ownship and intruder. So assuming reasonable data accuracies, rather than "worst case" or "best case", would provide better statistical performance evaluations. Appendix G provides background information on GNSS commercial system accuracies both for Commercial Air Transponder and General Aviation, which indicate that assuming NACp=8 and NACv=1 navigation and surveillance errors is a reasonable assumption.

Each pseudo true track encounter set has been run 3 times to capture the effect of the random errors on the system performance, thus requiring in total 3x3838 encounter simulations[16]. Alert counts for each run have been compared, which showed little variance as shown in Figure 26 and Figure 27 for the ANSP6 and ANSP3 GA_R encounter sets.

[16] With available computing resources for degrading 3838 encounters are necessary approximately 31 hours for each run

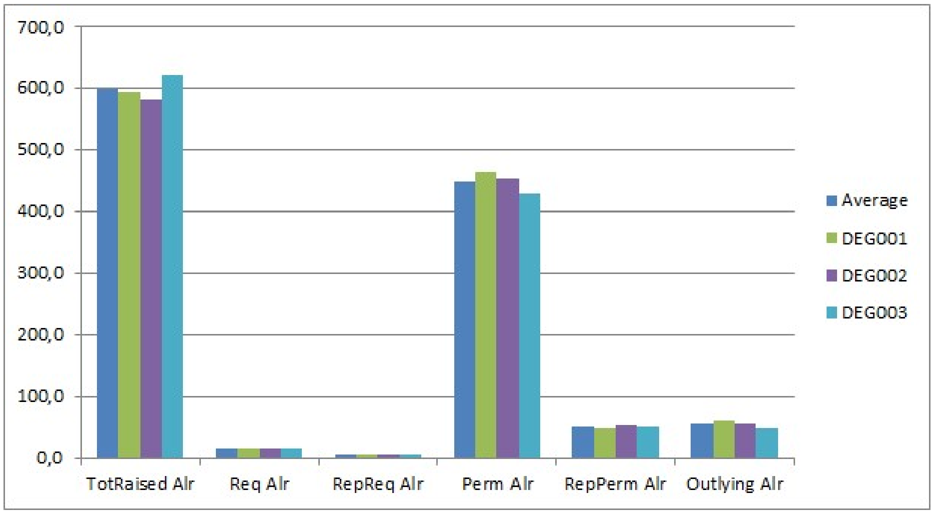


Figure 26: Degraded Tracks Alert Counts: Average & individual runs (ANSP6 GA_R)

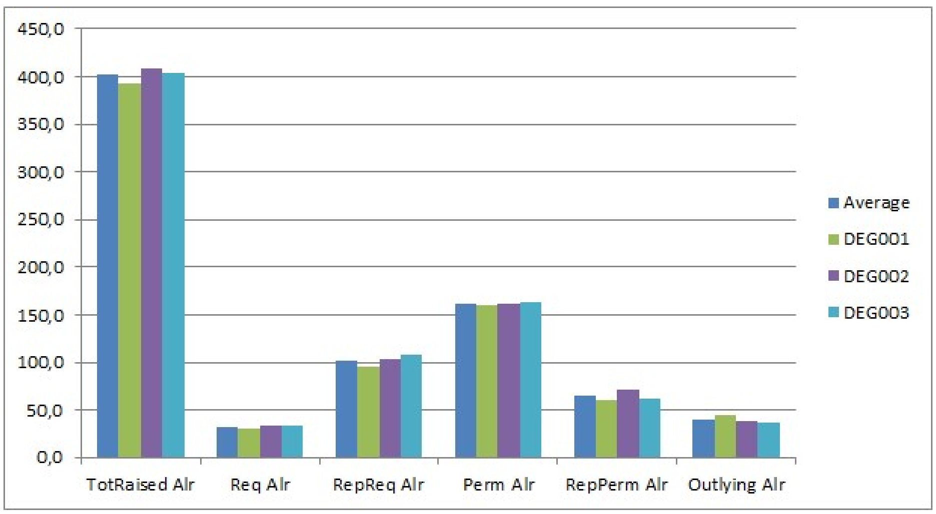


Figure 27: Degraded Tracks Alert Counts: Average & individual runs (ANSP3 GA_R)

It was then taken the average values of the Alert counts for the three degradation runs, as reported in Table 27.

Name	# HAZ penetr.	# HAZ penetr. with *in time Alert*	# HAZ penetr. with *Late Alert*	# HAZ penetr. with *No Alert*	Skipped	Total Raised Alr	Req Alr	Rep Req Alr	Perm Alr	Rep Perm Alr	Outlying Alr
ANSP6 GA_R	*15*	*14*	*1*	*0*	*0*	*600*	*15*	*6*	*449*	*51*	*55*
ANSP6 MIL	*0*	*0*	*0*	*0*	*0*	*13*	*0*	*0*	*10*	*0*	*4*
ANSP3 GA_R	*35*	*35*	*0*	*0*	*1*	*402*	*32*	*102*	*162*	*65*	*40*
ANSP3 MIL	*3*	*3*	*0*	*0*	*0*	*25*	*3*	*9*	*7*	*4*	*2*
ANSP1 GA_R	*10*	*10*	*0*	*0*	*0*	*141*	*10*	*4*	*109*	*13*	*6*
ANSP1 MIL	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*1*	*0*	*0*
TOT	*63*	*62*	*1*	*0*	*1*	*1182*	*60*	*122*	*738*	*132*	*107*
GA_R	**60**	**59**	**1**	**0**	**1**	**1142**	**57**	**113**	**720**	**129**	**101**
MIL	**3**	**3**	**0**	**0**	**0**	**40**	**3**	**9**	**18**	**4**	**6**

Table 27: Alert count per type and per ANSP – Degraded Tracks Encounters (average)

To understand the effect of track degradation we have compared alert counts for ANSP 6 ad ANSP3 GA_R encounters (Figure 28 and Figure 29).

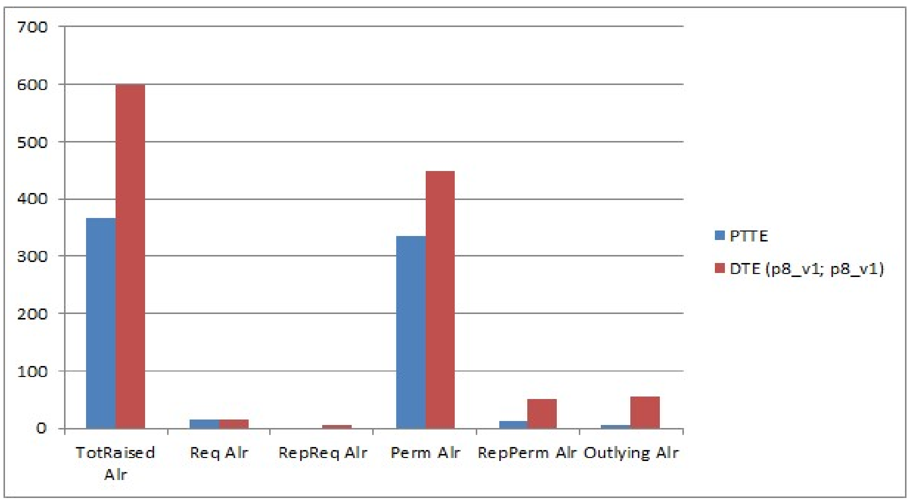


Figure 28: TSAA Alert count: Pseudo True vs Degraded Tracks (ANSP6 GA_R)

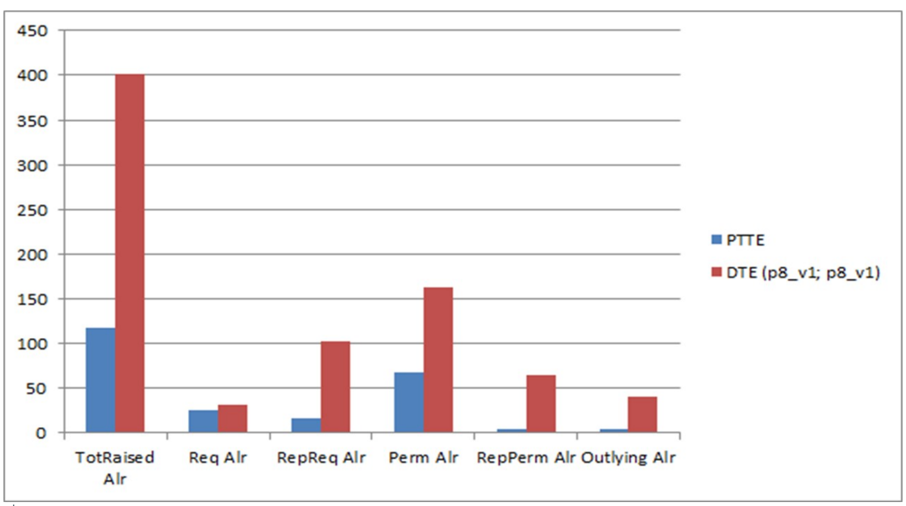


Figure 29: TSAA Alert count: Pseudo True vs Degraded Tracks (ANSP3 GA_R)

To understand the impact of track degradation on various alerts count, Figure 30 provides for ANSP6 and ANSP3 GA_R encounters, the (DTE count – PTTE count) / (DTE count) ratio: 100% means that all the Alert count in the degraded tracks encounter data set are due only to degradation (i.e. there were no PTTE equivalent alerts) and 0% means that there have been no extra alert count due to track degradation.

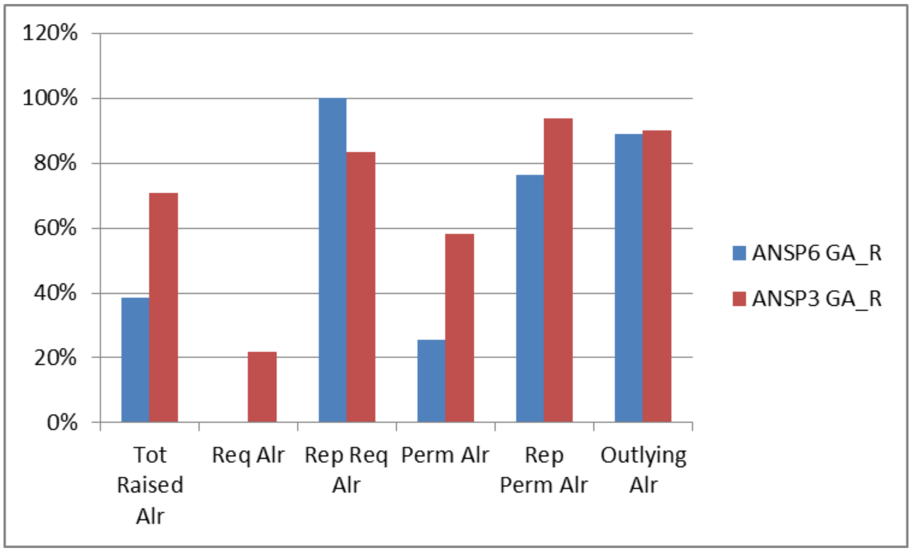


Figure 30: Portion of Alerts due to degradation

As it can be seen, while there is a considerable portion of total alert count due to degradation (40% for ANSP6 and 70% for ANSP3), the portion of Required Alert count which are caused by degradation is absent or limited (0% for ANSP6 and 20% for ANSP3) as could be expected. Repeated and Outlying Alert count portion due to degradation is considerably high (80% to 100%).

So what can be derived is that TSAA performance is very dependent on track data quality. For this reason assuming reasonable data accuracies, rather than "worst case", would provide better performance evaluations from a statistical point of view.

Mean Time to Alert analysis

The alert timing before CPA has been calculated for the 43 Must Alert encounters (41 GA_R and 2 MIL), generating a total of 63 Alerts (60 GA_R and 3 MIL).

In Figure 31 it is provided the distribution of "Alert time before CPA" for GA_R using undegraded tracks (PTTE), with 10 second bins. As it can be seen there are 19 alerts which are raised more than 100 s before the actual CPA, all part of ANSP 3 data set. The visual inspection of such encounters showed that these are specific situations as either these are part of those suspect encounter data set described in C.1.3 ("almost identical tracks" or "Eurocontrol suspect tracks") or are encounters in which intruder and ownship are flying in parallel close proximity deliberately, situations in which a TSAA Alert may be raised much in advance to the CPA. For this reason we have not considered these in the calculation of Alert Time to CPA average and standard deviations.

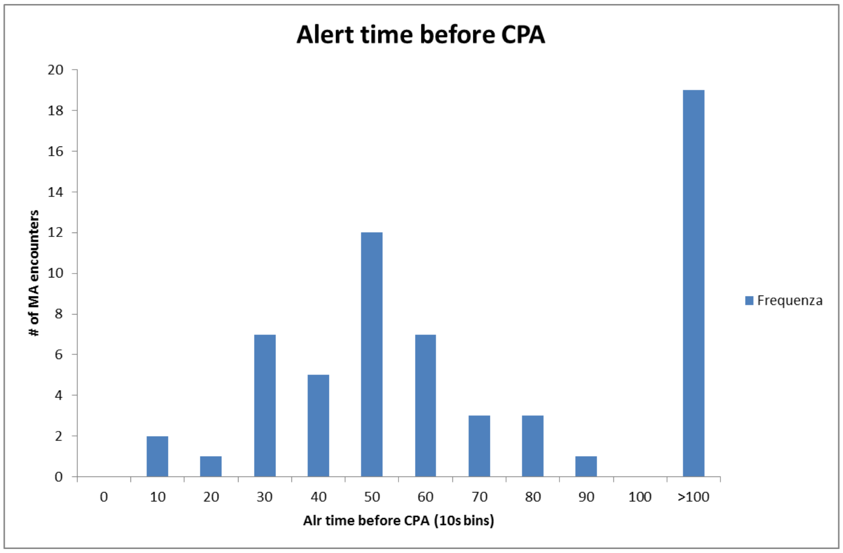


Figure 31: Alert Time before CPA (PTTE) distribution for Must Alert encounters (10s bins)

Alert Time before CPA			
	PTTE Results		
	Mean [s]	St. Dev. [s]	>100s [#]
ANSP 1	37	18	0
ANSP 3	49	20	19
ANSP 6	44	16	0
Overall	44	18	19

Table 28: Alert time before CPA (PTTE)

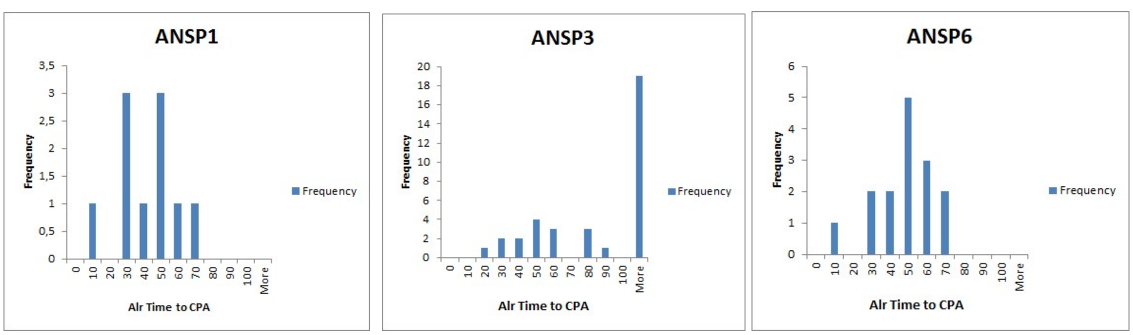


Table 29: Alert time before CPA (PTTE) for various ANSP's

The Alert time before CPA have been evaluated also for the Degraded tracks (DTE), for each Simulation run, calculating the average alert time value, the standard deviation and the count of alerts with a time above 100s.

Alert Time before CPA (DTE)									
	DEG001			DEG002			DEG003		
	Mean [s]	St. Dev. [s]	>100s [#]	Mean [s]	St. Dev. [s]	>100s [#]	Mean [s]	St. Dev. [s]	>100s [#]
ANSP 1	39	16	0	37	15	0	38	16	0
ANSP 3	55	26	12	55	24	11	58	25	10
ANSP 6	39	16	0	40	14	0	41	15	0
Overall	47	22	12	47	21	11	49	22	10

Table 30: Alert time before CPA data for each degraded simulation run

The data obtained in each degradation run have been averaged, and the standard deviation with these three data set is also provided in Table 31.

	DTE Results					
	Average of Mean [s]	StDev of Mean [s]	**Average of StDev [s]**	StDev of StDev [s]	**Average of >100s [#]**	StDev of >100s [#]
ANSP 1	**38**	0,9	**16**	0,3	**0**	0,0
ANSP 3	**56**	1,8	**25**	0,9	**11**	1,0
ANSP 6	**40**	0,7	**15**	0,8	**0**	0,0
Overall	**48**	1,2	**22**	0,8	**11**	1,0

Table 31: average Alert time before CPA in degraded simulation runs

Form Table 31 it can be derived that there is no dispersion of data within the three simulation run, and the average numbers (in bold) can be used to compare with PTTE data without losing information.

Alert Time before CPA						
	PTTE Results			**DTE (AVRG) Results**		
	Mean [s]	St. Dev. [s]	>100s [#]	**Mean [s]**	St. Dev. [s]	>100s [#]
ANSP 1	**37**	18	0	**38**	16	0
ANSP 3	**49**	20	19	**56**	25	11
ANSP 6	**44**	16	0	**40**	15	0
Overall	**44**	18	19	**48**	22	11

Table 32: comparison of PTTE and DTE Alert timing

For what concerns MIL encounters, the data set is too small to make statistical analysis and furthermore all three alerts are part of two suspect encounters with almost identical intruder and ownship tracks (cfr. section C.1.3)

Encounter ID	**CPALevel**	**TimeToCPA**
ansp3_2015-07-10_00745	27934	26
ansp3_2016-02-26_00511	2499	160
ansp3_2016-02-26_00511	2300	397

Table 33: MIL Alert time to CPA

Results per exercise objectives

EX3-OBJ-PJ.11-A4-VALP-0001: *"Evaluate from an operational point of view TSAA algorithms on board GA/Rotorcraft/Military within EU airspace context"*

	Aggregate		ANSP6		ANSP3		ANSP1	
	GA_R	MIL	GA/R	MIL	GA/R	MIL	GA/R	MIL
Outlying Alert %	8,8%	15,1%	9%	28%	10%	9%	4%	0%
Missed Alert %	1,7%	0,0%	7%	NA	0%	0%	0%	NA
No Alert %	0,0%	0,0%	0%	NA	0%	0%	0%	NA
Late Alert %	1,7%	0,0%	7%	NA	0%	0%	0%	NA
Repeat Alert %	21%	32%	10%	0%	42%	50%	12%	0%
Alr Time to CPA mean [sec]	48	NA	38	NA	56	NA	40	NA
Alr Time to CPA StDev [sec]	22	NA	16	NA	25	NA	15	NA

Table 34: TSAA Performance Metrics – Degraded Tracks Encounters

Missed Alert % is below 5% acceptability threshold for both GA_R (2%) and MIL (0%).

TSAA algorithm had always issued one alert for HAZ penetrations (No Alert % = 0).

Out of the 63 HAZ penetration events, part of 43 Must Alert encounters, only in one case TSAA algorithm has issued an alert with less than 12.5 sec before CPA. This happened with a GA_R encounter (Late Alert =1.7%).

Outlying Alert % is 8,8% for GA_R and 15,1% for MIL, hence above the 5% acceptability threshold.

Military Outlying Alert% has reduced w.r.t. Pseudo True Tracks, from 22% to 15%, notwithstanding the increase of Outlying alert count in the degraded scenario, but this is an artefact due to the fact that in the degraded scenario the total raised alert count increase considerably in such a way that the ratio between outlying alerts and total raised alert decrease.

The Mean Time to Alert for the encounter considered is 48 sec (standard deviation of 22 sec), which is higher than similar assessment done in other TSAA performance assessments ([13][19]).

Once an Alert has been issued, the percentage of subsequent raised Alerts within same HAZ or HAZ' volumes (Repeated Alert) is relatively high (21% for GA_R and 32% for MIL).

C.3.3 Unexpected Behaviours/Results

The Outlying Alerts percentage, i.e. the portion of the total issued Alerts, which are not due as the intruder never entered an HAZ' volume, has been calculated to be 8,8% for GA_R and 15,1% for MIL, which are above the acceptability thresholds of 5%, as established by FAA (see Appendix F).

A possible explanation could be related to the presence of helicopter data which could cause unexpected behaviour during TCAS and TSAA simulations. Simulations performed by RTCA on Helicopter specific encounter set (the "Wall Street Heliport", see DO-348 sect. B.4.5.1) showed that

TSAA performance for helicopters in the heliport environment does not perform as well as TSAA for the general flying population of aircraft.

Another concurring explanation are the suspect encounters (as described in C1.3).

C.3.4 Confidence in Results of Validation Exercise 3

1. Level of significance/limitations of Validation Exercise Results

Validation results obtained in this exercise are based on real mixed-equipage encounters in European airspace, collected from three European ANSPs and provided by EUROCONTROL. Such a limited number of real European encounters is considered as sufficient for V1 validation phase, even though the number of analysed encounters itself is a limitation to be taken into account when interpreting the exercise results and conclusions.

Provided encounters were mixed equipage encounters only, so not representing unequipped-unequipped encounters scenarios, also relevant for TSAA performance assessment (objective of EXE03).

Provided encounters were a mix of Airport and En-route environment encounters, but only Enroute HAZ/HAZ' volumes for encounter classification have been used, due to lack of information associated to encounters on vicinity to airports. Diversifying Airport and Enroute scenarios, different HAZ/HAZ' volumes could be used, ending up possibly in different encounter classification (e.g. from Must Alert to Could Alert) and consequently TSAA performance parameters results.

Provided encounters had the ownships with a mix of fixed wing aircraft and rotorcraft, so it has not been possible to assess performance in fixed wing and rotorcraft independently.

The number of Military encounter was too limited to make a full assessment of TSAA performance in Military platforms.

Rather than real recorded ADS-B data tracks, ADS-B data were extrapolated from recorded Radar data (4sec, low accuracy, no velocity vector). Adding real ADS-B recorded data could be useful to increase confidence on results.

Track data of few minutes before and after a close encounters were provided, so that it was not possible to extrapolate alerting rates (number of alerts per FH).

2. Quality of Validation Exercises Results

The results provided in this appendix are based on TSAA model implemented according to TSAA sample algorithm in DO-317B. Assessment was performed in form of fast-time simulations, using three sets of real European de-identified radar tracks with 4 second update rate. Such encounters were interpolated to provide every second inputs for both models. Output data were post-processed to assess alerting results.

The analysis included a number of suspect encounters (split tracks, other SUR anomalies, both unequipped, both MIL, intentional proximity).

Radar tracks data (sampled every 4 seconds) have been interpolated and completed (e.g. velocity vector) using InCAS software provided by EUROCONTROL to obtain Pseudo True Tracks data.

Pseudo True Tracks were degraded considering NACp=8 and NACv=1 case only, as most representative of commercial GA and CAT grade GNSS receivers.

3. Significance of Validation Exercises Results

Exercise results are based on 3838 European encounters involving one TCAS-equipped and one unequipped aircraft. Unequipped aircraft were distinguished between GA (fixed wing and rotorcraft) and Military (fixed wing and rotorcraft), for a total of 3726 and 112 encounters respectively. Encounters represent real situations recorded in central European airspace.

Out of the 3838 encounters 43 have been classified as Must Alert (MA), 1208 as Must Not Alert (MNA) and 2887 as Could Alert (CA), depending on the horizontal and vertical miss distance at CPA.

C.3.5 Conclusions

EXE03 had the objective to evaluate from an operational performance point of view TSAA algorithms on board GA Fixed Wing/Rotorcraft and Military aircrafts within EU airspace context.

Validation results obtained in this exercise are based on real mixed-equipage encounters (TCAS equipped intruder with TCAS Unequipped ownship) in European airspace, collected from three European ANSPs as provided by EUROCONTROL, as outcome of CFC (close encounter identification) and InCAS (1 Hz interpolation, position smoothing and velocity vector) tools. These encounters have been used as Pseudo True Tracks for initial TSAA characterization, and subsequently degraded for TSAA performance evaluation.

While DO-348 generic traffic alerting system performance framework and metrics have been adopted (e.g. encounter classification in MUST/MUST NOT/COULD ALERT), a different operational (and safety) criteria has been considered. While DO-348 has used TSAA Alerting rates as the key Operational (and Safety) metric, using TAS performance in same environment as the acceptability threshold, EXE03 has used Missed Alert % and Outlying Alert % as key performance parameters, and 5% as acceptability thresholds, as indicated in F. Kunzi Thesis [19] as derived from a FAA study involving a group of pilots from the US and Europe.

The encounters did not distinguish between Rotorcraft and Fixed wing GA to assess TSAA performance independently for the two scenarios, so that performance could be measured (simulated) for the combined GA_R. Furthermore the encounters did not contain the information on the proximity to airports, nor absolute coordinates, so it was not possible to assess independently Airport and En-Route encounter scenarios, so that performance could be measured (simulated) only for the DO-348 combined Airport and Low/High En-route scenarios.

EXE03 results indicate that:

- Miss Alerts % (sum of Late % and No Alerts %) are within the 5% threshold, for both GA_R and MIL mixed equipage encounters (~2% and ~0% respectively)
- Outlying Alerts % are above the 5% threshold for both GA_R and MIL mixed equipage encounters, being ~9% and ~15% respectively
- both Miss Alerts (%) and Outlying Alerts (%) performance parameters in the considered European encounter set have been measured to be smaller than the ones indicated in DO-348 for NAS encounters (Miss Alerts% ~ 40÷60% and Outlying Alerts% ~ 28÷67%, depending on specific operational scenario)
- Mean time to Alert has been measured to be ~ 45 sec in the considered encounter set (with 20sec standard deviation), which is sensibly greater than the one indicated by DO-348 for NAS encounters (26÷30 sec depending on specific operational scenario), also by eliminating specific cases with very long Time to Alert (i.e. above 100s) which could be generated by anomalous encounters.
- Due to the characteristics of the encounter data set available, TSAA alert rates metrics (i.e. number of alert per FH) could not be measured in EXE03 simulations and comparison with DO-348 data could not be performed.

1. Conclusions on concept clarification

SA+ concept, also referred as TSAA+, consist of already standardized ADS-B IN Traffic Situational Awareness with Alerts **(TSAA)** application enhanced to use information about intruder RA (Resolution Advisory), and indicate it to Pilot. So the TSAA+ concept operational feasibility must consider the TSAA operational feasibility in European context.

2. Conclusions on technical feasibility

The technical feasibility of TSAA application has not been addressed by EXE03, as TSAA application TRL is well above feasibility stage.

3. Conclusions on performance assessments

The KPA addressed by PJ11-A4 solution is Safety. Key TSAA capabilities which can be considered impacting TSAA (and TSAA+) operational and safety suitability are:

1. TSAA capability to provide to pilot traffic alerts when required (i.e. low Miss Alerts %)
2. TSAA capability to avoid traffic alerts to pilots when these are not necessary and would cause un-necessary pilot workload or distraction (i.e. low Outlying Alerts %)

The above 1) and 2) capabilities should be guaranteed both in case of “equipped” intruders (i.e. with TCAS) and “unequipped” intruders (i.e. w/o TCAS), as otherwise GA pilots would decide not to equip TSAA capability.

EXE03 has provided preliminary results (see limitations and level of confidence of Validation as described in C.3.4), on a set of recorded mixed encounters in central Europe, which indicate that:

- TSAA exemplar algorithm would have capability to provide to pilot traffic alerts when required (Miss Alerts % below 5% threshold)
- TSAA exemplar algorithm may risk to provide traffic alerts to pilots when these are not considered necessary (Outlying Alerts % above 5% threshold)

The Outlying Alerts % result may be negatively influenced by:

- Helicopter encounter scenarios, in which TSAA exemplar algorithm has been shown not to perform adequately by other TSAA Performance Assessments activities (see [13] and [19]),
- presence of anomalous encounters which have been identified during simulation results post processing phase
- use of En-route Hazard (HAZ) and Non Hazard (HAZ’) volumes for classifying all encounters, instead of using also Airport volumes, may have also negative impact

C.3.6 Recommendations

Waiting the development of European GA encounter models, for the next V2 validation activity it is recommended to:

- identify Helicopter encounters, in order to discriminate Fixed wing and Rotary wing within GA_R encounter set analysed in V1
- eliminate anomalous encounters from the encounter set used for performance assessment, possibly using expert pilot judgement and additional information available to Eurocontrol
- discriminate Airport scenario encounters from en-route encounters, by means of visual inspection of flight patterns, possibly using expert pilot judgement and additional information available to Eurocontrol
- Enrich encounter data set, in particular for what concerns Military encounters and other European geographical areas

With the above enhancement in encounter models, new simulation runs should be performed with the aim to:

- Assess TSAA performance in Helicopter and Fixed wing scenarios independently
- Assess TSAA performance in Airport and En-route scenarios independently
- Improved TSAA performance assessment in encounters involving Military aircrafts

- Improve representativeness of simulation results within eurpean encounter scenarios
- assess impact of different NACp / NACv levels (other than NACp=8 / NACv=1) in TSAA Performance

It would be also important to have from Eurocontrol radar tracks of close unequipped/unequipped encounters, as an anticipation of the full European GA encounter models.

Appendix D SESAR Solution(s) Maturity Assessment

Maturity assessment has been completed as a final step of this validation. Summary result is provided at the table below, full maturity assessment file is attached.

This assessment is to be refined after final SPR-INTEROP/OSED and initial CBA for V1 TSAA+ are available.

Maturity Assessment Tool - Summary			
Solution:	PJ.11-A4		
	OI Step		
Reference:	CM-0808-p	(5)	- Select -
(2)	- Select -	(6)	- Select -
(3)	- Select -	(7)	- Select -
(4)	- Select -	(8)	- Select -
Name:	Eva Jošth Adamová, PJ.11-A4		

	OPS	PER	PRG	STD & REG	SYS	TRA
V1	87%	50%	100%	100%	75%	100%
V2	0%	0%	0%	0%	0%	0%
V3	0%	0%	0%	0%	0%	0%

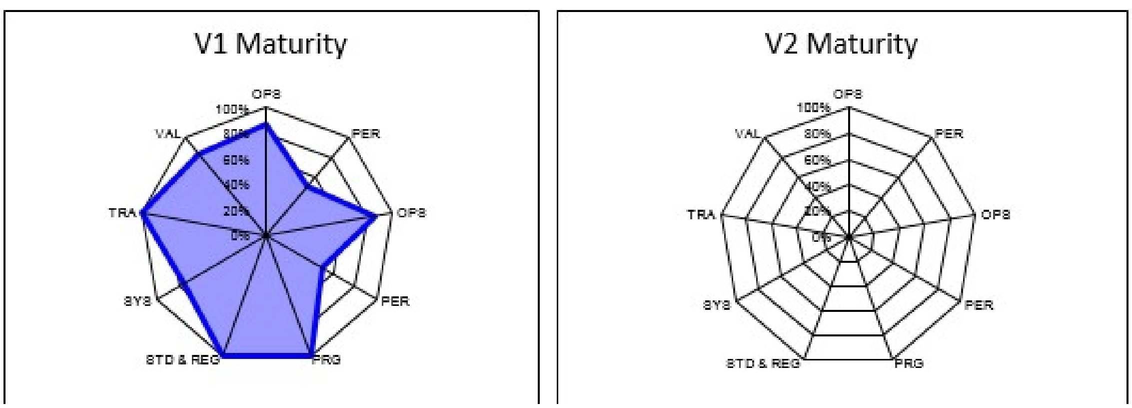


Figure 32: V1 maturity assessment for TSAA+ (at VALR level)

Maturity
Assessment Tool 202

Appendix E DO-348 Operational and Safety Performance Assessment

E.1 Introduction

TSAA application has been tuned and validated considering NAS airspace characteristics (i.e. encounters), while Leonardo's EXE03 scope is to evaluate TSAA Operational Performance in the EU airspace context.

DO-348 «TSAA Safety and Performance Requirement» (SPR), has defined a methodology and performance metrics to evaluate a generic traffic alerting system, in order to demonstrate TSAA safety objective (Safety Requirement SR-1):

"*The TSAA application shall alert less frequently than existing certified alerting systems that are designed to operate in the same operational environments*."

Traffic Alerting System (TAS, the GA equivalent for TCAS I) has been selected as existing certified alerting system, and the above requirement represents the overarching system requirement that drove the TSAA minimum Performance Requirements.

In the following highlights of DO-348 operational and safety performance assessment results.

E.2 TSAA OSA/OPA

DO-348/ED-232 Section B.4 discusses the required TSAA system performance as defined by the safety and functional requirements on the system. To meet the safety requirement, a comparative analysis is needed to determine the relative performance between the TSAA system and TAS as the existing alerting system. The assessment has been done for a Worst Case scenario and a Nominal Case scenario, depending on the assumptions done on ownship's and intruder's surveillance data source and accuracy characteristics.

In the Worst Case scenario (see [13], TABLE B–14) ownship and intruder had the absolute minimum accuracy performance required by TSAA application (i.e. NACp=5, 100 ft altitude quantization, very bad intruder vertical speed accuracy of 30 m/s), compatible with an intruder tracked using TIS-B with a single source radar (cfr. TIS-B2, with 12 second update rate).
In the Nominal Case scenario (see [13], TABLE B–18), which describes the scenario after 2020, when all aircarfts will have ADS-B in mandated airspace (so TIS-B is not used anymore as a tracking source), both ownship and intruder have better accuracies (e.g. NACp=8, NACv=1, alt quant. 25 ft for 1090 MHz ADS-B aircrafts).

The following table compare relevant Worst Case and Nominal Case for Ownship and Traffic used for DO-348 simulations.

	Worst Case (*)		Nominal Case (%)		AIRB / EVAcq
	Ownship (OS)	Traffic (TS)	Ownship (OS)	Traffic (TS)	(for Reference)
Horizontal Position Error [m, 95%]	926 (NACp=5)	926 (NACp=5)	92.6 (NACp=8)	92.6 (NACp=8)	Same
Horizontal Velocity Error [m/s, 95%]	10 (NACv=1)	30 (NACv=0)	10 (NACv=1)	10 (NACv=1)	OS=NACv0, TS=NACv1 or NACv0 for TIS-B
Altitude Error [m, 95%]	45	45	45	45	(GVA=2 or Valid Pressure)
Altitude Quantization [ft]	100	100	100	25	NA
Vertical Rate Error	--	--	--	--	NA

Table 35: Worst Case and Nominal Case Ownship/Traffic parameters

(*) Worst Case refer to system parameters as indicated in DO-348 Table B-14
(%) Nominal Case refer to system parameters as indicated in DO-348 Table B-18 (only ADS-B)

TSAA/TAS worst case performance results

The performance parameters indicated in Table 36 have been calculated for TSAA and TAS for the Airport (DO-348 - TABLE B–15), Low Enroute (DO-348 - TABLE B–16) and High Enroute (DO-348 – TABLE B–17) environments (with corresponding encounter set[17]).

[17] Airport, Low EnRoute and High Enroute encounter set comprised a suitably tailored portion of encounters gathered from the following three categories:

- output of the Multi-Sensor Fusion Tracker (MST) which combines **TIS-B tracks (radar)** with **ADS-B tracks** (both 1090ES and UAT)
- DO-348/ED-232 test tracks which characterizes a number of scenarios that represent the most **common midair collisions (MACs) and near mid-air collisions (NMACs),** based on 15 years of data collected by the **NTSB** for NAS.
- The Lincoln Laboratory Encounter Model (LLEM or Correlated Encounter Model), a theoretical framework used to model cooperative encounters between aircraft, representative of situations where at least one aircraft is in contact with Air Traffic Control (ATC), which randomly generates encounters between an ownship and one traffic aircraft that is statistically representative of the behavior of aircraft in the National Airspace System (NAS).

Perf. Parameter	Units
Total Alert Period	[Hrs/Alert]
% Repeated Alerts	[% of Total Alerts]
Outlying Alert Period	[Hrs/Alert]
Outlying Alert Rate	[Alerts/Hr]
% Outlying Alerts	[% of Total Alerts]
% Missed Alerts	[% of Required Alerts]
% No Alerts	[% of Required Alerts]
% Late Alerts	[% of Required Alerts]
% Correct Alerts	[100 - % Missed]
Time to Alert	[Sec prior to CPA]

Table 36: TSAA and TAS performance in the 3 different environments

For all performance parameters TSAA outperforms TAS, with the exclusion of % Outlying Alerts and % Missed Alerts, for which TSAA results performing sensibly worse than TAS (e.g. In airport scenario the % Missed Alerts is 60% for TSAA and 0.04% for TAS).

As already said it should be noted that the performance results in the Worst Case scenario represents the worst possible outcome. These results reflect the expected performance of an environment where ownship and every traffic aircraft have the minimum level of performance to qualify for TSAA. The data fed into the TSAA algorithm which provided the outputs as per DO-348 - TABLE B–15, TABLE B–16 and TABLE B–17, was the absolute worst case data you would expect to ever be fed to TSAA. Specifically, it is a TIS-B target, operating at the outer edges of an en-route radar (i.e. huge position and velocity errors, NACv=0 and NACp = 5), in view of only one radar (i.e. 12 second update rate), and maximum allowable latency. The only thing that those numbers tell us that you can't expect an alerting system to alert when you don't give it usable data. In that sense TAS has an advantage as it has its own surveillance system onboard the aircraft that will always give it good data.

So it is not representative of what you'd actually see in the real world, but more of a test to see what happens in the extreme corner cases of the trade-space. In today's environment it is expected that the performance would exceed these values, and as more aircraft equip with ADS-B OUT the actual performance will continue to improve.

The low en route result indicates that TSAA does not perform better than TAS for the Outlying Alert % metric. This result is somewhat misleading and points to a weakness in that metric. The table below, related to DO-348 low en route results, shows the actual alert count that the outlying alert count which is somewhat lower for TSAA than TAS, but the total alert rate for TAS is more than twice that of TSAA, thus causing the percentage to mislead about the performance.

	LOW EN ROUTE Alert Count	
	TSAA	**TAS**
Total Alerts Count	5684	14445
Repeated Alerts Count	65	1553
% Repeated Alerts	1,1%	10,8%
Outlying Alert Count	1599	1650
% Outlying Alerts	28,1%	11,4%

Table 37: Low Enroute details on alert counts

Due to this weakness in the % Outlying Alert metric, DO-348 experts decided that this metric should be informational only, and not used to drive the subsequent Performance Requirements.

Nominal Traffic Performance

To characterize the performance of TSAA for aircraft that exceed the minimum requirements determined in DO-348, and to consider the scenario post 2020, in which all aircrafts will have ADS-B in FAA mandated airspace, simulations were run to mimic a set of nominal traffic types.

Nominal Traffic Performance – Airport Environment results

According to DO-348 TSAA shows in nominal traffic conditions always better performance with respect to TAS when considering:

- Total Alert Period (see DO-348: FIGURE B–26)
- Outlying Alert Period (see DO-348: FIGURE B–27)
- Mean Time to Alert (see DO-348: FIGURE B–28) – TSAA (ADS-B Traffic, Basic) = 26 sec
- % Outlying Alerts (see DO-348: FIGURE B–29) – TSAA (ADS-B Traffic, Basic) = 45%
- % Repeated Alerts (see DO-348: FIGURE B–30) – TSAA (ADS-B Traffic, Basic) = 1,5%

Only exception is the Missed Alert % for which TSA always outperforms TSAA

- Missed Alert % (see DO-348: FIGURE B–31) - TSAA (ADS-B Traffic, Basic) = 3.4%

It is shown that the missed alert rate remains below 5% for all of the nominal traffic types characterized, except the TIS-B2 traffic type. It is important to note that DO-348 does not consider Missed Alert % as an overarching performance metric, hence this non optimal result on the Outlying Alert % (above %5 threshold), in the opinion of DO-348 experts, does not compromise TSAA safety or operational acceptability.

Nominal Traffic Performance – Low Enroute Environment

DO-348 simulations shows in nominal traffic conditions always better performance with respect to TAS when considering:

- Total Alert Period (see DO-348: FIGURE B–32)
- Outlying Alert Period (see DO-348: FIGURE B–33)
- Mean Time to Alert (see DO-348: FIGURE B–34) - TSAA (ADS-B Traffic, Basic) = 30 sec
- % Repeated Alerts (see DO-348: FIGURE B–36) - TSAA (ADS-B Traffic, Basic) = 1%

Only exception are the Outlying Alerts% and Missed Alert% for which TAS always outperforms TSAA. In particular:

- Outlying Alerts% (see DO-348: FIGURE B–35) – TSAA (ADS-B Traffic, Basic) = 21%
- Missed Alert% (see DO-348: FIGURE B–37) – TSAA (ADS-B Traffic, Basic) = 16%

Again, it is important to note that DO-348 does not consider Missed Alert % and Outlying Alerts% as an overarching performance metric, hence this non optimal results on the Missed Alert % and Outlying Alert % (both above %5 threshold), in the opinion of DO-348 experts, do not compromise TSAA safety or operational acceptability.

<u>Nominal Traffic Performance – High Enroute Environment</u>

DO-348 results shows that TSAA in nominal traffic conditions always performs better than TAS when considering:

- Total Alert Period (see DO-348: FIGURE B–38)
- Outlying Alert Period (see DO-348: FIGURE B–39)
- Mean Time to Alert (see DO-348: FIGURE B–40) - TSAA (ADS-B Traffic, Basic) = 28 sec
- % Outlying Alerts (see DO-348: FIGURE B–41) - TSAA (ADS-B Traffic, Basic) = 20%
- % Repeated Alerts (see DO-348: FIGURE B–42) - TSAA (ADS-B Traffic, Basic) = 0%

As for previous environments an exception is the Missed Alert % for which TAS always outperforms TSAA. In particular:

- Missed Alert % (see DO-348: FIGURE B–43) - TSAA (ADS-B Traffic, Basic) = 13%

Again, it is important to note that DO-348 does not consider Missed Alert % and Outlying Alerts% as an overarching performance metric, hence this non optimal result on Missed Alert % and Outlying Alerts% (both above %5 threshold), in the opinion of DO-348 experts, do not compromise TSAA safety or operational acceptability.

<u>Nominal Traffic Performance – Helicopter scenario</u>

In previous performance simulations RTCA experts report that:

1) the encounter data set coming from traffic recordings that was created for the airport environment was generated by collecting the full population of aircraft for the selected locations. No attempt was made to segregate fixed wing from helicopter tracks

2) the entire Wall St. Heliport data set had been removed from the airport master encounter set due to the excessive alerts issued

To understand how TSAA would perform on helicopters a helicopter-specific data set has been used by RTCA experts. Helicopter tracks have been extracted from the data collected from the Wall Street Heliport. To extract acceptable encounters an operational expert helped to develop a set of rules to reduce the data set. From this reduced set, manual classification of the encounters was done. A set of about 2400 helicopter encounters has been obtained that represent typical helicopter/helicopter and helicopter/fixed wing in an airport (heliport) operational environment.

DO-348 TABLE B–20 provides the performance results HELIPORT PERFORMANCE SUMMARY, which can be summarised as follows:

1) % Missed Alerts are totally unacceptable (90.7%), and considerably worse than for TAS (17.7%)

2) in general TSAA performance for helicopters in the heliport environment does not perform as well as TSAA for the general flying population of aircraft.

3) Where TSAA outperforms TAS, the improvement is marginal.

4) when the data accuracy increases, TSAA misses more alerts (% Missed Alerts metric which is 41.2% for NACp=5 and 90.7% for NACp=8)

According to RTCA these results show that the sample TSAA algorithm was not optimized for helicopter operations in close proximity, such as electronic news gathering, and indicate that if the sample algorithm is implemented as is during helicopter operations, alerting performance may not meet operator expectations.

Summary on DO-348 performance assessment results

DO-348 considered as the only overarching performance requirements the TSAA Alert rates (both Total and Outlying Alert rates), requiring that these should be greater than TAS in same operational scenarios. Simulations performed by RTCA using a mix of Recorded data, historical MAC/NMAC test tracks and MIT Lyncoln Lab correlated encounter models showed that TSAA in general outperforms TAS, in all operational scenarios in terms of:

- Total Alert Period [Hrs/Alert]
- % Repeated Alerts [% of Total Alerts]
- Outlying Alert Period [Hrs/Alert]
- Mean Time to Alert [sec]

For what concerns % Outlying Alert and % Missed Alert metrics, instead DO-348 performance assessment shows that TSAA generally not only performs worse than TAS, but reaches values which contrasts with previous work on TSAA which identified 5% as acceptable thresholds for Nuisance (Outlying) Alerts and Missed/Late Alerts (cfr. Appendix F). In particular % Outlying Alert metric has been found to always exceed 5%:

- found to be 67% / 28% / 38% in Airport / Low / High Enroute environments in "worst case"[18]
- found to be 45% / 20% / 20% in Airport / Low / High Enroute environments in "nominal case"[19]

and for what concerns % Missed Alert metric:

- In worst case data scenario are 40% to 60% depending on the environment[20]
- In nominal case data scenario is below 5% only for the Airport Environment, while it is ~15% in both Low and High En Route scenarios[21]

Simulations performed on Helicopter specific encounter set (Wall Street Heliport) showed that TSAA performance for helicopters in the heliport environment is worse than for the general flying population of aircraft. In particular:

- when the ownship/traffic data accuracy increases, TSAA misses more alerts, reaching up to 90% for % Missing Alerts
- considering % Outlying Alert (as for other metrics where TSAA outperforms TAS), the improvement is marginal

These results shows that, as recognised by DO-348 experts, the sample TSAA algorithm was not optimized for helicopter operations in close proximity, such as electronic news gathering, and indicate that if the sample algorithm is implemented as is during helicopter operations, alerting performance may not meet operator expectations.

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[18] Cfr. Airport (DO-348 - TABLE B–15), Low Enroute (DO-348 - TABLE B–16) and High Enroute (DO-348 – TABLE B–17)

[19] Cfr. Airport (DO-348 - FIGURE B–29), Low Enroute (DO-348 - FIGURE B–35) and High Enroute (DO-348 – FIGURE B–41)

[20] Cfr. Airport (DO-348 - TABLE B–15), Low Enroute (DO-348 - TABLE B–16) and High Enroute (DO-348 – TABLE B–17)

[21] Cfr. Airport (DO-348 - FIGURE B–31), Low Enroute (DO-348 - FIGURE B–37) and High Enroute (DO-348 – FIGURE B–43)

Appendix F DO-348 Performance Metrics and Acceptability Thresholds

Regarding the Outlying Alerts and Missed Alerts (late + No alerts) acceptability thresholds, these have been established for EXE03, as previously done in [19], on the basis of a FAA study involving a pilots focus group from the US and Europe. The pilots received a presentation of the DO-348 scoring approach. The group consisted of 24 pilots with logged flight times ranging from 250 hours to 33,000 hours and certifications ranging from Private Pilot to ATP. On average, the pilots had 790 hours of flight time experience with TCAS I type systems (TAS, TIS, etc.) and an average of 2750 flight hours in aircraft equipped with TCAS II.

The focus group was asked to set levels of acceptable performance rates for nuisance (outlying), late, and missed alerts. As an alert issued too late to allow for the flight crew to respond to the situation can have a similar effect as a missed alert, late alerts were combined with no alerts, so that combination of the two are Missed alerts.

Given that the rate of Outlying alerts depends on the operational environment, the group defined the percentage of nuisance alerts instead of a rate. During the evaluation of a particular environment, this percentage can then be translated into a rate, given the total number of flight hours in the data set and the number of alerts issued by the alerting system.

For both, Outlying and Missed alerts, the group defined a desirable performance level of less than or equal to 5%.

The following Table 38 provides for the RTCA DO-348 Performance Metrics, the acceptability thresholds used by DO-348 experts ([13]), in F. Kunzi PhD thesis ([19]) and what can be measured as part of EXE03 considering the available encounter data set.

	RTCA DO-348 [13]	F. Kunzi PhD Thesis [19]	EXE03 Success Criterias
Total Alert Period [hours between alerts]	*Always better than TAS*	Target to be greater than TAS	*Cannot be calculated*
Outlying Alert Period [hours between outlying alerts]	*Always better than TAS*	Target to be greater than TAS	*Cannot be calculated*
Outlying Alert Percent [% of total alerts issued]	*not considered a driving performance metric*	Key perf. Indicator Acceptability threshold <5%	Key perf. Indicator Acceptability threshold <5%
Missed Alert Percent [% of required alerts]	*not considered a driving performance metric*	Key perf. Indicator Acceptability threshold <5%	Key perf. Indicator Acceptability threshold <5%
No Alert Percent [% of required alerts]	*not considered a driving performance metric*	Key perf. Indicator (as part of Missed Alert%)	Key perf. Indicator (as part of Missed Alert%)
Late Alert Percent [% of required alerts]	*not considered a driving performance metric*	Key perf. Indicator (as part of Missed Alert%)	Key perf. Indicator (as part of Missed Alert%)
Repeat Alert Percent [% of total alerts issued]	*Always better than TAS*	Not considered	*For info only*
Mean Time to Alert [seconds before CPA]	*Always better than TAS*	Acceptability threshold >12.5 sec	*For info only*

Table 38: Performance Metrics and acceptability thresholds comparison

Appendix G Navigation source accuracies

Table 39 and Table 40 provide DO-260B Position (NACp) and Velocity (NACv) accuracy encodings (accuracies incompatible with TSAA minimum requirement is greyed).

		95% Hor and Vert accuracy bounds (EPU and VEPU)					
NACp	Comment	EPU			VEPU		
		m	km	NM	m	km	NM
0	Unknown accuracy		18,52	10		18,52	10
1	RNP-10 accuracy		18,52	10		18,52	10
2	RNP-4 accuracy		7,41	4		7,41	4
3	RNP-2 accuracy		3,70	2		3,70	2
4	RNP-1 accuracy	1852		1	1852		1
5	**RNP-0.5 accuracy**	**926**		**0,5**	926		0,5
6	**RNP-0.3 accuracy**	**555,6**		**0,3**	555,6		0,3
7	**RNP-0.1 accuracy**	**185,2**		**0,1**	185,2		0,1
8	**e.g., GPS (with SA on)**	**92,6**		**0,05**	92,6		0,05
9	**e.g., GPS (SA off)**	**30**			**45**		
10	**e.g., WAAS**	**10**			**15**		
11	**e.g., LAAS**	**3**			**4**		
12	reserved						
13	reserved						
14	reserved						
15	reserved						

Table 39: DO-260B Horizontal (EPU) and Vertical (VEPU) position accuracies (NACp)

NACv	Hor velocity error	m/s	km/h	Knots
0	> 10m/s or unknown	10	36	20
1	**< 10m/s**	**10**	**36**	**20**
2	**< 3m/s**	**3**	**11**	**6**
3	**< 1m/s**	**1**	**4**	**2**
4	**< 0.3m/s**	**0,3**	**1**	**0,6**

Table 40: Velocity accuracies (NACv)

It should be noted that for TSAA there is no requirement on Vertical velocity, as the algorithm is capable to derive a vertical velocity from the reported altitude data. This latter has a requirement as follows: "the Altitude Accuracy must be 45 m at 95% probability or better (valid pressure altitude or Geometric Vertical Accuracy (GVA) ≥ 2)"

In the following example of GPS receivers for Commercial Transport and General Aviation, exemplifying that assuming that for both categories NACp>=8 and NACv>=1 is a reasonable assumption.

GPS high-end, certified for ADS-B

CMA-4124

Hor. Position Accuracy	15 meters, 95%, S/A off
Differential	Better than 1.0 meters, 95%
Altitude Accuracy	20 meters, 95%, S/A off
Velocity Accuracy	0.5 knots, 95%, S/A off (0.33kts horizontal, 68 ft/min. vertical)

CMA-5124 (evolution of CMA-4124)

Navigation Accuracy	SA-OFF, RNP0.1 >99.999% availability with SBAS, and Primary Means Navigation as per RTCA/DO-229D
Velocity Accuracy	< 0.5 knots, 95%, SA-OFF, velocity as per RTCA/DO-229D Appendix F

GA grade "commercial" GPS

GLOBOS C200 (dated)

4.1.2.1.1 GPS-Position-accuracy * (95 %, SPS)

	Horizontal	Vertical	3-D
Signal not degraded (w/o SA):	29 m	46 m	51 m
Signal degraded (with SA):	100 m	159 m	174 m

* with GDOP ≤ 3.6, minimum of 4 satellites in calculation and FOM = 1

4.1.2.2 Typical test results

Position stability	: < 2 m (RMS) *
Position bias (without SA)	: < 25 m *
Velocity, no SA	: 0.1 m/s (- 0.2 knots) *

GPS Garmin 150

PERFORMANCE

Receiver:	MultiTrac 8™
Acquisition Time:	2-2.5 minutes (typical) 15 seconds (warm start, with ephemeris)
Update Rate:	1 per second, continuously
Accuracy:	15 meters (49ft.) RMS**
Dynamics:	999 knots velocity, 3g acceleration

GPS Jupiter 12

	Position (metres)				Velocity (m/s)
	Horizontal		3D	Vertical	
	CEP (50%)	2 DRMS (95%)	SEP (50%)	VEP (50%)	3D (2 sigma)
Full accuracy C/A	2.8	4.9	5	3.2	0.1
Standard Positioning Service (SPS)	50	100	200	173	Note 1
Note 1: velocity accuracies for SPS are not specified for the GPS system.					

Table 2-2 Jupiter navigational accuracies

GPS uBlox TIM-CJ

Statistical Overview	2D (LTP)	Altitude	3D
50% eqv. CEP (2D), SEP (3D)	2.1 m	4.6 m	5.4 m
Sigma-1 (68.3%)	2.8 m	6.1 m	6.8 m
Sigma-2 (95.5%) eqv. R95	4.9 m	10.9 m	11.2 m
Sigma-3 (99.7%)	7.9 m	15.2 m	15.4 m
RMS	2.4 m	5.8 m	6.4 m

Appendix H Pseudo True Track degradation model

The Encounter Degrader (ENCDEG) is composed of two parts:

1. Ownship Degrader
2. Intruder Degrader

The Ownship degrader provides degradation of the Ownship data track based on the error characteristics of the navigation system of the ownship.

The Intruder data are degraded considering both the characteristics of the transmitter (ADS/B and navigation system) of the Intruder and the receiver of the ownship.

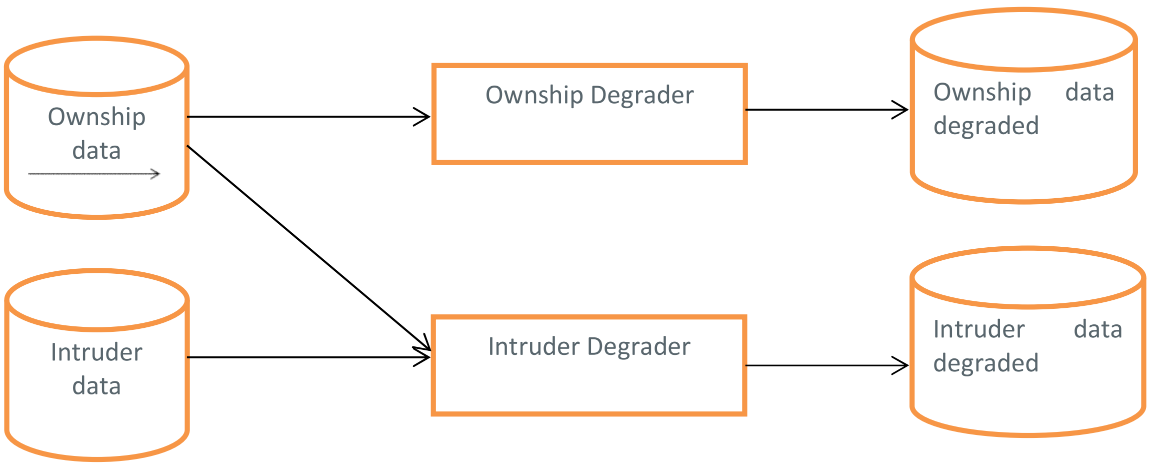

Figure 33: Encounter Degrader (ENCDEG)

From the logical point of view the Intruder Degrader is composed of three degrader modules as represented in the following figure:

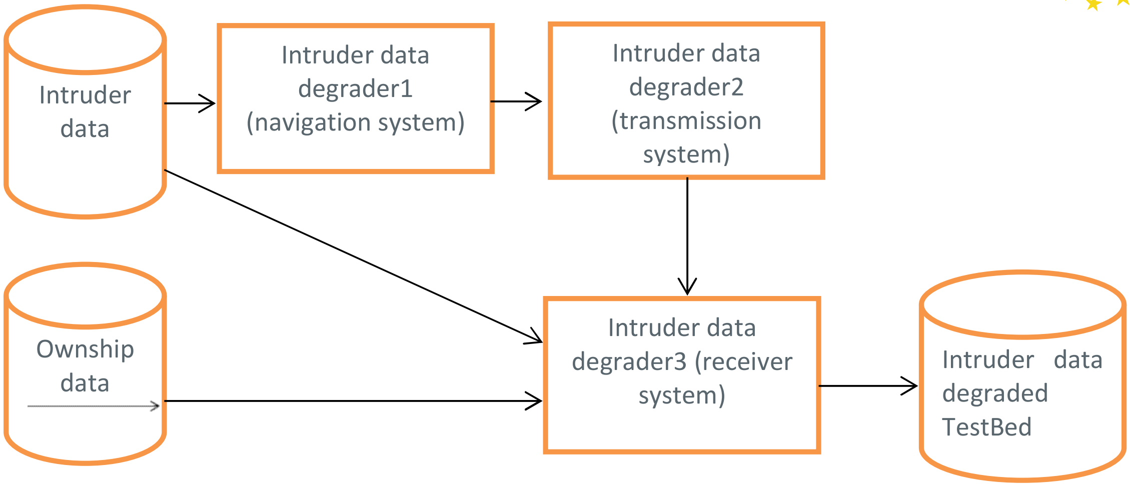

Figure 34: Intruder Track Degradation

The intruder data *degrader1* degrades the position of the intruder based of the characteristics of the navigation system. The *degrader2* models the ADSB transmitter (squitter, data quantization). The *degrader3* models the receiver antenna and the data reconstruction. For the degrader3 uses the information of the intruder and the ownship.

Appendix I Register BDS 1,0 description

The purpose of this register is to report the data link capability of the Mode S transponder/data link installation.

Bit 16 of Message Comm-B (MB) field set to ONE (1) indicates that the transponder TCAS interface is operational and set to ZERO (0) to indicate that TCAS has failed or is on standby.

-END OF DOCUMENT-