INDUSTRIAL RESEARCH

# PJ.11-A4 V2 SA+ VALR

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| 00.01.04 | 20th August | Revision | Silvie Luisa Brázdilová | SJU comments incorporated |

# CAPITO

CAPITO

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## Abstract

This document provides the Validation report for PJ.11-A4: SA+ capability for V2. It shows results and conclusions of simulations about SA+/TSAA+ capability defined in V2 OSED document, in order to achieve V2 maturity level.  Three exercises have been performed within V2 phase of SA+ capability validation. Two additional exercises were devoted to initial assessment of ACAS Xu usability and interoperability for GA. Each exercise has been independent, performed by different solution partner (Honeywell, Thales, Leonardo) using different simulation platforms and techniques, and addressing different solution objective.

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# 1 Executive summary

This document provides validation results addressing V2 maturity phase for TSAA+ (enhanced Traffic Situational Awareness system with Alerts). The document is a follow-up to Validation Report (Deliverable D6.1.060), which provided results relevant for maturity phase V1.

This document also provides initial validation results regarding usability and interoperability of ACAS Xu, which is a variant of ACAS X tailored for Remotely Piloted Aircraft Systems, for General Aviation.

The first two exercises aim at **Operational evaluation of TSAA+ during mixed equipped encounters**. Exercise #4[1] (performed by Honeywell) consists of simulator sessions with pilots, comparing and assessing their performance on baseline scenarios (ownship without TSAA), reference scenarios (ownship with TSAA) and solution scenarios (ownship with TSAA+).

Exercise #5 was performed by Thales and consists of fast-time simulations of representative European encounters. The first task was to quantify the probability of Near Mid-Air Collisions in TCAS II equipped and TSAA+ equipped aircraft and compare it to the TSAA only scenarios. The second task was to assess reduction of compromising TCAS Resolution Advisories.

Exercise #6 done by Leonardo explores **operational benefits of TSAA** (as a baseline for TSAA+ improvements) **in European airspace**. It represents a refinement of Exercise #3 of V1 validation. The aim was to assess missed and outlying alert percentage.

Exercise #7, executed by Honeywell, assesses **ACAS Xu usability for General Aviation and Rotorcraft**. Specifically, the main research question was whether ACAS Xu could be potentially used onboard a manned aircraft. Fast time simulations were performed to get a first impression of the manoeuvres suggested by ACAS Xu on board an ownship. Subsequently, operational workshops were run in order to assess pilot's acceptability from the GA perspective.

Exercise #7 also investigates **interoperability of General Aviation & Rotorcraft with drones**. This objective is complemented by Exercise #8 performed by Thales, in which the probability of Near Mid-Air Collisions with ACAS Xu was compared with that of TSAA+.

Obtained results justify TSAA+ V2 maturity with a recommendation to minor Human Machine Interface improvements.
ACAS Xu is a promising system however, it seems that interoperability with current rules of the air requires further development.

[1] Exercises #1 to #3 were performed as part of V1 maturity assessment and are to be found in the V1 VALR.

# 2 Introduction

## 2.1 Purpose of the document

This document provides the Validation Report for PJ.11-A4: SA+ capability for V2. It describes the results of validation exercises defined in VALP (D6.2.010) and how they have been conducted and provides a set of relevant conclusions and recommendations.

This report presents the results of five exercises. Three of them (EXE #4, EXE #5 and EXE #6) focus on V2 validation of TSAA+ solution. The remaining two exercises (EXE #7 and EXE #8) are related to interoperability aspects of AXAS Xu and the GA community.

## 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/StA 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.

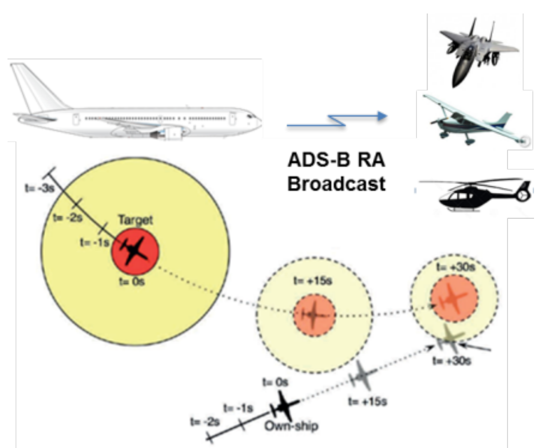



**Figure 2-1: TSAA+ pictorial view**

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 state, powered aircraft or rotorcraft which is not under TCAS II mandate.

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 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 Commercial Air Transport (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).

TSAA+ capability has not been addressed in SESAR 1, and **its current maturity level is V1, aiming to reach V2 in 2019**.

List of past evaluation activities addressing TSAA+/TSAA, ACAS system for GA/R/StA:

- Initial analysis of TSAA alerting functions has been performed in the past within SESAR 9.47 project, using system and test vectors as defined in TSAA SPR and MOPS. 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.

- In 2018, TSAA performance evaluation on more than 3500 real European encounters in both En-Route and TMA environment has been performed within V1 phase of this solution. EXE-03 results confirmed that performance of TSAA meets the required thresholds in most of the cases, however, improved data set with better distinction of the encounters is needed for more significant results. EXE-02 showed promising benefits in terms of NMAC probability in European airspace (by up to 5.3%).

- Initial TSAA+ analysis during V1 phase of the solution (EXE-01) evaluated and analysed incremental benefits to TSAA+ on top of TSAA showed that "+" functionality can potentially improve safety by 49%[2].

- V1 OSED for TSAA+ has been published in May 2018, defining high-level operating method of TSAA+ including three potential use cases.

During V2 maturity phase, in addition to TSAA/TSAA+ specific exercises, interoperability aspects were addressed involving ACAS Xu system. ACAS Xu is a variant of ACAS X tailored for Remotely Piloted Aircraft Systems (RPAS). ACAS Xu development was launched later than ACAS Xa, and the European activities in this area are starting in SESAR 2020. The work builds on the results and development done so far by FAA ACAS X program – in particular, Run 3 of ACAS Xu which was used as a starting point for PJ.11-A2 to achieve V1 maturity. PJ.11-A4 activities will use Run4.1 (EXE-08) and Run4.2

[2] V1 VALR indicate improvement of 28.5% by mistake. Correct improvement value is 49% (TSAA+ can potentially bring benefits in every situation when at least TCAS II alerts, e.g. in 78,4%, while pure TSAA has potential to help in 52,6% of alerting scenarios) – results in improvement of 49%.

(EXE-07) releases of the system. Technically, ACAS Xu reuses (potentially with some adaptation) several elements - in particular, concerning vertical collision avoidance or cooperative surveillance - already developed and validated for ACAS Xa.

## 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, C, D and E** provide more details per Validation exercise.

**Appendix F** provides maturity assessment of solution.

## 2.5 Glossary of terms

| 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".<br><br>This encompasses a wide range of activity:<br>• Pilot training<br>• Business aviation<br>• Recreation including balloon, glider and model aircraft flying<br>• Agriculture including crop spraying<br>• Mail and newspaper deliveries<br>• Transport of dangerously ill people and of urgently needed human organs, medical | PJ.11-A4 |

| | | |
|---|---|---|
| | equipment and medicines<br>• Monitoring ground traffic movements from the air<br>• Civil search/rescue<br>• Law enforcement including operations against smuggling<br>• Aerial survey including photography for map making and pipeline and power cable patrols<br>• Pollution control and fire fighting<br>• Flying displays<br>and aircraft platforms:<br>• Fixed wing<br>• Rotary wing<br>• Unconventional (e.g. balloons, airships, gliders, autogyro)<br>In the context of PJ11-A4 "General Aviation" will indicate Fixed Wing platforms used for GA activities.<br><br>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 state 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 aircraft. 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.<br><br>Remark: state aircraft is defined as "any aircraft used for military, customs and police purposes" in COMMISSION IMPLEMENTING REGULATION | PJ.11-A4<br><br>COMMISSION IMPLEMENTING REGULATION (EU) No 1207/2011 |

| | | |
|---|---|---|
| | (EU) No 1207/2011 | |
| **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**

## 2.6 Acronyms and Terminology

| Acronym | Definition |
|---|---|
| **A/C** | Aircraft |
| **ACAS** | Airborne Collision Avoidance System |
| **ACAS Xa** | ACAS X – Active |
| **ACAS Xp** | ACAS X – Passive |
| **ADD** | Architecture Definition Document |
| **ADS-B** | Automatic Dependent Surveillance – Broadcast |
| **AOPA** | Aircraft Owners and Pilots Association |
| **ASA** | Aircraft Surveillance Applications |
| **ATC** | Air Traffic Control |
| **ATM** | Air Traffic Management |
| **CA/CAS** | Collision Avoidance (System) |
| **CAT** | Commercial Air Transport |
| **CAZ** | Collision Airspace Zone |
| **CPA** | Closest Point of Approach |
| **DAA** | Detect and Avoid |
| **DWC** | DAA Well Clear |
| **EATMA** | European ATM Architecture |

| Acronym | Definition |
|---|---|
| **E-ATMS** | European Air Traffic Management System |
| **E-OCVM** | European Operational Concept Validation Methodology |
| **EASA** | European Aviation Safety Agency |
| **FAA** | Federal Aviation Administration |
| **FW** | Fixed Wing |
| **GA/R** | General Aviation (Fixed Wing) and Rotorcraft |
| **GNSS** | Global Navigation Satellite System |
| **HAZ** | Hazard Zone |
| **HAZ’** | No Hazard Zone |
| **HMD** | Horizontal Miss Distance |
| **IFR** | Instrument Flight Rules |
| **IMC** | Instrument Meteorological Conditions |
| **INTEROP** | Interoperability Requirements |
| **MAC** | Mid-Air Collision |
| **MOPS** | Minimum Operational Performance Standards |
| **NAS** | National Airspace System |
| **NMAC** | Near Mid-Air Collision |
| **PAZ** | Protected Airspace Zone |
| **RA** | Resolution Advisory |
| **RTCA** | American Standardisation body that produces MOPS for TCAS |
| **SBSOSED** | Operational Service and Environment Definition |
| **SA** | Situation Awareness |
| **SA+** | Enhanced Situation Awareness (TSAA+) |
| **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 |
| **StA** | State Aircraft |

| Acronym | Definition |
|---|---|
| **SUA** | Special Use Airspace |
| **SUT** | System Under Test |
| **TA** | Traffic Advisory |
| **TCAS** | Traffic Alert and Collision Avoidance System |
| **TIS** | Traffic Information Service |
| **TIS-B** | Traffic Information Services – Broadcast |
| **TS** | Technical Specification |
| **TSA** | Traffic Situational Awareness |
| **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 |

**Table 2: Acronyms and terminology**

# 3 Context of the Validation

## 3.1 SESAR Solution PJ.11-A4: a 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, i.e. encounters involving TCAS-equipped and non-TCAS-equipped aircraft, which are one of the remaining sources of mid-air collision **(MAC)** risks [40]. 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 state, 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 currently from the EATMA point of view addressed under PJ11-A4, Airborne Collision Avoidance for General Aviation and Rotorcraft – ACAS Xp, but the change request is currently in process to address changes in the solution name, OI, EN and their descriptions.

The applicable EATMA version is EATMA V13.0 Draft / DS20 Draft.

For the time being, TSAA+ reference to EATMA and SESAR CONOPS is as defined in the tables below.

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<br><br>Airborne Collision Avoidance for General Aviation and Rotorcraft (ACAS Xp) | 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<br><br>Collision Avoidance for General Aviation and Rotorcraft (ACAS Xp) | AC-54a |

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

### 3.1.1 Deviations with respect to the SESAR Solution(s) definition

Change requests are ongoing due to re-scoping the project (to focus on TSAA+ rather than ACAS Xp). Key information on the CRs in progress can be found in Table 4 and more details on Figure 2.

| CR ID | Element under change | Current value | Requested value |
|---|---|---|---|
| CR 03337 | SOL<br><br>PJ.11-A4 | Airborne Collision Avoidance for General Aviation and Rotorcraft (ACAS Xp) | Enhanced traffic situation awareness of GA/R/StA addressing interoperability with collision avoidance systems |
| CR 0338 | OI<br><br>CM-0808-p | Collision Avoidance for General Aviation and Rotorcraft (ACAS Xp) | Enhanced traffic situation awareness of GA/R/StA treating interoperability with collision avoidance systems |
| CR 0339 | EN | A/C_54a<br><br>Enhanced Airborne Collision Avoidance (ACAS) | A/C_54d<br><br>Enhanced traffic situation awareness system with Alerts (TSAA+) |

**Table 4: CRs in progress**

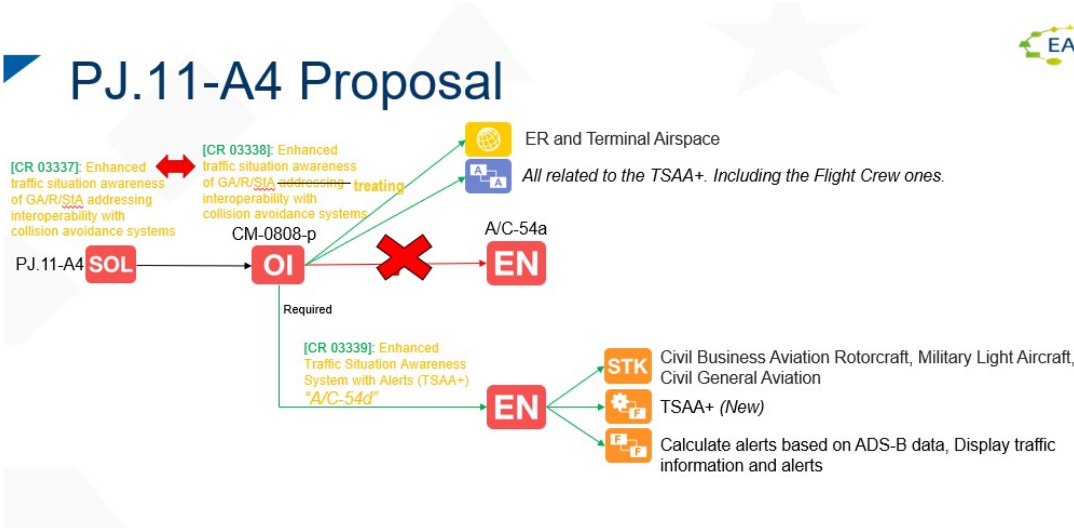



**Figure 2: On-going EATMA changes**

## 3.2 Summary of the Validation Plan

### 3.2.1 Validation Plan Purpose

This validation report consists of five exercises which aimed to elaborate and validate the operational concept and achievable benefits of TSAA+ and TSAA systems, as well as ACAS Xu interoperability and reusability aspects during mixed equipage encounters.

1. Honeywell exercise (EXE-04) was a real-time simulation using TSAA+ system prototype in a cockpit simulator, focusing on validation of human and technology integration, and pilot's acceptability using selected GA and R scenarios.
2. Thales exercise (EXE-05) was a fast-time simulation aiming to assess quantitatively the benefits of TCAS II information broadcast ("+" functionality of TSAA) on TSAA-equipped aircraft, in terms of probability of near-mid-air collision (NMAC). Four different types of potential GA pilot manoeuvres will be simulated and evaluated in terms of NMAC probability.
3. Leonardo exercise (EXE-06) was a fast-time simulation complementing EXE-03 of V1 validation, by refining evaluation of TSAA alerting performance through differentiation between GA fixed wing and helicopter scenarios, high and low airspace, and evaluation of additional state mixed-equipage encounters. The need for refined evaluation has been identified during V1 validation.
4. Honeywell exercise (EXE-07) was a fast-time simulation aiming to assess in terms of interoperability and reusability aspects, the operational acceptability of Airborne Collision Avoidance System designed for remotely piloted aircraft (ACAS Xu) for GA/R as follows:
   - Acceptability/feasibility of ACAS Xu RA instructions for GA/R pilots when installed on GA/rotorcraft platform (ownship),
   - Acceptability of ACAS Xu behaviour when installed on drone during encounters with GA aircraft.

5. Thales exercise (EXE-08) was a fast-time simulation will concern the assessment of ACAS Xu (ADS-B IN only) benefits in terms of NMAC probability in encounters where the intruder is a TCAS II equipped aircraft.

EXE-05 and EXE-08 considered European encounter model (developed primarily for the purpose of ACAS Xa – PJ.11-A1) to be available for the evaluation.

EXE-06 and EXE-07 considered real European encounter set provided by EUROCONTROL (already availbale since V1 validations) further refined.

Results of V2 validations are used as a basis to address last solution objective **"to define and consolidate initial European operational and technical recommendations for ACAS Xp development"**.

### 3.2.2 Summary of Validation Objectives and success criteria

As in the VALP, for deviations see 3.3.2

### 3.2.3 Validation Assumptions

Most of the assumptions were exercise-related assumptions and are detailed in Appendices. There was just one assumption which was considered as applicable at solution level since it might have an impact on V2 validation significance and results representativeness. Even though it is not applicable anymore, it is left here for the sake of completeness:

| Identifier | Title | Type of Assumption | Description | Justification | Flight Phase | KPA Impacted | Source | Value(s) | Owner | Impact on Assessment |
|---|---|---|---|---|---|---|---|---|---|---|
| ASS-PJ.11-A4-V2-001 | Encounter model | Traffic Characteristics | CAFÉ encounter model will be provided to PJ.11-A4 towards the end of year 2018. | EXE-05 and EXE-08 are dependent on encounter model availability. | All | Safety | EUROCONTROL | N/A | THALES | High |

**Table 5: Validation Assumptions overview**

### 3.2.4 Validation Exercises List

There is an update (correction) of VALP. The situation is also shown in the following figure.

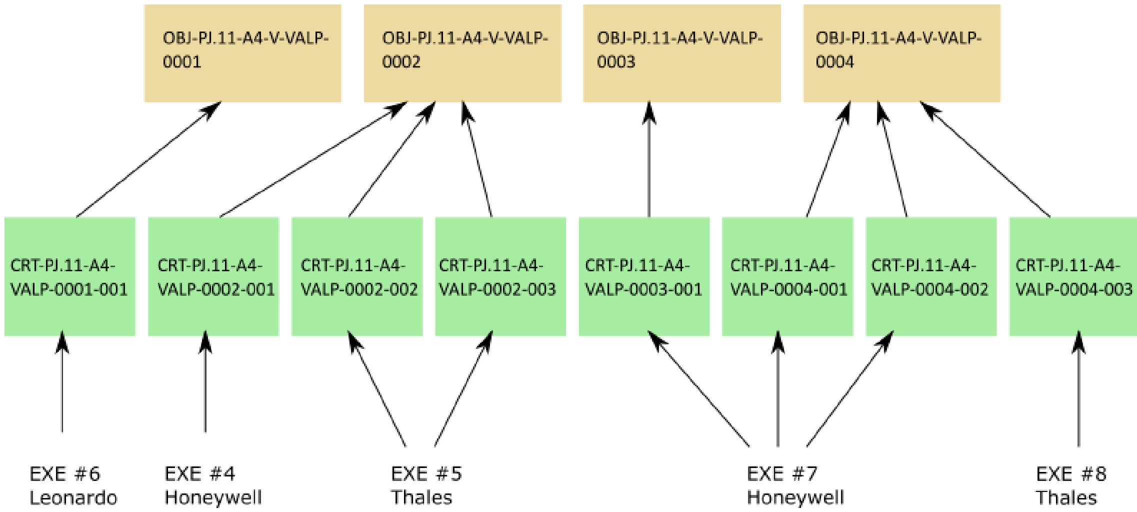



**Figure 3: Objectives, Criteria and Exercises overview**

[EXE]

| | |
|---|---|
| Identifier | EXE-PJ11.A4-V2-VALP-004 |
| Title | Real-time evaluation of TSAA+ |
| Description | Real-time human-in-the-loop cockpit simulation demonstrating safety benefits and HMI acceptability for GA and rotorcraft pilots.<br><br>A Human Performance analysis will be conducted as well as part of the activities. |
| Expected Achievements | Improved situation awareness |
| V Phase | V2 |
| Use Cases | UC1, UC2, UC3 from the V1 SPR-INTEROP/OSED |
| Validation Technique | Real Time Simulation |
| KPA/TA Addressed | <Safety>, <Human Performance> |
| Start Date | 03/12/2018 |
| End Date | 12/12/2018 |
| Validation Coordinator | Honeywell |
| Validation Platform | Honeywell part-task simulator |
| Validation Location | Brno, Czech Republic |
| Status | Completed |

| | |
|---|---|
| Dependencies | No other dependant exercises |

[EXE Trace]

| Linked Element Type | Identifier |
|---|---|
| <SESAR Solution> | PJ.11-A4 |
| <Sub-Operating Environment> | ER Very High Complexity, ER High Complexity, ER Medium Complexity, TMA Very High Complexity, TMA High Complexity, TMA Medium Complexity |
| <Validation Objective> | OBJ-PJ.11.A4-VALP-0002 |

**Table 6: Validation EXE-04 layout**

[EXE]

| | |
|---|---|
| Identifier | EXE-PJ11.A4-V2-VALP-005 |
| Title | Pilot reaction & safety assessment of TSAA+ by Thales |
| Description | Fast Time Simulation on Thales SIMPLY simulation platform |
| Expected Achievements | Dedicated evaluation of TSAA+ surveillance performance using EUROCONTROL encounters model. |
| V Phase | V2 |
| Use Cases | N/A |
| Validation Technique | Fast Time Simulation |
| KPA/TA Addressed | Safety |
| Start Date | 03/12/2018 |
| End Date | 28/02/2019 |
| Validation Coordinator | Thales |
| Validation Platform | SIMPLY |
| Validation Location | Paris, France |
| Status | Completed |
| Dependencies | No other dependant exercises |

[EXE Trace]

| Linked Element Type | Identifier |
|---|---|
| <SESAR Solution> | PJ.11-A4 |
| <Sub-Operating Environment> | ER Very High Complexity, ER High Complexity, ER Medium Complexity, TMA Very High Complexity, TMA High Complexity, TMA Medium Complexity |
| <Validation Objective> | OBJ-PJ.11.A4-VALP-0002 |

**Table 7: Validation EXE-05 layout**

[EXE]

| | |
|---|---|
| Identifier | EXE-PJ11.A4-V2-VALP-006 |
| Title | TSAA alerting capability assessment by Leonardo |
| Description | Fast-time simulation using Leonardo simulation platform with TSAA system implemented, the exercise will aim to address gaps identified in V1 execution (EXE-03), and complement incomplete V1 results for:<br>○ TSAA alerting performance assessment differentiated between GA Fixed Wing and Helicopter scenarios;<br>○ TSAA alerting performance assessment differentiated between Low Altitude (Airport and Low En-route, <10.000 feet) and High altitude (En-route, >10.000 feet);<br>○ Enhance TSAA Assessment for TCAS <-> StA encounters; |
| Expected Achievements | Improved TSAA alerting capability assessment |
| V Phase | V2 |
| Use Cases | N/A |
| Validation Technique | Fast Time Simulation |
| KPA/TA Addressed | <Safety> |
| Start Date | 01/9/2018 |
| End Date | 28/02/2019 |
| Validation Coordinator | Leonardo |
| Validation Platform | Leonardo TSAA simulator |
| Validation Location | Genova, Italy |
| Status | Completed |
| Dependencies | No other dependant exercises |

[EXE Trace]

| Linked Element Type | Identifier |
|---|---|
| <SESAR Solution> | PJ.11-A4 |
| <Sub-Operating Environment> | ER Very High Complexity, ER High Complexity, ER Medium Complexity, TMA Very High Complexity, TMA High Complexity, TMA Medium Complexity |
| <Validation Objective> | OBJ-PJ.11.A4-VALP-0001 |

**Table 8: Validation EXE-06 layout**

[EXE]

| | |
|---|---|
| Identifier | EXE-PJ11.A4-V2-VALP-007 |
| Title | Interoperability with and reusability of ACAS Xu for GA/R by Honeywell |
| Description | Operational acceptability of ACAS Xu for GA/R operations when:<br>• ACAS Xu installed on GA/R platform – assessment of acceptability/feasibility of ACAS Xu RA instructions for GA/R;<br>• ACAS Xu installed on drone during mixed equipage encounters – assessment of acceptability of drones manoeuvring against GA/R pilots. |
| Expected Achievements | ACAS Xu manoeuvres are compatible with rules of the air & drones manoeuvring is predictable and acceptable for GA/R pilots. |
| V Phase | V2 |
| Use Cases | N/A |
| Validation Technique | Fast Time Simulation |
| KPA/TA Addressed | <Safety> |
| Start Date | 01/09/2018 |
| End Date | 07/03/2019 |
| Validation Coordinator | Honeywell |
| Validation Platform | CASCARA with ACAS Xu Run4.1 model implemented |
| Validation Location | Brno, Czech Republic |
| Status | Completed |
| Dependencies | EXE-PJ11.A4-V2-VALP-004 |

[EXE Trace]

| Linked Element Type | Identifier |
|---|---|
| <SESAR Solution> | PJ.11-A4 |
| <Sub-Operating Environment> | ER Very High Complexity, ER High Complexity, ER Medium Complexity, TMA Very High Complexity, TMA High Complexity, TMA Medium Complexity |
| <Validation Objective> | OBJ-PJ.11.A4-VALP-0003, OBJ-PJ.11.A4-VALP-0004 |

**Table 9: Validation EXE-07 layout**

[EXE]

| | |
|---|---|
| Identifier | EXE-PJ.11-A4-V2-VALP-008 |
| Title | V2 validation of the ACAS Xu (ADS-B only) surveillance performance by Thales |
| Description | Fast Time Simulation on Thales SIMPLY simulation platform |
| Expected Achievements | Dedicated evaluation of ACAS Xu (ADS-B only) surveillance performance using EUROCONTROL encounters model. |
| V Phase | V2 |
| Use Cases | N/A |
| Validation Technique | <Fast Time Simulation> |
| KPA/TA Addressed | <Safety> |
| Start Date | 03/12/2018 |
| End Date | 28/02/2019 |
| Validation Coordinator | Thales |
| Validation Platform | SIMPLY |
| Validation Location | Paris, France |
| Status | Completed |
| Dependencies | N/A |

[EXE Trace]

| Linked Element Type | Identifier |
|---|---|
| <SESAR Solution> | PJ.11-A4 |
| <Sub-Operating Environment> | ER Very High Complexity, ER High Complexity, ER Medium Complexity, TMA Very High Complexity, TMA High Complexity, TMA Medium Complexity |
| <Validation Objective> | OBJ-PJ.11.A4-VALP-0004 |

**Table 10: Validation EXE-08 layout**

## 3.3 Deviations

### 3.3.1 Deviations with respect to the SJU Project Handbook

N/A

### 3.3.2 Deviations with respect to the Validation Plan

**Exercise #4:**

Reference scenarios were changed when compared with VALP scenarios definition to be able better assess the difference between pilot performance when flying without ADS-B IN application (what represent current situation) compared to situation when pilot is equipped with pure TSAA, and then TSAA+. This allowed us to better assess the benefits of "+" functionality of TSAA+. More details can be found in Section A.2.

**Exercise #5:**

Unequipped aircraft in Equipped-Unequipped encounters are considered TSAA-equipped because the encounters are from controlled airspace.

**Exercise #6:**

During the Validation Planning phase new state encounters extracted from other ANSP Radar tracks were envisioned, which did not materialise due to lack of resources from Eurocontrol.

**Exercise #7:**

- According to VALP, GA/R pilots participating on EXE-04 were supposed to be used for discussion about Xu scenarios. Since fast-time simulations were not completed at the time of EXE-04 execution, planned per-pilot discussion was changed into dedicated workshop with Honeywell internal GA pilots. This deviation, however, allowed more consistent and better focused execution of EXE-07 itself involving higher number of GA pilots.

- Second fast-time simulation (aiming to assess acceptability of ACAS Xu behaviour when installed on drone during encounters with GA aircraft) did not simulate TSAA+ equipped ownship, but the ownship was considered unequipped. This deviation had no impact on the objective. Deviation was driven by the goal not to confuse pilots with two new systems (TSAA+ & ACAS Xu) they are not familiar with, keeping the focus on ACAS Xu behaviour while flying unequipped GA aircraft.

- Data set for second fast-time simulation, as described in the VALP, envisaged altitude values of 29000 and 29200 ft what was shown inappropriate for GA operations. Data set executed during the evaluation was simulated for altitude of 3,000 ft.

**Exercise #8:**

No deviations.

# 4 SESAR Solution V2 Validation Results

## 4.1 Summary of SESAR Solution V2 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-V2-VALP-0001 | Operational benefits of TSAA in European airspace | CRT-PJ.11-A4-VALP-0001-001 | Missed Alert % and Outlying Alert % are < 5% for GA fixed wing, R, and StA encounters with TCAS equipped intruders in all EU Airport/Low En-Route and High En-Route operational environments. | Missed Alert % has been confirmed below 5% acceptability threshold, with a confidence level of 95%. Only for Rotorcraft Low Airspace and High Airspace we can conclude that Outlying Alert is below 5% acceptability Threshold. | POK |
| OBJ-PJ.11-A4-V2-VALP-0002 | Operational evaluation of SA+ during mixed equipage encounters | CRT-PJ.11-A4-VALP-0002-001 | Real-time cockpit simulation demonstrated TSAA+ safety benefits (see and avoid failures involving GA aircraft are reduced by about 3%, improvement in GA pilot induced conflict situations) and TSAA+ HMI acceptability for pilots. | The results were overall positive, and all the individual sub-criteria were met. | OK |

| | | | | | |
|---|---|---|---|---|---|
| | | CRT-PJ.11-A4-VALP-0002-002 | The probability of NMAC with TSAA+ is lower than with TSAA. | Fast time simulations show that this criterion is fulfilled. For some manoeuvres, the reduction is up to 30 %. | OK |
| | | CRT-PJ.11-A4-VALP-0002-003 | 50% reduction of the cases when GA aircraft compromises an ACAS RA on a nearby equipped aircraft intended to resolve a potential collision with it (risk of avoidance invalidated by other aircraft is currently 6%). | The majority of manoeuvres lead to 44 % reduction of RA compromising. This value is almost the target value (50 %). Higher number of analysed encounters should give a more representative result. | POK |
| OBJ-PJ.11-A4-V-VALP-0003 | ACAS Xu usability for GA/R | CRT-PJ.111A4-VALP-0003-001 | Majority of ACAS Xu RAs are considered as feasible and acceptable for GA/R/StA pilots. | The main issue was that the manoeuvre was not compliant with rules of the air. | NOK |
| OBJ-PJ.11-A4-V-VALP-0004 | GA/R interoperability with drones | CRT-PJ.111A4-VALP-0004-001 | All ACAS Xu manoeuvres are compatible with rules of the air. | Some manoeuvres are not compliant with rules of the air. | NOK |

| | | | | | |
|---|---|---|---|---|---|
| | | CRT-PJ.111A4-VALP-0004-002 | Drones' manoeuvring is predictable and acceptable for GA/R pilots. | Pilots are used to rules of the air and are negative about manoeuvres that do not comply with them. | NOK |
| | | CRT-PJ.111A4-VALP-0004-003 | The probability of NMAC with ACAS Xu (ADS-B IN only) is lower than with TSAA+ for encounters including GA. | The reduction of NMAC probability is approx. 45 %. | OK |

**Table 11: Summary of Validation Exercises Results**

## 4.2 Detailed analysis of SESAR Solution Validation Results per Validation objective

### 4.2.1 OBJ-PJ11-A4-V2-VALP-0001 Results

This V2 validation exercise has provided a significant improvement w.r.t previous one (V1) as:

a) used more specific data sets separating GA Fixed Wing from Rotorcrafts encounters and High/Low Airspace scenarios.

b) used an improved dataset, as 80 encounters previously used in V1 Validations were found faulty and have been removed and 2 encounter tracks have been corrected.

c) more realistic error models for Ownship's and Intruder's position and velocity data have been used

d) furthermore 7 degradation Runs have been performed instead of the previous 3 Runs of V1, increasing the number of overall data set and reducing confidence interval.

Missed Alert % has been confirmed to be below 5% acceptability threshold, with a confidence level of 95% in all encounter types and scenarios.

For what concerns Outlying Alerts the observations are more articulated:

- Only for Rotorcraft Low Airspace and High Airspace we can conclude that Outlying Alert is below 5% acceptability Threshold. But as we have no evidence that the collected radar data include "Heliport like" scenarios, anything can be said in relation to the problem described in DO-348[3]

- For State Aircraft Low Airspace we have observed an average Outlying Alert % of 29,5% and we can state that it is above 5% threshold with 95% confidence.
- For General Aviation Fixed Wing (GA) High/Low Airspace and State Aircraft Fixed Wing (StA) High Airspace we have observed an average Outlying Alert % of approx. 5% but in neither case we can conclude anything with respect to the 5% threshold.
- For General Aviation Fixed Wing (GA) High/Low Airspace if a threshold of 7% is considered, we can conclude that Outlying Alert % is below 7% with a confidence level of 95%.

### 4.2.2 OBJ-PJ.11-A4-V2-VALP-0002 Results

This validation objective was covered by two exercises (#4 and #5).

#### 4.2.2.1 Exercise #4

Honeywell exercise was a real-time simulation using TSAA+ system prototype in a cockpit simulator, focusing on validation of human and technology integration, and pilot's acceptability using selected GA and rotorcraft scenarios. Both safety and human performance aspects has been addressed by this validation exercise.

Major issues to be addressed were covering the see and avoid paradigm regarding the situational awareness, support of GA pilot´s decision making process in mixed encounter environment, understanding proposed HMI design and it´s benefits during real-time simulation.

Three types of scenarios have been used based on the ownship equipment:

1. Ownship not equipped with any transponder (Baseline), meaning that TCAS II intruder does not identify threat (ownship), and therefore does not generate RA against the ownship. GA/rotorcraft ownship applied see-and-avoid only.

2. Ownship equipped with ADS-B IN/OUT capability and TSAA technology. TCASII equipped intruder identifies threat (ownship) and generates RA. Ownship had TSAA application with TSAA functionality – mainly alerting when threat is identified, but ownship had no information about the RA that was generated by intruder.

[3] Cfr. the "Wall Street Heliport", see DO-348 sect. B.4.5.1, which showed that TSAA performance for helicopters in the heliport environment (high density and low speed) does not perform as well as TSAA for the general flying population of aircraft.

3. Ownship equipped with ADS-B IN/OUT capability and TSAA+ technology. TCASII equipped intruder identifies threat (ownship) and generates RA. Compared with only TSAA technology, ownship had information about the RA that was generated by intruder.

All scenarios were initiated approximately 2 minutes before the potential collision. Pilot should have manoeuvred after identifying the intruder. There were six solution scenarios in each type (Baseline, TSAA, TSAA+ technology) defined applicable for both GA and rotorcraft. With one exception – scenario 3 was not performed within type Baseline because spotting the intruder flying from behind is almost impossible without avoidance technology.

Compared with baseline, see and avoid failures were decreased by 20 % with TSAA+ technology and by 32 % with only TSAA technology. This is probably caused by the pilot's unfamiliarity with TSAA+.

Pilots have considered the position of RA message acceptable. But RA message was not easily detected on the display and the colour of RA message was unaccepted.

The TSAA+ information about RA has been taken by majority of subjects as an additional information to TSAA, that can either confirm decision of a pilot or improve already performed manoeuver.

Within exercise #4, pilots expressed concern that RA issued against other aircraft could have been understood as a command to the ownship.

Pilots objected confusion between TSAA and TSAA+ displayed data that seemed to be contradictory. TSAA shows current vertical trend of aircraft (↑↓) and TSAA+ displays issued RA (i.e. CLIMB).

#### 4.2.2.2 Exercise #5

This exercise for V2 maturity level was performed as FTS (Fast Time Simulation) on Thales simulation platform SIMPLY using TCAS II model according to [39].

Data received from EUROCONTROL (10^6 encounters) was generated by CAFÉ encounter model and were filtered to eliminate equipped-equipped or unequipped-unequipped encounters. Such filter eliminated 68% of the encounters, leaving a sample of 320000.

Encounter data from CAFÉ was sampled every second and interpolation has been done using MATLAB software to get data every 100 milliseconds.

CAFÉ Encounters included one unequipped aircraft (ownship) and one TCASII equipped aircraft (intruder).

Two scenarios have been used to analyse TSAA+ performances versus TSAA:

1. TCASII vs TSAA,
2. TCASII vs TSAA+.

In the first scenario original trajectories from EUROCONTROL have been used with the assumption that aircraft were equipped respectively with TCASII and TSAA (cf. B.2).

The ownship aircraft in scenario 1 is supposed to react to intruder as a TSAA equipped aircraft and its original trajectory has not been modified unlike in V1 exercise where the ownship trajectory has been modifies according preliminary pilot reaction model that has been discarded for V2 exercise.

In the second scenario four manoeuvres have been defined for the ownship aircraft [40] in order to implement TSAA+ function:

- **Level Off**: The logic on the GA aircraft issues a level-off advisory that requires the pilot to manoeuvre to maintain a vertical speed equal to 0 ft/min.
- **Do Not Descend/Do Not Climb**: The logic of the GA aircraft issues an advisory to maintain a vertical speed that complies with the sense of intruder RA. If the sense is **Upward**, then vertical speed less or equal to 0 ft/min complies with the advisory. Thus, if the GA aircraft is climbing the pilot must level off. If the GA aircraft is already descending, then the pilot must maintain current vertical speed.
- **Descend/Climb:** The logic of the GA aircraft issues an advisory to maintain a vertical speed of 500 ft/min in the direction that complies with the sense of RA. If the sense is Upward, then descent rate equal to 500 ft/min complies with the advisory. We assume the aircraft is always able to achieve 500 ft/min.
- **Maintain Vertical Speed**: The pilot maintains the current vertical speed of the aircraft.

Reaction delays used for TSAA+ have been 3 s and 5 s.

Reaction delay for TCASII has been 5 s.

**OBJ-PJ.11.A4-VALP-0001**

According to the TCAS MOPS [39], Near Mid Air Collision (NMAC) occurs when two aircraft come within 100ft vertically (VMD) and 500ft horizontally (HMD). The number of encounters used in simulations is too low for high level confident results.

Based on observations of European radar data, EUROCONTROL found that when HMD < 3000ft and VMD < 400ft there is a uniform distribution of observed encounters so NMAC conditions were extended to 400ft vertically (the maximum HMD is already less than 3000ft for all encounters) in order to have representative value of NMAC.

Results for TCAS II vs TSAA scenario are based on the assumption in B.2.

The computed PNMAC in TSAA scenarios is the reference for TSAA+ scenarios. The value is 0.83%.

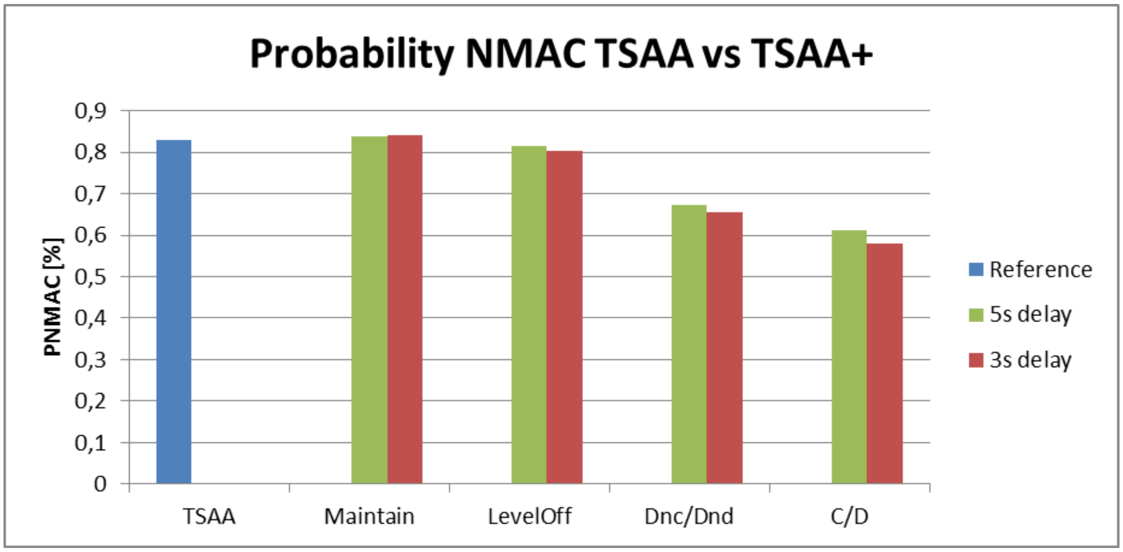



**Figure 4-1: Probability NMAC TSAA vs TSAA+**

In the figure on the top the best manoeuver among the four ones described in B.1.1 in order to reduce PNMAC is Climb/Descent. The reduction is 30%. Differences between 5s and 3s pilot reaction delays are negligible.

## OBJ-PJ.11.A4-VALP-0002

RA compromising occurs when a manoeuvre (instigated by ATC or Pilot) leads to a new conflict situation (with a different aircraft) that would not have occurred without the manoeuvre. In this case TSAA/TSAA+ manoeuver could compromise intruder RA, generating an increase/decrease rate RA or reversal RA.

Results for TCAS II vs TSAA scenario are based on the assumption in B.2.

The computed ratio in TSAA scenarios is the reference for TSAA+ scenarios. The value is 0.44%.

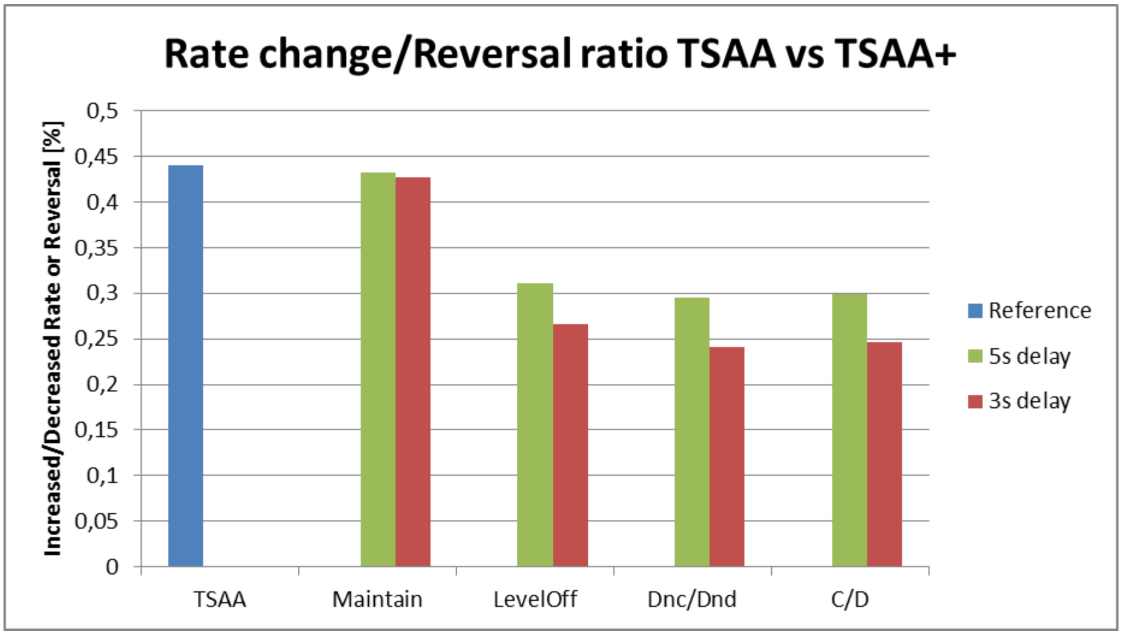



**Figure 4-2: Rate change/Reversal ratio TSAA vs TSAA+**

According to RA compromising definition (cf. B.3.21), **Climb/Descend** and **DoNotClimb/DoNotDescend** manoeuver (cf. manoeuver 2 in B.1.1) are the safest with 44% of reduction compared to TSAA. Differences between 5s and 3s pilot reaction delays are negligible.

This result doesn't satisfy **EX5-CRT-PJ.11-A4-V2-VALP-002** successful criterion but it is important to keep in mind that the low number of analyzed encounters (370000) could decrease the real value and so larger number (e.g. several millions) should give a more representative result.

### 4.2.3 OBJ-PJ.11-A4-V2-VALP-0003 Results

This validation objective was covered by exercise #7, Honeywell ACAS Xu workshop.

GA pilots understand the meaning of ACAS Xu RAs. However, there were cases when the manoeuver proposed by ACAS Xu has been in contradiction to what would GA pilot do in this situation without advisory. In some cases, the ACAS Xu RAs have not been provided sufficiently in advance to GA pilot to be able to decide the manoeuver.

Pilots considered RAs as acceptable in situation when the same RA is assumed as meaningful. Whenever the proposed manoeuver has been considered obsolete (too late or too soon), the GA pilot tended to lose confidence to ACAS Xu logic.

In 5 of 9 scenarios, majority of pilots expressed negative attitude to the statement that the behaviour (RAs) of ACAS Xu is trustworthy / acceptable.

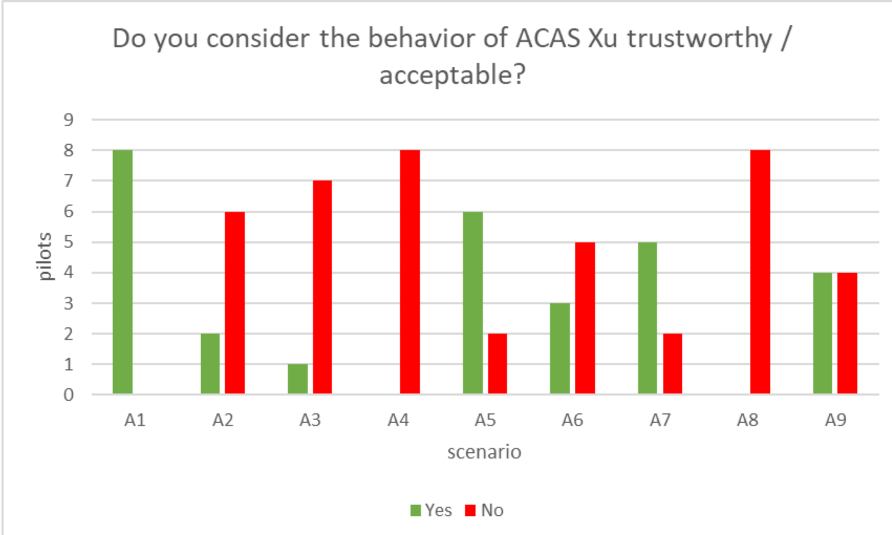



**Figure 4-3: ACAS Xu acceptability throughout scenarios**

ACAS Xu RAs has been rated as partially feasible from GA pilot point of view and with regards to the aircraft performance. Partial ambiguity among the confidence to ACAS Xu logic has been risen because of the quick changing of RAs. This changing has been caused by the design of simulations where the ACAS Xu equipped aircraft did not manoeuver and was flying on defined track.

### 4.2.4 OBJ-PJ.11-A4-V2-VALP-0004 Results

This validation objective was covered by two exercises (#7 and #8).

#### 4.2.4.1 Exercise #7

This exercise was in form of workshop with GA pilots. There were two types of scenarios:

1. GA pilot following RA produced by ACAS Xu technology. (Type A)
2. GA pilot reacting to UAV intruder equipped with ACAS Xu technology. (Type B)

In 67% of scenarios, pilots have expressed negative attitude to the statement that the manoeuver is compliant with GA flying rules.

From 8 proposed scenarios where UAV has been equipped with ACAS Xu and GA pilot has been evaluating, if the manoeuver is understandable, we have found 2 cases where all pilots or majority of pilots did understand the RA. In the rest of the scenarios the understanding to UAV manoeuver was low.

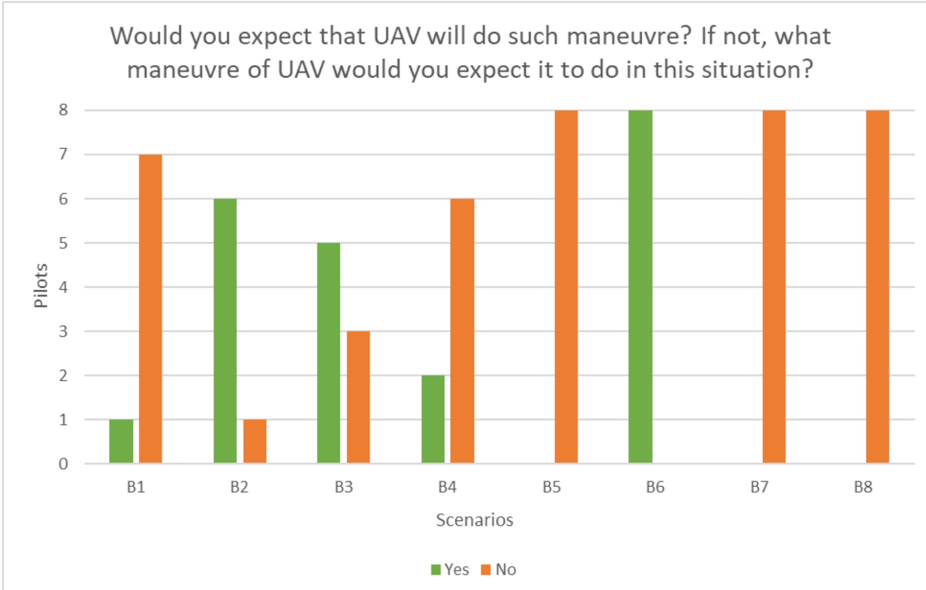



**Figure 4-4: The predictability of drones manoeuvring.**

In 6 out of 8 scenarios with UAV, pilot expressed negative attitude to the statement that drones manoeuvring was acceptable.

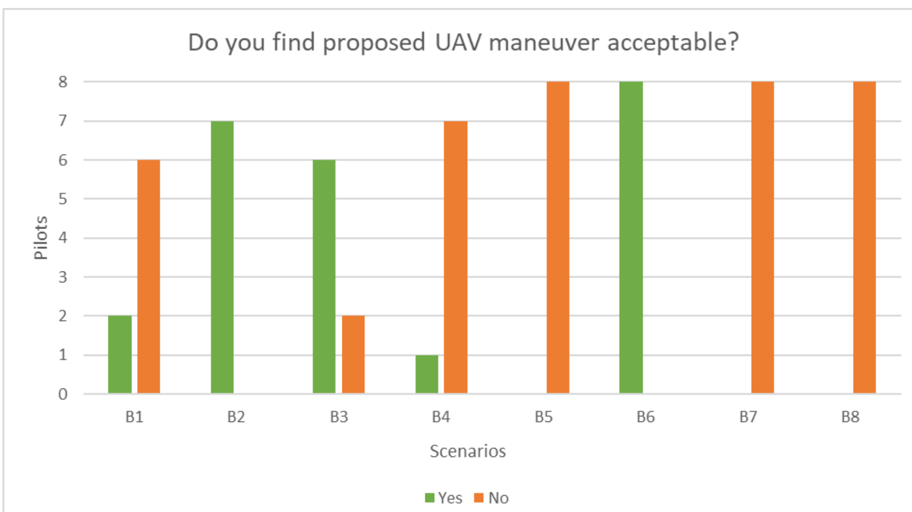



**Figure 4-5: The acceptability of drones manoeuvring.**

### 4.2.4.2 Exercise #8

Two scenarios have been used to analysis ACAS Xu performances:

1. TCAS II versus TSAA,
2. TCAS II versus ACAS Xu ADS-B in Only,

In the first scenario original trajectories from EUROCONTROL have been used with the assumption that aircraft were equipped respectively with TCASII and TSAA (cf. B.2).

The ownship aircraft in scenario 1 is supposed to react to intruder as a TSAA equipped aircraft and its original trajectory has not been modified unlike in V1 exercise where the ownship trajectory has been modifies according preliminary pilot reaction model that has been discarded for V2 exercise.

The ownship aircraft in scenario 2 is equipped with ACAS Xu (ADS-B in Only) and avoidance manoeuvres could be on horizontal or vertical plane.

Reaction delays used for ACAS Xu have been 3 s and 5 s.

Reaction delay for TCASII has been 5 s.

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

According to the TCAS MOPS [39], Near Mid Air Collision (NMAC) occurs when two aircraft come within 100ft vertically (VMD) and 500ft horizontally (HMD). The number of encounters used in simulations is too low for high level confident results.

Based on observations of European radar data, EUROCONTROL found that when HMD < 3000ft and VMD < 400ft there is a uniform distribution of observed encounters so NMAC conditions were extended to 400ft vertically (the maximum HMD is already less than 3000ft for all encounters) in order to have representative value of NMAC.

Results for TCAS II vs TSAA scenario are based on the assumption in B.2.

The computed PNMAC in TSAA scenarios is the reference for ACAS Xu scenarios. The value is 0.83%.

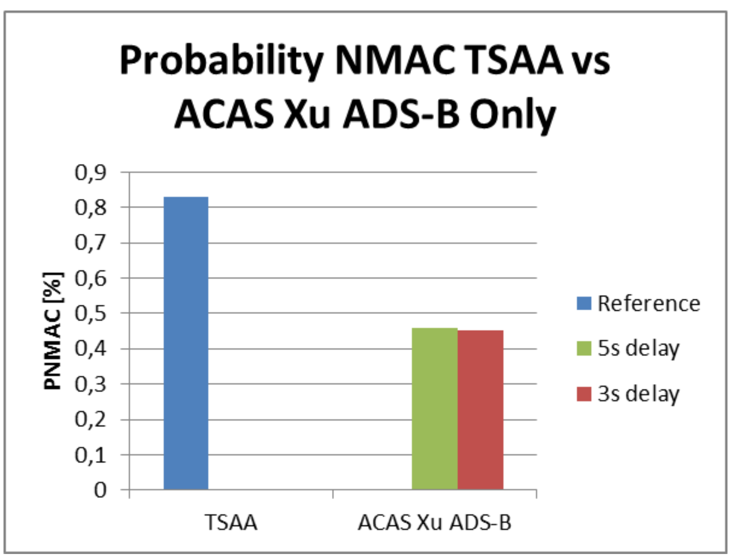



**Figure 4-6: Probability of NMAC with TSAA and ACAS Xu ADS-B Only**

In the figure on the top the reduction of NMAC probability is 45%. Differences between 5s and 3s pilot reaction delays are negligible.

## 4.3 Confidence in Validation Results

### 4.3.1 Limitations of Validation Results

Size and composition of the encounters set and the limited number of pilots in the operational workshop are the main limitations of the presented results. Methodology was adapted to this limitation through reduced use of statistical metrics.

Beyond this some of the more specific limitations are:

- Division of encounters into operational environments and airspace classes (A, C, F and G) was not available.
- ACAS Xu of versions 4.1/4.2 are early development versions, not fully optimized for operational evaluations
- Only two aircraft encounters were considered
- Scenarios presented to workshop participants were not dynamic
- Equipped aircraft from CAFÉ model are supposed to have a TCAS II equipped aircraft behaviour but sometimes this behaviour doesn't comply with TCAS II MOPS

#### 4.3.1.1 Quality of Validation Results

**TSAA+**

The limited size of encounters set has impact on the confidence of the results considering corner cases, missed and outlying alerting (although significant improvements have been reached since the V1 phase). Future work in this area would be recommended.

**ACAS Xu**

New versions of ACAS Xu were released during the work on V2 deliverables. The validation was using versions 4.1 and 4.2., while the results may differ for the new version 5.0. Here are the relevant changes between successive versions of ACAS Xu.

- changes between 4.1 and 4.2:
  - **blended maneuvers**,
  - active Interactive Multi Modal (IMM) tracker,
  - vertical band calculation updated to improve alignment with SC-228 objectives,
- changes between 4.2 and 5.0:

- **vertical action space extended by maintain action to deal with high vertical rate situations (vertical_rate > 1000fpm),**
- horizontal coordination changes to reduce slave reversals due to surveillance noise,
- DAA alerting tuning,
- blended sensitivity tuning, and
- STM updates introducing uncertainty check for rejection of Air-to-Air Radar (ATAR) tracks: If uncertainty of any track dimension exceeds Xu ATAR requirement by selected factor, the input is rejected.

More details on the versions could be found in [43].

The verification/refinement of the observed trends for new version of ACAS Xu will need to be addressed.

#### 4.3.1.2 Significance of Validation Results

As stated above the applied methodology was adapted to the known limitations of the validation exercises. In this context, the qualitative results of TSAA+ operational evaluation and pilots' workshop should be considered as significant, knowing that larger set of encounters scenarios or number of pilots could of course allow to improve these results and get more representative statistical measures.

As for the comparison of ACAS Xu and TSAA in terms of NMAC, these results are affected by the fact that ACAS Xu is still under intensive development and there are ongoing changes directly affecting results of any operational evaluations. For instance, while version 4.2 provides blended manoeuvres, version 4.1 only offers pure vertical and horizontal manoeuvring, etc. It means that these results/evaluation needs to be revisited using the recently published version 5 and follow up releases.

# 5 Conclusions and recommendations

## 5.1 Conclusions

This document provides validation results relevant for V2 maturity phase for TSAA+ (enhanced Traffic Situational Awareness system with Alerts). The SESAR solution is from the EATMA point of view addressed under PJ11-A4, Airborne Collision Avoidance for General Aviation and Rotorcraft – ACAS Xp, but on the V1 gate it was agreed that the solution should be modified into “Enhanced traffic situation awareness of GA/R/StA addressing interoperability with collision avoidance systems”.

This document also provides initial validation results regarding usability and interoperability of ACAS Xu, which is a variant of ACAS X tailored for Remotely Piloted Aircraft Systems, for General Aviation.

### 5.1.1 Conclusions on SESAR Solution maturity

The presented results of the SESAR Solution supports exit of V2 maturity level and transition to V3 phase. All the activities planned in VALP were performed with minor deviations. They consist of one real-time and four fast-time simulations performed independently by three consortium partners. While three exercises focus on (enhanced) Traffic Situation Awareness with Alerts (TSAA/TSAA+), two additional exercises address interoperability with and operational feasibility of ACAS Xu during mixed equipage encounters.

The success criteria on TSAA and TSAA+ were all assessed as either OK or POK. There were only two cases leading to only partial success of the criteria and none of them was critical. The first case is 44 % of reduction of compromising RA (EXE #5) instead of 50 %. The second case is that the reduction of Outlying alerts was not as expected, but only for some types of aircraft. The criterion related to reduction of Missed alerts was met without exceptions.

Some criteria related to ACAS Xu were not met due to the fact that pilots expected compliance with the rules of the air. However, the solution under maturity assessment in this project is TSAA+, and the maturity of ACAS Xu has no impact on it.

### 5.1.2 Conclusions on concept clarification on TSAA+

**Operational concept**

TSAA+ operational concept addressing information on RA is still not fully “frozen”, expert opinions differ in whether:

- All active RAs are to be displayed to GA pilot, even though they are not issued against TSAA+ a/c
- Only RA issued against TSAA+ a/c should be displayed
- For some pilots, only information that intruder is TCAS equipped is sufficient

Workload

The workload of pilots using TSAA+ has increased but remained well within acceptable margins.

Awareness

The awareness of the crew has increased and allowed satisfactory separation.

HMI

The presentation of TSAA+ data requires minor HMI adjustments (colour, symbology, zoom).

### 5.1.3 Conclusions on ACAS Xu usability and interoperability

Results indicate that using ACAS Xu onboard of a manned aircraft is at the current stage (version 4.1 or 4.2) not acceptable as the system frequently generates manoeuvres that are not in line with existing rules of the air.

For the same reason, current version of ACAS Xu on board of an unmanned aircraft does not seem to be interoperable with general aviation.

It should be stated that versions 4.x of ACAS Xu are still development releases not fully mature for operational evaluations. In this context, it is important to verify the above conclusions with actual version 5 and potentially focus on future development that would result in producing manoeuvres compatible with rules of the air.

### 5.1.4 Conclusions on technical feasibility

Technical feasibility was not assessed at this stage.

For the future phase (V3), no feasibility issues are envisioned. The provision of RA manoeuvre to the crew using TSAA+ is technically feasible, as the information is part of ADS-B message that is broadcasted by the ACAS equipped aircraft. Different decoding must be performed for TCAS II and ACAS X systems. Aural annunciations and display information are technically feasible as well as a software update of the TSAA system.

### 5.1.5 Conclusions on performance assessments

The following Validation Targets have been given to PJ.11-A4 Solution:

| KPA/Sub-Operating Environment | ER Very High Complexity | ER High Complexity | ER Medium Complexity | TMA Very High Complexity | TMA High Complexity | TMA Medium complexity |
|---|---|---|---|---|---|---|
| SAF | -5% | -5% | -5% | -85,37% | -85,37% | -85,47% |

Table 12: Safety Validation Targets apportioned to the SESAR Solution PJ.11-A4 per sub-OE

These targets are based on [22], expressed as reduction in the “total number of fatal accidents per year” due to SESAR 2020 improvements with respect to a hypothetical “do nothing” scenario, in which no changes are made to ATM safety of the Baseline (2005) while traffic is allowed to increase until it reaches the estimated capacity level per Sub-OE in 2035.

Based on these validation targets, validation objectives with success criteria were developed in VALP. This VALR summarizes the validation objectives as follows:

- Missed alerts percentage was below 5 % for TSAA.
- Outlying alerts percentage was below 5 % for TSAA for all the cases with sufficiently large dataset, except for State Aircraft.
- The NMAC probability of TSAA+ is lower that NMAC probability of TSAA. The reduction is up to 30 % in the case of vertical manoeuvres.
- The risk of avoidance invalidated by other aircraft has decreased by 44 % with TSAA+ (compared to TSAA).

## 5.2 Recommendations

### 5.2.1 Recommendations for next phase

#### 5.2.1.1 TSAA+

It is recommended to focus on HMI improvement. Specifically, symbol for RA shown on display must be guaranteed not to be confusing.

Regarding concept clarification, more human performance experiments would be useful to identify which pieces of information (existence of anti-collision system; RA to ownship only; any RA) should be presented to the crew of TSAA+ equipped aircraft.

It would be beneficial to perform further tests of TSAA outlying alerts with more representative data.

#### 5.2.1.2 ACAS Xu

Compatibility with rules of the air (right of way) is a key factor that should be incorporated. Alternatively, a concept of operations must be further refined with focus on interoperability between piloted aircraft and unmanned system with ACAS Xu on-board.

### 5.2.2 Recommendations for updating ATM Master Plan Level 2

No recommendations. The project will not continue in the next phase.

### 5.2.3 Recommendations on regulation and standardisation initiatives

No recommendations.

# 6 References

## 6.1 Applicable Documents

### Content Integration


[1] PJ.19 D5.7 EATMA Guidance Material and Report (2018) V11

[2] EATMA Community pages

[3] SESAR ATM Lexicon


### Content Development


[4] PJ.19 D2.1 Concept of Operations Edition 2017


### System and Service Development


[5] 08.01.01 D52: SWIM Foundation v2

[6] 08.01.01 D49: SWIM Compliance Criteria

[7] 08.01.03 D47: AIRM v4.1.0

[8] 08.03.10 D45: ISRM Foundation v00.08.00

[9] B.04.03 D102 SESAR Working Method on Services

[10] B.04.03 D128 ADD SESAR1

[11] B.04.05 Common Service Foundation Method


### Performance Management


[12] PJ.19 D4.4Performance Framework (2018)

[13] PJ.19 D2.4 Validation Strategy (2018)

[14] B.05 D86 Guidance on KPIs and Data Collection support to SESAR 2020 transition.

[15] 16.06.06-D68 Part 1 –SESAR Cost Benefit Analysis – Integrated Model

[16] 16.06.06-D51-SESAR_1 Business Case Consolidated_Deliverable-00.01.00 and CBA

[17] Method to assess cost of European ATM improvements and technologies, EUROCONTROL (2014)

[18] ATM Cost Breakdown Structure_ed02_2014

[19] Standard Inputs for EUROCONTROL Cost Benefit Analyses

[20] 16.06.06_D26-08 ATM CBA Quality Checklist

[21] 16.06.06_D26_04_Guidelines_for_Producing_Benefit_and_Impact_Mechanisms

[22] D4.8 PJ19: Validation Targets (2019)

### Validation

[23] 03.00 D16 WP3 Engineering methodology

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

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

### System Engineering

[26] SESAR Requirements and V&V guidelines

### Safety

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

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

[29] SESAR, Final Guidance Material to Execute Proof of Concept, Ed00.04.00, August 2015

[30] SESAR, Resilience Engineering Guidance, May 2016

### Human Performance

[31] 16.06.05 D 27 HP Reference Material D27

[32] 16.04.02 D04 e-HP Repository - Release note

### Environment Assessment

[33] SESAR, Environment Reference Material, alias, “Environmental impact assessment as part of the global SESAR validation”, Project 16.06.03, Deliverable D26, 2014.

[34] ICAO CAEP – “Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes” document, Doc 10031.

### Security

[35] 16.06.02 D103 SESAR Security Ref Material Level

[36] 16.06.02 D137 Minimum Set of Security Controls (MSSCs).

[37] 16.06.02 D131 Security Database Application (CTRL_S)

## 6.2 Reference Documents

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

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

[40] ATC-374, "Coordinating General Aviation Manoeuvres with TCAS Resolution Advisories", MIT, 07/02/2011

[41] ACAS Xu Algorithm Definition Description V4.1

[42] SESAR2020 V1 SA+ VALR (PJ.11-A4), D6.1.060, February 2018

[43] SESAR Solution PJ.11-A2 Initial Technical Specifications (TS/IRS) for V2, D4.2.050Initial, August 2018

[44] Development of a High-Precision ADS-B based Conflict Alerting System for Operations in the Airport Environment, Fabrice Kunzi (MIT), 2013

[45] Lincoln Laboratory, ATC-152, "Unalerted Air-to-Air Visual Acquisition", 1991-11-26

# Appendix A Validation Exercise #04 Report

## A.1 Summary of the Validation Exercise #04 Plan

As in the VALP project PJ.11-A4 (D6.2.010).

### A.1.1 Validation Exercise description, scope

Operational scope of the exercise: This exercise involves the only actor relevant for the solution: Flight Crew covering Use Cases as defined in V1 OSED (D6.2.050).

The key validation objective of this exercise is to "*Evaluate operational and safety benefits of SA+ during mixed equipage encounters and achieve V2 maturity level for this capability*" which is then broken into several exercise objectives listed in next section. Although the division of an objective into several sub-objectives is not a standard approach in SESAR, it was stated in VALP and is kept for the sake of clarity.

Exercise objective were assessed by running six TMA/Airport environment encounters in three types of scenarios:

1. Baseline scenario – ownship being not equipped with TSAA+ system (ownship can but does not have to be equipped with Mode C/Mode S transponder);
2. Reference scenario – ownship being equipped with TSAA application (without "+" functionality);
3. Solution scenario – ownship being equipped with TSAA+ application.

The scenarios included one or two intruders equipped with TCAS II. Ownship scenarios are designed to fit both GA and helicopter operations supported by simulator allowing to simulate both GA and helicopter performance. During the scenarios, ownship flew with autopilot mode turned on up to the time when pilot decided to manoeuvre to avoid collision. TSAA+ application run on a mobile device (a cell phone or a tablet, depending on pilots' preference).

To validate the exercise objectives, the following data collection methods were applied:

- Qualitative collection methods which were based on:
    - Over the shoulder observations performed by operational and human factor experts during each run. The aim was to take note of the behaviour of the pilot pilots during encounter situations, to get the idea of their situation awareness as well as their appraisal of the relevance of the TSAA+ system and information available when using it. The observations were also an opportunity to identify unexpected pilots' behaviour during simulations. The key points observed were used in support to the discussions during the debriefing sessions.
    - Questionnaires on the validation objective / success criteria.
    - Debriefing sessions held at the end of simulation. The pilots had the opportunity to discuss any issues / particular situations they experienced during the run. The observations and questionnaire answers were used to further discuss the pilots' HMI acceptability, and feedback on TSAA+ system in general.
- Quantitative collection methods which consisted mainly of system data logs.

Tools and equipment required for validation exercise were as depicted at the figure below. Simulations were performed in Honeywell part-task lab which consists of curved projection screen with 240° view and 7m x 1.5m in dimension that is lit by four short throw projectors with resolution of 1280 x 800 each, and a flight simulator. Input data with scenarios descriptions were provided both to V&V platform and to TSAA+ SW porototype for synchronization purposes. Real-time trajectories were provided to TSAA+ prototype to provide its intended function. Surveillance data including TSAA+ alerts were provided to tablet (experimental mock-up) display via wifi.

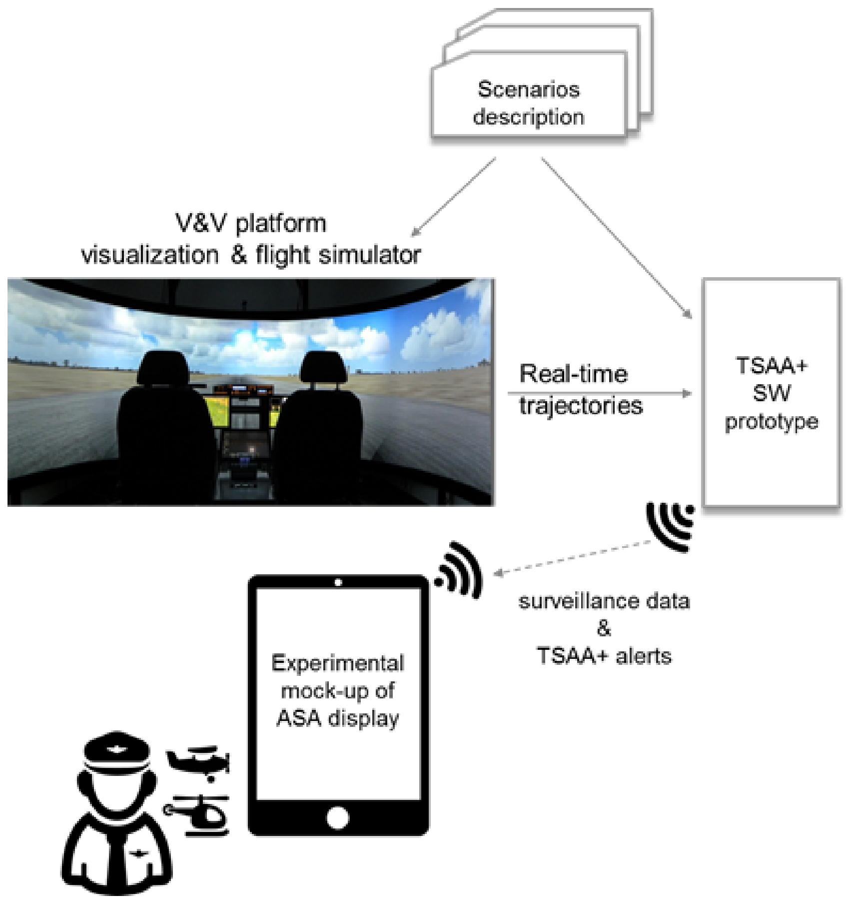



**Figure 7: Exercise #4 simulation overview**

## A.1.2 Summary of Validation Exercise #04 Validation Objectives and success criteria

| | |
|---|---|
| Identifier | EX4-0BJ-PJ.11-A4-V2-VALP-001 |
| Objective | Assess pilot performance on the tasks when he has the option to consult the system display for the traffic information as opposed to looking OTW. |
| Title | Task allocation changes. |

| | |
|---|---|
| Category | <HP> |
| EX4-CRT-PJ.11-A4-V2-VALP-001 | Using TSAA+ (as opposed to no TSAA) did not lead to the degradation of pilot performance. |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-002 |
| Objective | Assess pilot's workload coming from the need to intermittently check TSAA+ information. |
| Title | Pilot workload |
| Category | <HP> |
| EX4-CRT-PJ.11-A4-V2-VALP-002 | The potential changes to the level of workload/task demands and/or cognitive demands and the mitigation identified are acceptable. |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-003 |
| Objective | Assess if pilot's information needs regarding the surrounding traffic are met with TSAA+. |
| Title | Pilot information requirements |
| Category | <HP> |
| EX4-CRT-PJ.11-A4-V2-VALP-003 | There is no discrepancy between system-provided information and user-required information. |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-004 |
| Objective | Assess whether the pilot understands each system state (symbols, alerting information and their combinations). |
| Title | User interface usability |
| Category | <HP> |
| EX4-CRT-PJ.11-A4-V2-VALP-004 | End user experiences integrated interface including any new system components as sufficiently usable. |
| EX4-CRT-PJ.11-A4-V2-VALP-005 | Pilot can clearly interpret all the system states (based on the symbols and the information provided by TSAA and TSAA+). |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-005 |

| | |
|---|---|
| Objective | Assess the potential for errors occurring. |
| Title | User interface design vs. human errors |
| Category | <HP> |
| EX4-CRT-PJ.11-A4-V2-VALP-006 | The number or severity of errors in the solution scenarios are not greater than in the reference scenario. |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-006 |
| Objective | Assess pilot's SA. |
| Title | Level of situation awareness |
| Category | <HP> |
| EX4-CRT-PJ.11-A4-V2-VALP-007 | End user is able to perceive and interpret task relevant information and anticipate future events/actions. |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-007 |
| Objective | Assess the acceptability of SA with TSAA+. |
| Title | Acceptability of SA with TSAA+ |
| Category | <HP> |
| EX4-CRT-PJ.11-A4-V2-VALP-008 | Level of individual situation awareness within acceptable limits (‘acceptable limits’ to be defined with regard to the tool used for the assessment). |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-008 |
| Objective | Assess whether pilots find the application and associated operations acceptable. |
| Title | Roles and responsibilities |
| Category | <HP> |
| EX4-CRT-PJ.11-A4-V2-VALP-009 | End users do not predict negative impact with regard to changes in roles and responsibilities or means for mitigating negative impacts are identified. |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-009 |

| | |
|---|---|
| Objective | Assess whether training for pilots will be needed. Objectives need to be generated on the basis of arguments specified for the Solution under investigation (i.e. considering the proposed change and the benefits & issues identified). |
| Title | Knowledge, skill and experience |
| Category | <HP> |
| EX4-CRT-PJ.11-A4-V2-VALP-010 | Where possible, initial knowledge, skill and experience requirements are identified. |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-010 |
| Objective | Demonstrate that see and avoid failures involving GA aircraft were reduced by about 3% (which is about half of the IFR/GA *6%* cases where see and avoid currently fails) |
| Title | Improved see and avoid failures |
| Category | <safety> |
| EX4-CRT-PJ.11-A4-V2-VALP-011 | See and avoid failures involving GA aircraft were reduced by about 3% |

| | |
|---|---|
| Identifier | EX4-OBJ-PJ.11-A4-V2-VALP-011 |
| Objective | Demonstrate that GA pilot induced conflict situation identified during scenarios (if any) shows improvement when using TSAA+ system. |
| Title | GA pilot induced conflict situations |
| Category | <safety> |
| EX4-CRT-PJ.11-A4-V2-VALP-012 | GA pilot induced conflict situation identified during scenarios (if any) shows improvement when using TSAA+ system. |

### A.1.3 Summary of Validation Exercise #04 Validation scenarios

Two types of **reference scenarios**, mirroring the solution scenarios, were used to assess the difference in safety benefits:

1. **Ownship not equipped with TSAA (nor TSAA+).** TCAS II equipped intruder will fly planned trajectory, GA/rotorcraft ownship will apply see-and-avoid only.

2. **Ownship equipped with TSAA** but **not equipped with TSAA+.** This scenario will give ownship pilot ability to identify intruder using TSAA application and potentially generate TSAA (visual) alert, but without information about RA on board of the intruder.

**Solution scenario** represents **ownship being equipped with transponder with ADS-B IN & OUT capability and TSAA+ application.** TCAS II intruder/s will be able to identify threat (ownship) and generate RA against it, and ownship will be aware of the surrounding traffic situation thanks to TSAA+ application on tablet/mobile, which will even provide ownship pilot with information about RA issued on board of TCAS II equipped intruders.

All validation scenarios are applicable to both High and Low Utilisation airports with both simple and complex layouts as sub-operating environments.

To allow ownship aircraft to fly precise trajectory as defined below, ownship had an autopilot mode turned on from the simulation initialization up to the time when the pilot decided to manoeuvre. All scenarios were initiated approximately 2 minutes before the potential collision.

There were six solution scenarios defined applicable for both GA and R.

**Scenario no.1:**

Head-on encounter of two aircraft. GA/rotorcraft ownship flies at FL=70, at speed 120 kts. TCAS II-equipped intruder is flying at the same FL (FL=70), speed 250 kts.

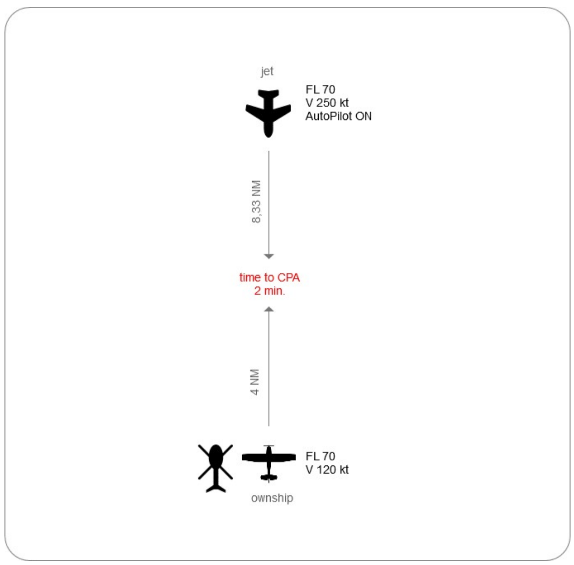



**Figure 6-8: Scenario no.1**

**Scenario no.2:**

Encounter involving three aircraft converging on each other with an angle of 90 degrees between their tracks. GA/rotorcraft ownship flies at FL=80, speed 120 kts. One TCAS II-equipped intruder is flying at FL=90, speed 250 kts, the second TCAS II-equipped intruder is flying at FL=80, speed 250 kts.

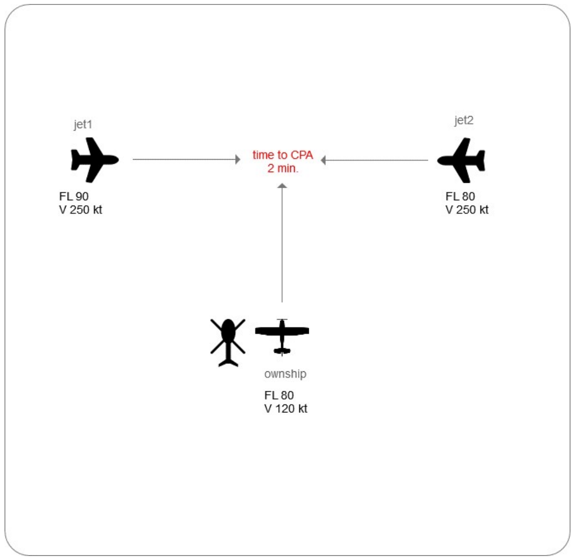



**Figure 6-9: Scenario no.2**

**Scenario no.3:**

Overtaking encounter involving two aircraft in the same flight phase. GA/rotorcraft ownship flies at FL=70, speed 120 kts. TCAS II-equipped intruder is flying behind ownship at the same FL (FL=70), speed 250 kts.

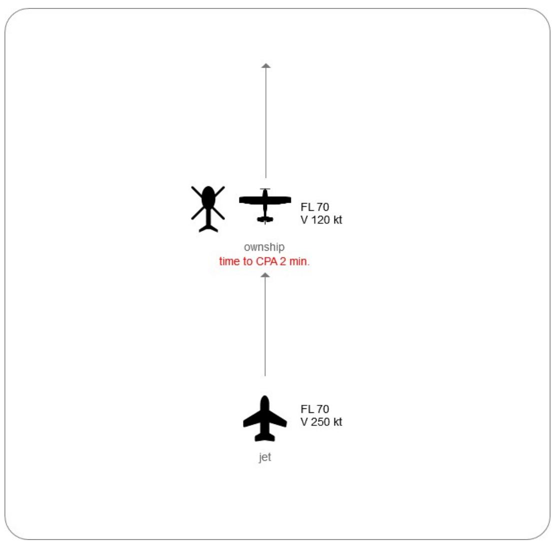



**Figure 6-10: Scenario no.3**

**Scenario no.4:**

Overtaking and head-on encounter involving two TCAS II-equipped intruders and GA/rotorcraft ownship in between the intruders on the same track. Ownship flies at FL=80, speed 120 kts. First intruder is following the ownship at the same FL (FL=80), speed 250 kts. Second intruder is flying against ownship at FL=90, speed 250 kts.

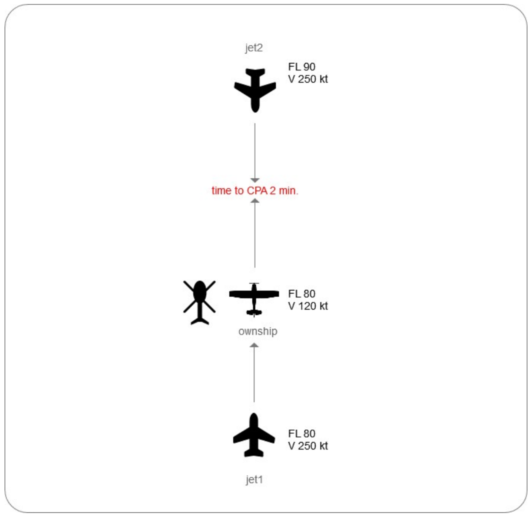



**Figure 6-11: Scenario no.4**

**Scenario no.5:**

Encounter involving three aircraft with two TCAS-equipped intruders are converging on GA/rotorcraft ownship trajectory from the same direction with an angle of 90 degrees between their tracks. GA/rotorcraft ownship flies at FL=80, speed 120 kts. Both intruders are flying from the same direction, with the same speed of 250 kts, one flying at FL=70 and second one at FL=90.

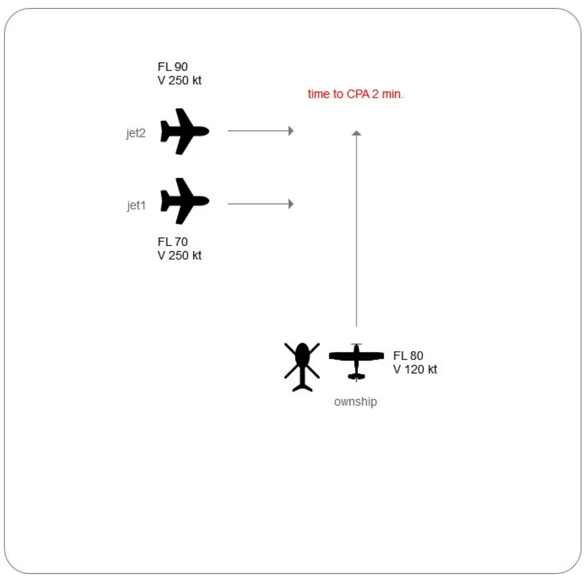



**Figure 6-12: Scenario no.5**

**Scenario no.6:**

Encounter involving GA/rotorcraft ownship and TCAS II-equipped intruder representing airport environment situation when a departing TCAS II-equipped intruder is climbing out at 3000 ft/min from a nearby airport and encounters the cruising GA/rotorcraft ownship cruising at 3000 ft, speed 120 kts.

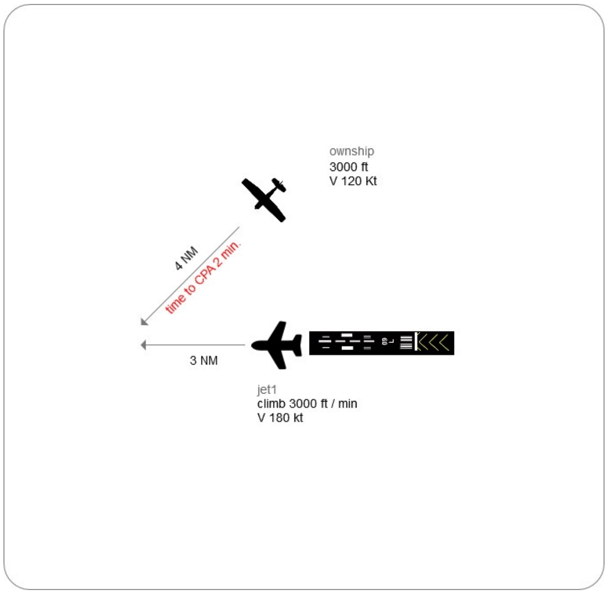



**Figure 6-13: Encounter no.6**

## A.1.4 Summary of Validation Exercise #04 Validation Assumptions

| Identifier | Title | Type of Assumption | Description | Justification | Flight Phase | KPA Impacted | Source | Value(s) | Owner | Impact on Assessment |
|---|---|---|---|---|---|---|---|---|---|---|
| EX4-ASS-PJ.11-A4-001 | Autopilot mode | Human Performance | Ownship aircraft will fly on autopilot by the time when GA/rotorcraft. | In order to be able to create conflicting encounter introducing RA on-board of TCAS II-equipped a/c, ownship a/c will fly on autopilot until pilot decides to manoeuvre due to collision risk. | All (Airport, TMA, en-route) | Safety, HP | Expert | N/A | Honeywell within PJ.11-A4 | Low |
| EX4-ASS-PJ.11-A4-002 | No revers RAs | Aircraft performance | TCAS II aircraft will not issue reverse RAs against ownship. | TCAS II-equipped intruder trajectory will be fixed and won't change during the scenario due to simulator capabilities. | All (Airport, TMA, en-route) | Safety, HP | Expert | N/A | Honeywell within PJ.11-A4 | Low |

| Identifier | Title | Type of Assumption | Description | Justification | Flight Phase | KPA Impacted | Source | Value(s) | Owner | Impact on Assessment |
|---|---|---|---|---|---|---|---|---|---|---|
| EX4-ASS-PJ.11-A4-003 | No ATC communication | Airport Characteristics | No ATC communication will be simulated | Uncontrolled airspace is assumed during evaluation, i.e. ATC is not managing separation. | All (Airport, TMA, en-route) | Safety, HP | Expert | N/A | Honeywell within PJ.11-A4 | Medium |
| EX4-ASS-PJ.11-A4-004 | Part-task simulator | Ground tools / Technology | Simulator environment behaviour is sufficiently realistic. | N/A | All (Airport, TMA, en-route) | HP | Expert | N/A | Honeywell within PJ.11-A4 | High |
| EX4-ASS-PJ.11-A4-006 | Weather conditions | Environment Constraints and Characteristics | VMC weather conditions will be simulated. | This simulation will consider good weather conditions (VMC) to allow pilot easily identify surrounding traffic. | All (Airport, TMA, en-route) | Safety, HP | Expert | VMC | Honeywell within PJ.11-A4 | Medium |
| EX4-ASS-PJ.11-A4-007 | TSAA+ display | Aircraft Equipage / Technology | TSAA+ display will be implemented on mobile device | Ownship pilots will be for solution scenarios provided with tablet or mobile (as preferred) to display traffic situation. | All (Airport, TMA, en-route) | HP | Expert | N/A | Honeywell within PJ.11-A4 | Low |

| Identifier | Title | Type of Assumption | Description | Justification | Flight Phase | KPA Impacted | Source | Value(s) | Owner | Impact on Assessment |
|---|---|---|---|---|---|---|---|---|---|---|
| EX4-ASS-PJ.11-A4-008 | Airport & TMA environment scenarios | Airspace Layout & Airport Characteristics | TMA operating environment will be addressed in this validation | Even though majority of scenarios is applicable for en-route too, results obtained by this evaluation will represent TMA environment only.<br>TMA environment is considered as the most relevant for TSAA+ applicability. | Airport, TMA | Safety, HP | Expert | N/A | Honeywell within PJ.11-A4 | Low |
| EX4-ASS-PJ.11-A4-009 | Intruder equipage | Aircraft equipage / Technology | Intruder will be always commercial aircraft with ADS-B OUT and TCAS II. | TSAA+ is expected to bring benefits during mixed equipped encounters. | All (Airport, TMA, en-route) | Safety, HP | Expert | N/A | Honeywell within PJ.11-A4 | High |

**Table 13: Validation EXE-04 Assumptions**

## A.2 Deviation from the planned activities

Reference scenarios were changed when compared with VALP scenarios definition to better assess the difference between pilot performance when flying without ADS-B IN application (which represents the current situation) compared to pure TSAA, and then TSAA+. This allowed us to better assess the benefits of "+" functionality of TSAA+.

| VALP | Deviation from the VALP |
|---|---|
| Reference scenarios:<br>1. **Ownship being not equipped with any transponder** (e.g. nor TSAA+), meaning that TCAS II intruder/s will not be able to | Reference scenarios:<br>1. **Ownship not being equipped with TSAA, nor TSAA+ system** (ownship can but does not have to be equipped with |

| | |
|---|---|
| identify threat (ownship), and therefore will not generate RA against the ownship. TCAS II equipped intruder will fly planned trajectory, GA/rotorcraft ownship will apply see-and-avoid only.<br><br>2. Ownship being **equipped with Mode C or Mode S transponder** with or without ADS-B IN/OUT capability, but **not equipped with TSAA+.** This scenario will give TCAS II equipped intruder/s the ability to identify threat (ownship), generate RA and manoeuvre against GA/rotorcraft ownship. Ownship will however have no other than see-and-avoid mean to identify the intruder. | Mode C / Mode S transponder), meaning that TCAS II intruder/s might or might not be able to identify threat (ownship), and therefore can but does not have to generate RA against the ownship. TCAS II equipped intruder will fly planned trajectory, GA/rotorcraft ownship will apply see-and-avoid only.<br><br>2. Ownship being **equipped TSAA system** but **not equipped with TSAA+.** This scenario will give ownship pilot ability to identify intruder using TSAA application and potentially generate TSAA (visual) alert, but ownship will not know what (if any) RA is issued on board of intruder, i.e. would not benefit from "+" functionality of TSAA. |
| Solution scenario:<br><br>Solution scenario represents **ownship being equipped with transponder with ADS-B IN & OUT capability and TSAA+ application.** TCAS II intruder/s will be able to identify threat (ownship) and generate RA against it, and ownship will be aware of the surrounding traffic situation thanks to TSAA+ application on tablet/mobile, which will even provide ownship pilot with information about RA issued on board of TCAS II equipped intruders. | No change. As in the VALP. |

**Table 14: EXE-04 deviations from the planned activities**

## A.3 Validation Exercise #04 Results

### A.3.1 Summary of Validation Exercise #04 Results

| Validation Exercise #04 Validation Objective ID | Validation Exercise #04 Validation Objective Title | Validation Exercise #04 Success Criterion ID | Validation Exercise #04 Success Criterion | Sub-operating environment | Exercise #04 Validation Results | Validation Exercise #04 Validation Objective Status |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| EX4-OBJ-PJ.11-A4-V2-VALP-001 | Task allocation changes. | EX4-CRT-PJ.11-A4-V2-VALP-001 | Using TSAA+ (as opposed to no TSAA) did not lead to the degradation of pilot performance. | | Pilots have considered displayed TSAA+ information beneficial, especially when it is difficult to spot traffic out of the window (OTW). TSAA+ informs about traffic sufficiently in advance. Compared with baseline, pilot's time to recognize traffic and time to start manoeuvre have improved. Information from TSAA+ influenced the ongoing manoeuvre of pilot and resulted in satisfactory separation. | OK |
| EX4-OBJ-PJ.11-A4-V2-VALP-002 | Pilot workload | EX4-CRT-PJ.11-A4-V2-VALP-002 | The potential changes to the level of workload/task demands and/or cognitive demands and the mitigation identified are acceptable. | | Bedford workload scale (BWS) rating resulted in "enough spare capacity" (1 -3 on BWS) and "reduced spare capacity" (4 – 6 on BWS). The workload of pilots using TSAA+ has | OK |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | slightly increased (meaning 0,23 on BWS scale) in comparison with baseline. However, based on the questionnaires, pilot’s workload should decrease or stay the same. | |
| EX4-0BJ-PJ.11-A4-V2-VALP-003 | Pilot information requirements | EX4-CRT-PJ.11-A4-V2-VALP-003 | There is no discrepancy between system-provided information and user-required information. | | TSAA+ provides sufficient information to predict aircraft´s trajectory and avoid the collision. The set of RA is intuitive and adequate for GA pilot manoeuvring. The presentation of TSAA+ data requires minor HMI adjustments. | OK |
| EX4-0BJ-PJ.11-A4-V2-VALP-004 | User interface usability | EX4-CRT-PJ.11-A4-V2-VALP-004 | End user experiences integrated interface including any new system components as sufficiently usable. | | Pilots have considered the position of RA message acceptable. RA message was not easily detected on the display and the colour of RA message was | NOK |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | unaccepted. | |
| | | EX4-CRT-PJ.11-A4-V2-VALP-005 | Pilot can clearly interpret all the system states (based on the symbols and the information provided by TSAA and TSAA+). | | Pilots objected confusion between TSAA and TSAA+ displayed data that seemed to be contradictory. TSAA shows current vertical trend of aircraft (↑↓) and TSAA+ displays issued RA (i.e. CLIMB). | NOK |
| EX4-OBJ-PJ.11-A4-V2-VALP-005 | User interface design vs. human errors | EX4-CRT-PJ.11-A4-V2-VALP-006 | The number or severity of errors in the solution scenarios are not greater than in the reference scenario. | | Pilots occasionally missed the RA message visualized near the intruder symbol, when it appeared later than with the symbol. Until pilots are familiar with TSAA+, they could misinterpret the RA of the intruder as a command to ownship. The RA message, presented as a symbol, was repeatedly misunderstood or missed. | OK |
| EX4-OBJ-PJ.11-A4-V2-VALP-006 | Level of situation awareness | EX4-CRT-PJ.11-A4-V2-VALP-007 | End user is able to perceive and interpret task | | During the simulation, pilots were aware of the | OK |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | relevant information and anticipate future events/actions. | | situation with only minor errors . From 75 situational cases only 11 errors have been made in total. Pilots stated, that evaluation of situation during the simulated flight has been easier in case of TSAA+ in comparison with no TSAA+. | |
| EX4-OBJ-PJ.11-A4-V2-VALP-007 | Acceptability of SA with TSAA+ | EX4-CRT-PJ.11-A4-V2-VALP-008 | Level of individual situation awareness within acceptable limits ('acceptable limits' to be defined with regard to the tool used for the assessment). | | The situation awareness with TSAA+ will increase or will likely stay in acceptable limits. Overrating of TSAA+ traffic display could lead to decreased situational awareness, since any traffic not equipped with ADS-B could appear in the air but may not be displayed. | OK |
| EX4-OBJ-PJ.11-A4-V2-VALP-008 | Roles and responsibilities | EX4-CRT-PJ.11-A4-V2-VALP-009 | End users do not predict negative impact with regard to changes in roles and | | Based on the questionnaires, TSAA+ application is acceptable for GA purposes. We presume | OK |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | responsibilities or means for mitigating negative impacts are identified. | | that TSAA and TSAA+ will have impact on GA operations and VFR flying rules. Gradual penetration of TSAA+ may limit the acceptance of this technology in GA environment. Usage of TSAA+ in GA requires understanding of TCAS functionality. | |
| EX4-OBJ-PJ.11-A4-V2-VALP-009 | Knowledge, skill and experience | EX4-CRT-PJ.11-A4-V2-VALP-010 | Where possible, initial knowledge, skill and experience requirements are identified. | | Special licence for TSAA+ in GA aircraft is unnecessary. Training on TSAA+ will be needed in a form of theory and practice (simulator, e-learning, video demonstration). | OK |
| EX4-OBJ-PJ.11-A4-V2-VALP-010 | Improved see and avoid failures | EX4-CRT-PJ.11-A4-V2-VALP-011 | See and avoid failures involving GA aircraft were reduced by about 3% | | Compared with baseline, see and avoid failures were decreased by more than 3 % with TSAA+ technology and even more with only TSAA technology. This was probably caused by the | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | pilot's unfamiliarity with TSAA+. | |
| EX4-OBJ-PJ.11-A4-V2-VALP-011 | GA pilot induced conflict situations | EX4-CRT-PJ.11-A4-V2-VALP-012 | GA pilot induced conflict situation identified during scenarios (if any) shows improvement when using TSAA+ system. | | Based on the separation throughout the scenarios of every type, TSAA+ shows improvement from baseline. | |

**Table 15: Validation Results for Exercise 4**

## A.3.2 Analysis of Exercise 4 Results per Validation objective

This exercise partially covers the following objective. The same objective is also covered by Exercise #5.

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

**CRT-PJ.11-A4-V2-VALP-0002-001**

To preliminarily evaluate, that the performance of pilot will not be degraded when using TSAA+ as opposed to no TSAA+, we have prepared questions, that has been included in questionnaire after the simulator session:

*1) I consider TSAA+ information (broadcasted RA of surrounding traffic) on display beneficial. Why?*

*2) Do you agree, that TSAA+ brings you information about possible aircraft intruder sufficiently in advance, before you can see an aircraft out of the window?*

Part of the exercise was also observation of pilot behaviour that has been followed with post-scenario questionnaire with the following questions:

*3) What was the traffic action?*

*4) What was the position of the intruder when you detected it? Within solution scenario (TSAA+) the following question has been asked:*

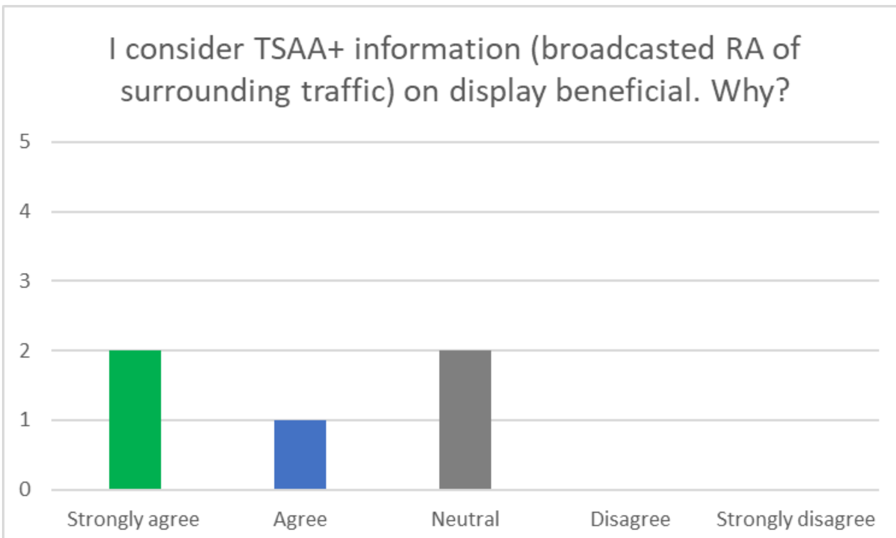
*5) Did TSAA+ help you to have a better overview of the surrounding/conflicting traffic? Why?*

The outcomes from either observation or post-scenario questionnaire will be provided to validation objective to depict the complete picture of pilot performance.

The analysis of objective data covers the results of separations between intruder and ownship statistics with regard to mid-air collision (MAC), near mid-air collision (NMAC) and reduced separation (RS). The analysis of objective data covers also the "time needed for intruder traffic recognition" for each type (baseline, solution) and scenario (1 – 5) for comparison and "time needed to start manoeuvre".

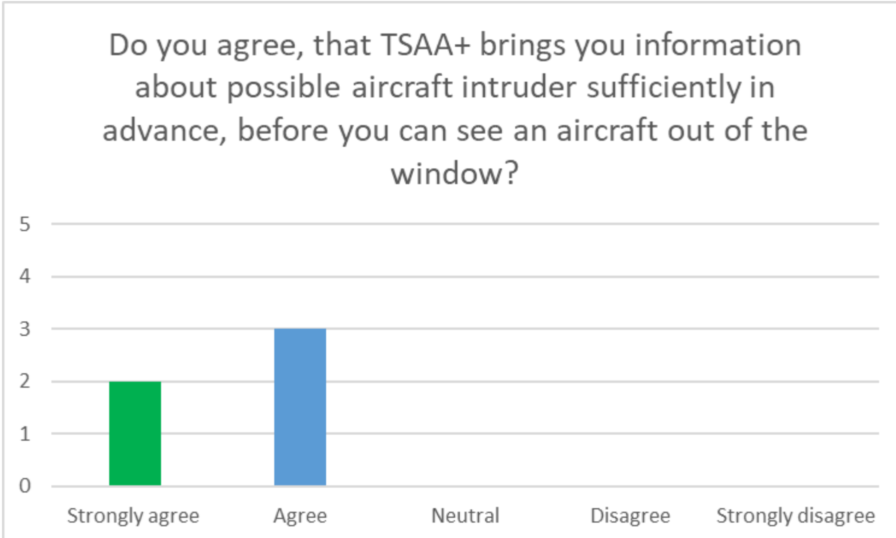
**Questionnaire:**

3 out of 5 pilots expressed positive attitude ("strongly agree" and "agree") to the statement that they *consider TSAA+ information (broadcasted RA of surrounding traffic) on display beneficial* with a note that *it improves the situation awareness and enhances safety especially in conditions of poor visibility and that it helps pilot to make decision easier and faster*. 2 out of 5 pilots expressed neutral attitude to this statement with a note that *it's an additional information that would confirm pilot's decision, but his actions would be already performed to avoid conflict*:




Graph 1 – value of TSAA+ information to pilots

5 out of 5 pilots expressed positive attitude ( "strongly agree" and "agree") to the statement that they *agree, that TSAA+ brings information about possible aircraft intruder sufficiently in advance, before seeing an aircraft out of the window* with a note that *it's very difficult to spot out of windows sometimes and so they had enough time to take a proper action.*:

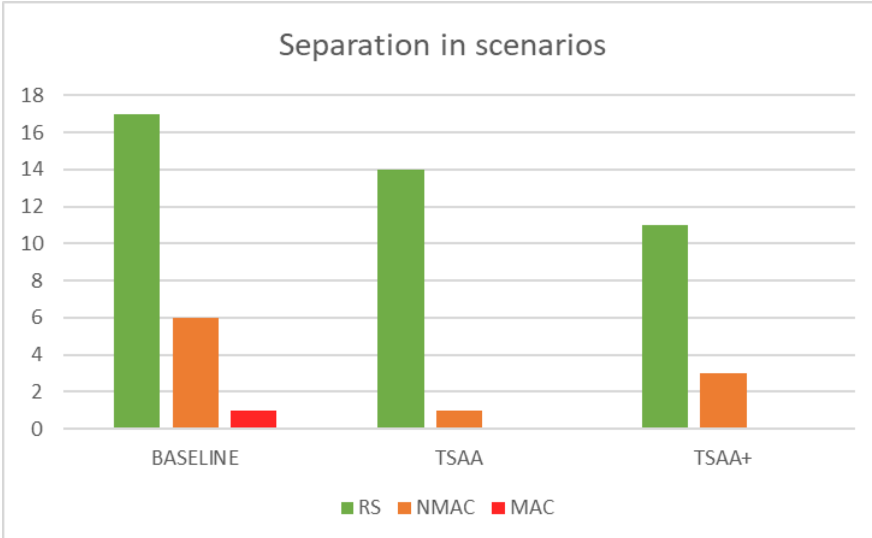



Graph 2 – TSAA+ information forwardness

**Objective data:**

To measure that perfomance of pilot has not been degraded when using TSAA+, we have analyzed the objective data logged from all scenarios. We were focusing on the resulting separation between ownship and intruder. The scale has been set to 3 parameters (sorted from the severest): MAC – Mid Air Collision (Horizontal separation and Vertical separation < 60 ft slant), NMAC – Near Mid Air Collision (Horizontal separation < 500 m and Vertical separation < 600 ft), RS - Reduced separation (Horizontal separation < 3 NM and Vertical separation < 1000 ft).

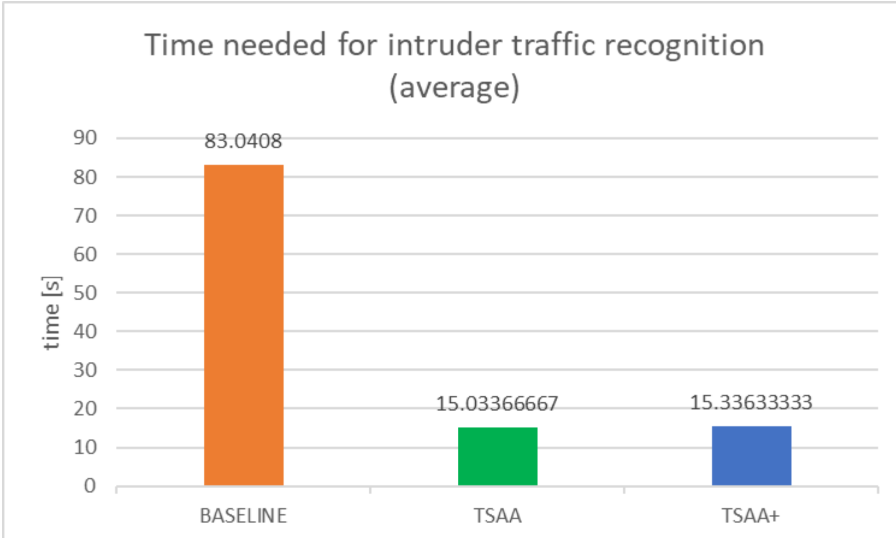
On the following graph it can be seen that in baseline scenario we detected all 3 types of collisions we have been focusing on (MAC, NMAC and RS). The amount of collisions is getting smaller in solution scenarios and the severest type (MAC) has been completely mitigated within solution scenarios in comparison to baseline. We can see that there is increased number of NMAC in TSAA+ in comparison to TSAA (3 occurencies in TSAA+ in comparison to 1 occurrence in TSAA):




Graph 3 – separation results in scenarios

In each scenario, pilots were asked to express whenever they recognize traffic in their sight by saying "traffic". The same pattern has been used for baseline as well as solution scenarios, where in case of solution scenarios pilots could use the display for this recognition. The following graph shows average time (in sec.) needed for traffic recognition. The difference between baseline and solution scenarios is quite significant (average difference approx. 68 secs.). This significance in average results is caused by the difference between the performance of pilot when spotting the aircraft out of the window by continous scanning of the area and spotting the aircraft on the dedicated experimental display where no scanning is necessary.

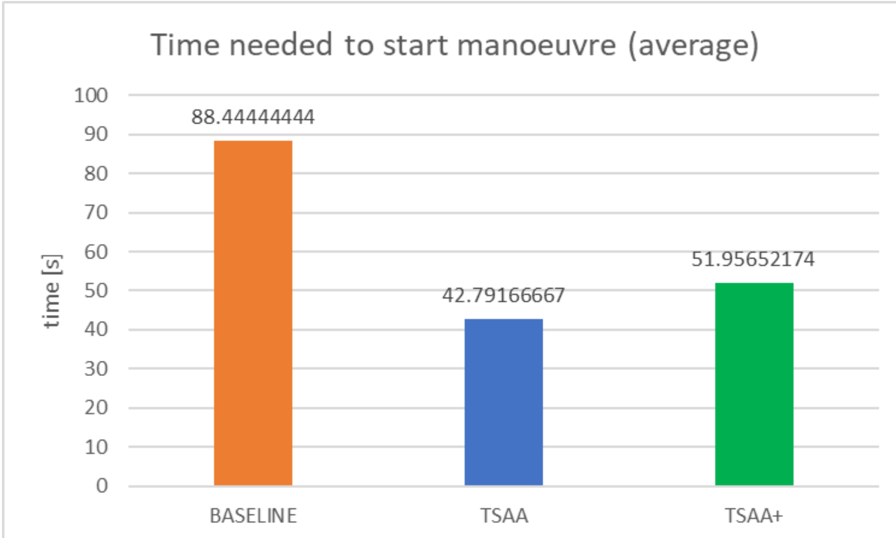
The experimental display has been set to 5 NM range that set the proximity area around the ownship. Surrouding traffic on the experimental display showed also the trend of trajectory of each aircraft (showing where the aircraft would be in 1 minute). This information was significant help to the pilot to be aware of intruder right after the start of solution scenario. Because the above mentioned information is also the part of TSAA solution (not TSAA+ only), the difference between the TSAA and TSAA+ is not that significant (average difference aprox. 0,3 secs.).




Graph 4 – time needed to recognize traffic

Each scenario started to be flown on autopilot. The reason is that we must bring the aircraft to the closest point of approach (CPA) area at the time and on prescribed condition. Any action taken by pilot would influence the performance of the aircraft and so the CPA could be missed. During the autopilot run, pilots were asked every 15 sec. for secondary task (callout of actual speed and altitude) to distract their attention. Pilots were asked to not manoeuvre with the aircraft unless they would like to avoid the collision. When a manoeuvre was performed, the autopilot was automatically switched off. Switching autopilot off has been recorded to the log of each scenario.

The following graph shows significant difference between the time needed to start manoeuvre between baseline and solution scenarios (average difference of time between baseline and TSAA+ is approx. 36,5 secs. and 45,6 secs. between baseline and TSAA). The difference between TSAA and TSAA+ is approx. 9,2 secs. Observation of pilots has shown that this difference is caused by issued RA in case of TSAA+. In case of TSAA+ pilots waited with the manoeuvre until the RA has been issued and broadcasted on the display. Objective data confirm the abovementioned note, that information of intruder's RA (TSAA+) helped pilots to think over the suggested manoeuvre and take more appropriate action that they would do without knowing this RA (no TSAA+):




Graph 5 – time needed to start manoeuvre

**EX04-CRT-PJ.11-A4-V2-VALP-002**

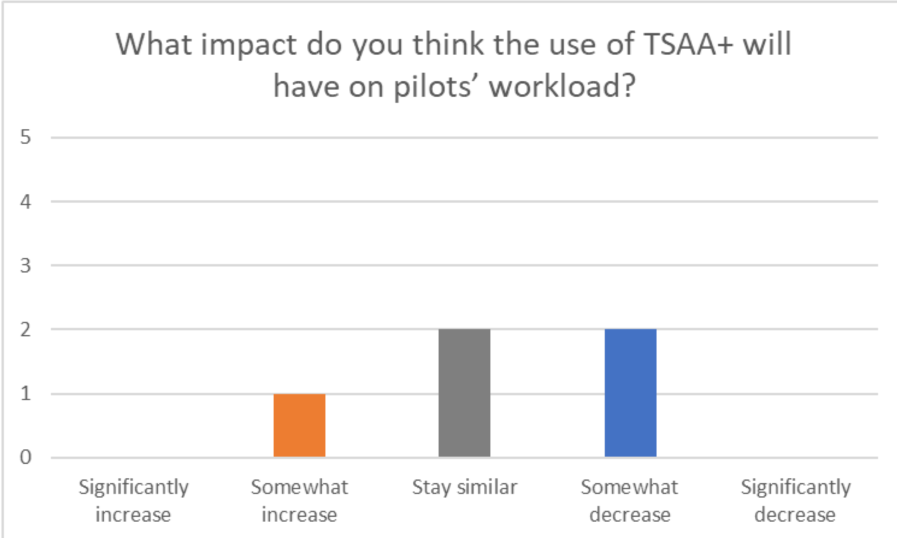
To identify the impact of TSAA+ functionality on pilot's workload we have prepared the following question included in questionnaire:

*What impact do you think the use of TSAA+ will have on pilots' workload? The workload is likely to stay similar/decrease/increase… Why?*

Within the simulation, we have prepared the post-scenario questionnaire with a question on workload. This question was asked after each scenario run to be able to compare workload between solution and baseline. Bedford workload scale (BWS) has been used as evaluation method to measure workload of pilots.

**Questionnaire:**

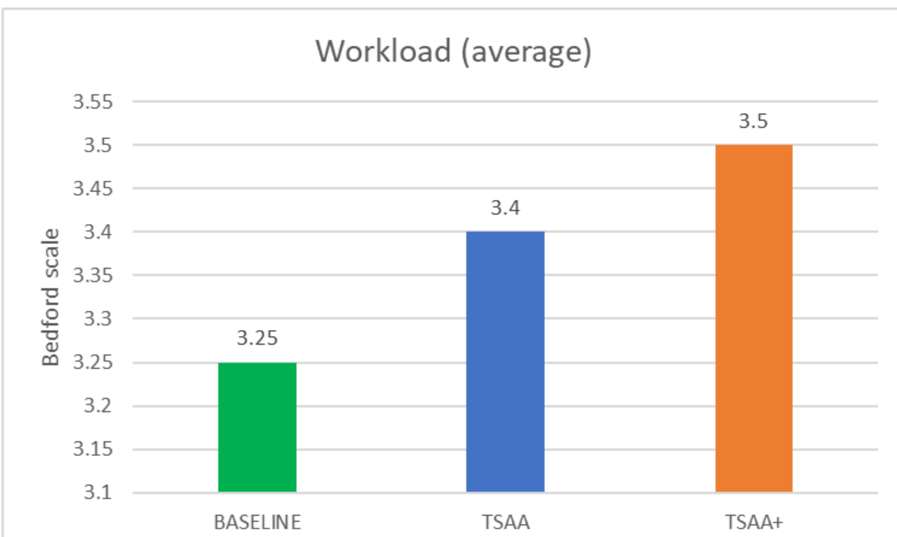
2 out of 5 pilots expressed that the workload will somewhat decrease. 2 out of 5 pilots expressed that workload will stay on same level. 1 out of 5 pilots expressed that the workload will somewhat increase with a note that *from the point of situation awareness the workload decreases but from the point of head down time the workload increases, as a GA pilot you will still need to watch for UAV/UAS/drones, birds, LSA without ADS-B:*




Graph 6 – TSAA+ impact on workload

**Post-scenario questionnaire:**

Graphs shows average rating provided from pilots. Rating wobbled around "enough spare capacity" (1 -3 on BWS) and "reduced spare capacity" (4 – 6 on BWS). The workload of pilots using TSAA+ has slightly increased (meaning 0,23 on BWS scale) in comparison to baseline. An increased workload of pilots might have been caused due to the novelty, amount of TSAA+ (ADS-B) information and related head down time, in comparison to baseline (no device). The difference of BWS workload rating between TSAA and TSAA+ is very low (means 0,1 on BWS scale). This could have been caused by the added information on RA in case of TSAA+ in comparison to no RA in case of TSAA:




Graph 7 – workload comparison between scenario types

To asses that there is no discrepancy between system-provided information and user-required information we have prepared the following list of questions into the questionnaire:

*1) I feel that the content of TSAA+ information is enough for my decisions.*

*2) Please provide a list of information, you (ownship) would need to add to be able to proceed with RA when surrounding aircraft is a threat to you.*

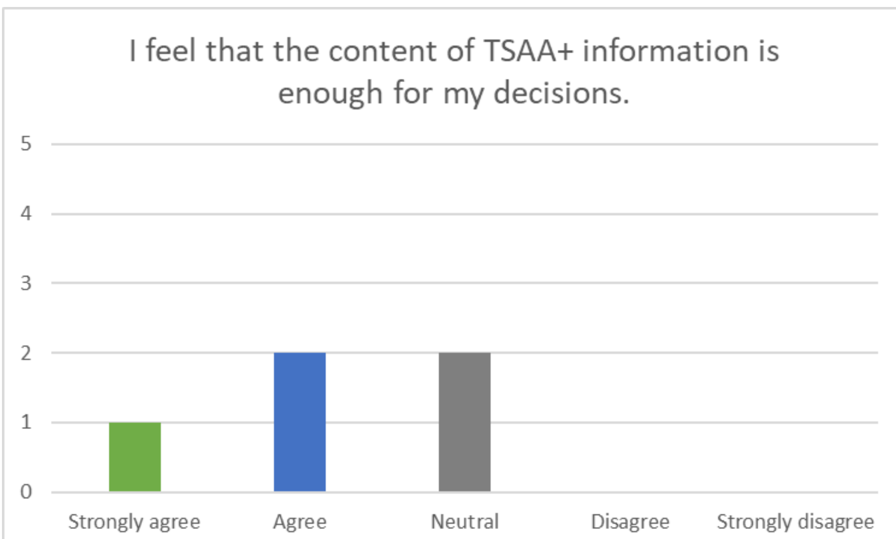
*3) Please provide a list of information, you (ownship) would need to add to be able to proceed with RA when surrounding aircraft is a threat to someone else.*

*4) Currently the proposed set of RA messages displayed through TSAA+ to GA pilot is as following: climb, descent, level off, crossing, do not climb, do not descent. Please provide your feedback to the following statement: The set of RA messages is intuitive.*

*5) The given set of RA messages is sufficient for GA pilot.*

**Questionnaire:**

3 out of 5 pilots expressed positive attitude ( "strongly agree" and "agree") to the statement that *the content of TSAA+ information is enough for their decisions.* 2 of 5 pilots expressed neutral attitude with a note *expressing worries of the potential HMI clutter in case of dense traffic environment with up to 6 intruders*:

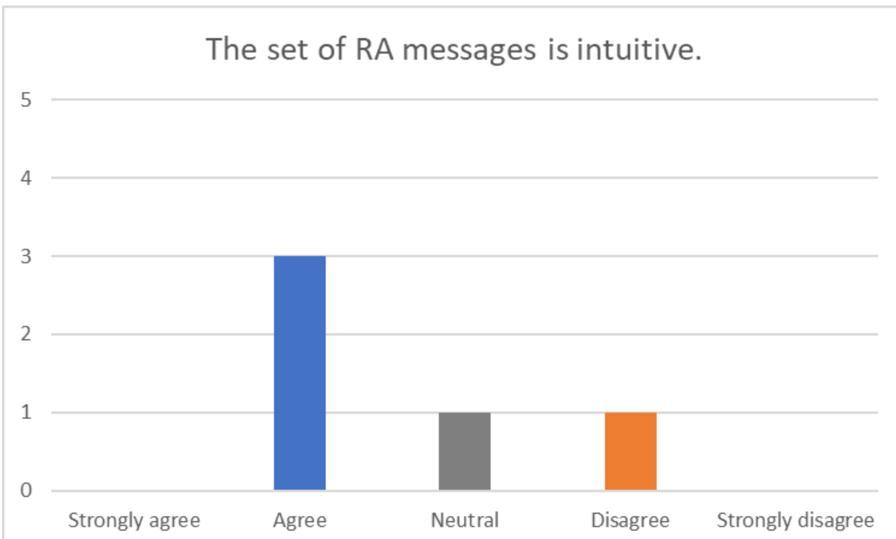



Graph 8 – sufficiency of TSAA+ information content

When we asked the pilots to provide a list of information they would like to add to currently proposed content of TSAA+ in case when **surrounding traffic is threat to them**, the answers of 3 pilots were that there is no need to add anything. 1 pilot suggested to add information whether the RA is issued against ownship. 1 pilot expressed worries of potential confusion between current vertical trend of aircraft taken from ADS-B data as part of TSAA logic (↑↓) and issued RA (ie. CLIMB)

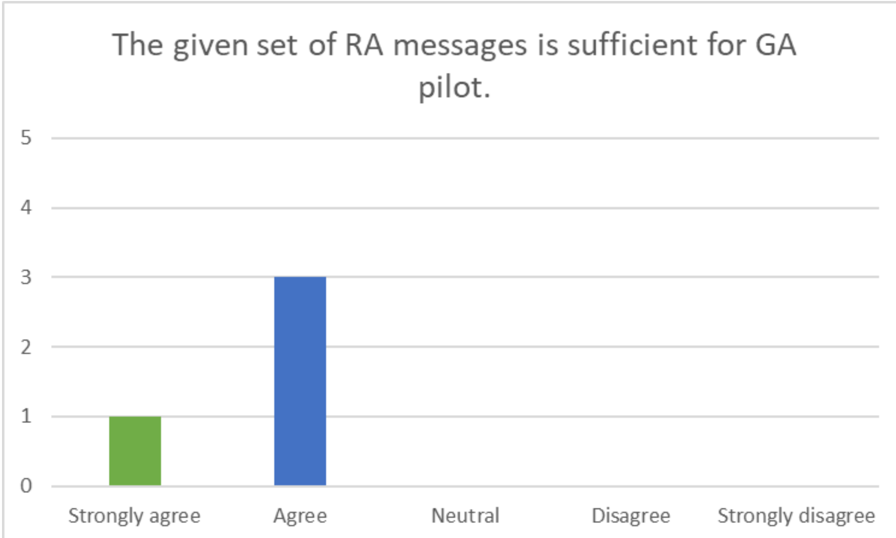
When we asked the pilots to provide a list of information they would like to add to currently proposed content of TSAA+ in case when **surrounding traffic is threat to someone else**, the answers of 4 pilots were that there is no need to add anything. 1 pilot expressed worries of potential confusion between current vertical trend of aircraft taken from ADS-B data as part of TSAA logic (↑↓) and issued RA (ie. CLIMB) as part of TSAA+ logic.

We have defined the following set of RA messages: Climb, Descend, Level off, Crossing climb, Crossing descend, Do not climb, Do not descend. 3 out of 5 pilots expressed positive attitude (“agree”) to the statement that the *set of RA messages is intuitive*. 1 out of 5 pilots expressed neutral attitude to this statement. 1 out of 5 pilots expressed negative attitude (“disagree”) to this statement with a note that *crossing RAs are confusing as it climbs or descends anyway so there is no additional info brought here:*




Graph 9 – intuitiveness of RA messages

4 out of 5 pilots expressed positive attitude ( “strongly agree” and “agree”) to the statement that the *set of RA messages is sufficient for GA pilot*. 1 of 5 pilots did not answer*:*




Graph 10 – sufficiency of RA messages list

**EX04-CRT-PJ.11-A4-V2-VALP-004**

To assess if the TSAA+ end user experiences integrated interface as sufficiently usable, we have prepared the following set of questions in questionnaire:

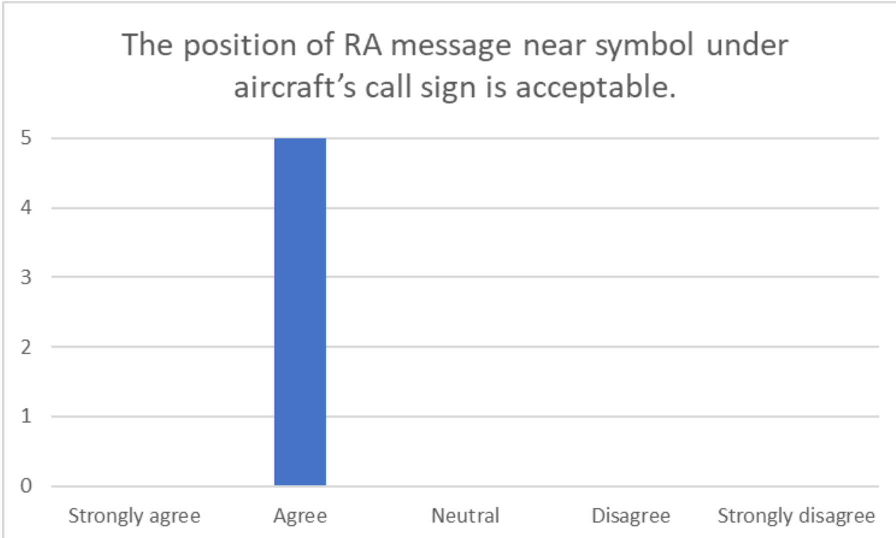
*1) The position of RA message is acceptable.*

*2) The color of RA message is acceptable.*

*3) The RA message is easy to detect on display.*

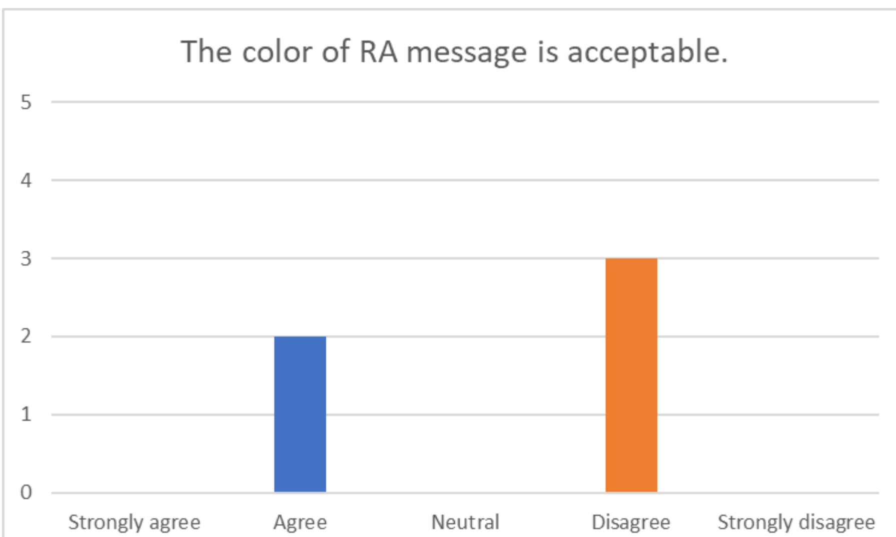
**Questionnaire:**

5 out of 5 pilots expressed positive attitude ("agree") to the statement that *the position of RA message is acceptable*. The position of RA has been proposed near aircraft symbol under aircraft' s call sign. The justification for placement of the RA near aircraft symbol is to guide pilot that it is RA issued to the aircraft and not to ownship. Second justification is that this RA is always visible without the need to tap on traffic (select traffic). 1 pilot expressed that *the position is ok, assuming the pilot is sufficiently familiar with TSAA+ logic:*




Graph 11 – acceptability of RA message placement

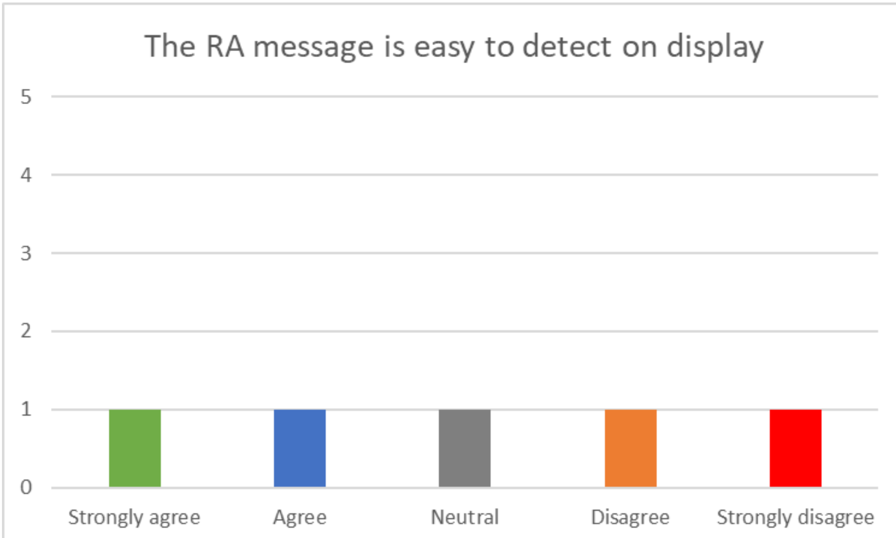
The color of RA has been set to same color as is the symbol of aircraft. The symbol of aircraft changes color regarding the TSAA logic and so does the RA. 2 out of 5 pilots expressed positive attitude ("agree") to the statement that *the color of RA message is acceptable*. 3 out of 5 pilots expressed negative attitude ("disagree") to this statement with a note that *it should have different color to be more eye catching considering the RA information is displayed (if) later and so could be missed*, in other words the severity of threat should not be triggered by TSAA logic only but TSAA+ logic too:




Graph 12 – acceptability of RA message color

2 out of 5 pilots expressed positive attitude ("strongly agree" and "agree") to the statement that *the RA message is easy to detect on display*. 1 out of 5 pilots expressed neutral attitude to this statement.

2 out of 5 pilots expressed negative attitude ("disagree" and "strongly disagree") to this statement. This result shows us pilot concernes about the easiness of detection of RA – possibly caused by the same color of RA and traffic symbol together with that the RA is showed when issued – it means that it is added to the symbol later and so could be missed if not somehow highlighted. 1 pilot expressed worries of potential contradiction between current vertical trend of aircraft taken from ADS-B data as part of TSAA logic (↑↓) and issued RA (ie. CLIMB) as part of TSAA+ logic:




Graph 13 – easiness of RA message detection

**EX04-CRT-PJ.11-A4-V2-VALP-005**

To assess that pilot can clearly interpret all the system states of TSAA+, we have prepared the following set of questions in questionnaire:

*1) The RA message is easy to understand.*

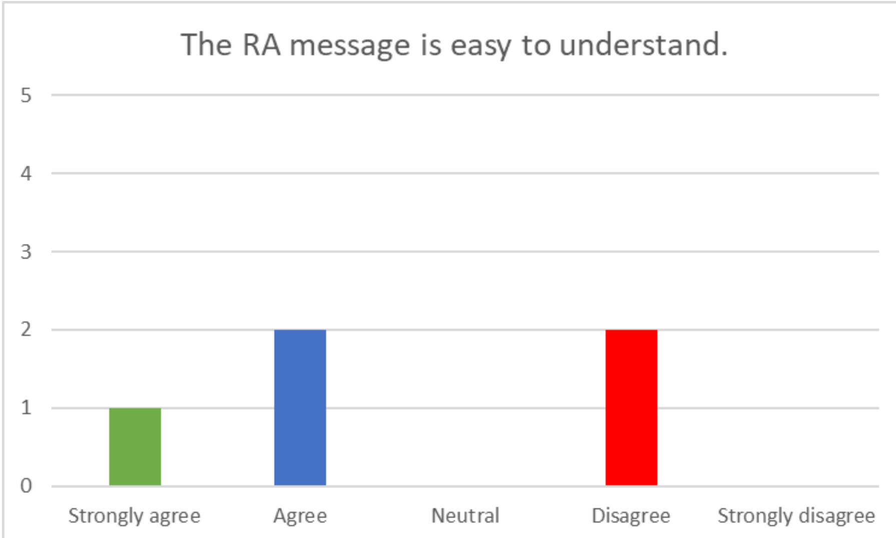
*2) How would you interpret this symbol when it appears on your display in relation to ownship?*

*3) How would you interpret this symbol when it appears on your display in relation to ownship?*

**Questionnaire:**

The interpretation of symbols and alerts provided to pilots has been correct with no major issues.

3 out of 5 particpants expressed postitve attitude ("strongly agree" and "agree") to the statement that the *RA message is easy to understand*. 2 out of 5 pilots expressed negative attitude ("strongly disagree") to this statement. The reason for this negative attitude may have been influenced by potential contradiction between current vertical trend of aircraft taken from ADS-B data as part of TSAA logic (↑↓) and issued RA (ie. CLIMB) as part of TSAA+ logic:




Graph 14 – easiness of understanding to RA message

**EX04-CRT-PJ.11-A4-V2-VALP-006**

To assess that the user interface design reduces human error as far as possible, we have prepared the following set of questions in questionnaire:

*1) How likely is it that you may mislead the intruder aircraft symbol on screen? Why? Please highlight the likeliness in percent on the scale below.*

*2) How likely is that you may misinterpret the RA in wording?*

*3) How likely is that you may misinterpret the RA in symbol?*

*4) How likely is that you may misinterpret the RA of aircraft as a resolution advisory command to ownship?*

After the simulator session pilots were asked to run application which was prepared to evaluate the accuracy of fixation of RA to pilot memory. The application showed the RA by clicking the button. Application contained 3 sets of 7 RAs. First set of RA was a displayed as label with RA text in small letters, second set of RA was displayed as label in capital letters and last set of RA was displayed as a symbol. The display time has been set to 250 milliseconds. This is the time needed for human brain to fix a word into short term memory. After 250 milliseconds, the RA disappeared, and pilot had to write down the RA he remembered. We have measured the error rate.

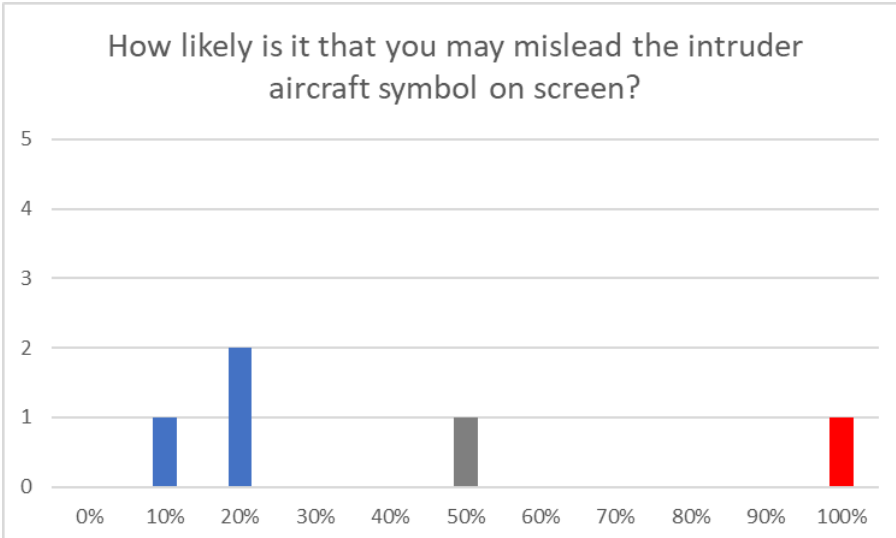
After this session pilots were given questionnaire with the following questions:

*7) Please highlight the easiness of readability of RAs on the scale below.*

*8) Please highlight the easiness of understanding of RAs on the scale below.*

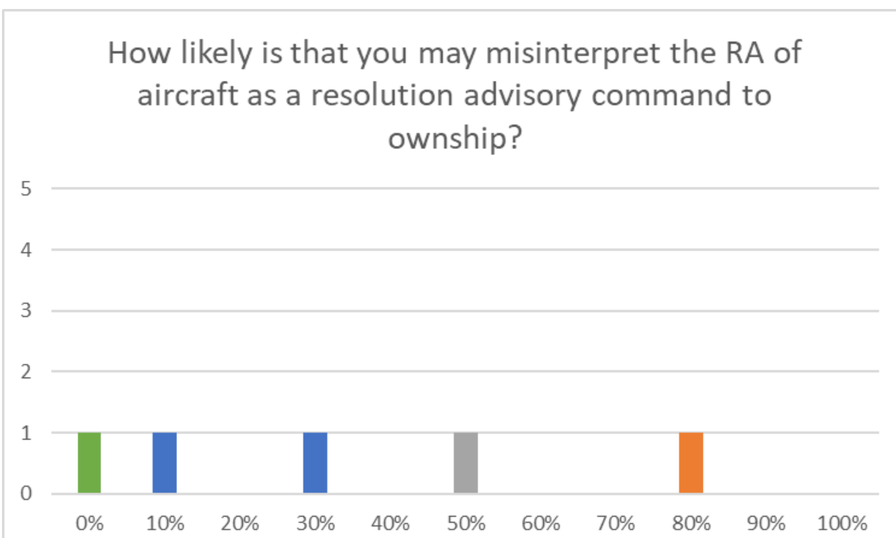
**Questionnaire:**

Pilots have been asked on *the likeliness of mislead the traffic symbol on the screen*. 3 out of 5 pilots expressed low likeliness (10% and 20%). 1 out of 5 pilots expressed the likeliness is 50%. 1 out of 5 pilots expressed, that the likeliness is 100% with a note, that *you could possibly mislead the RA. TSAA+ should convey the message that there is RA, unless it is hard to notice*:



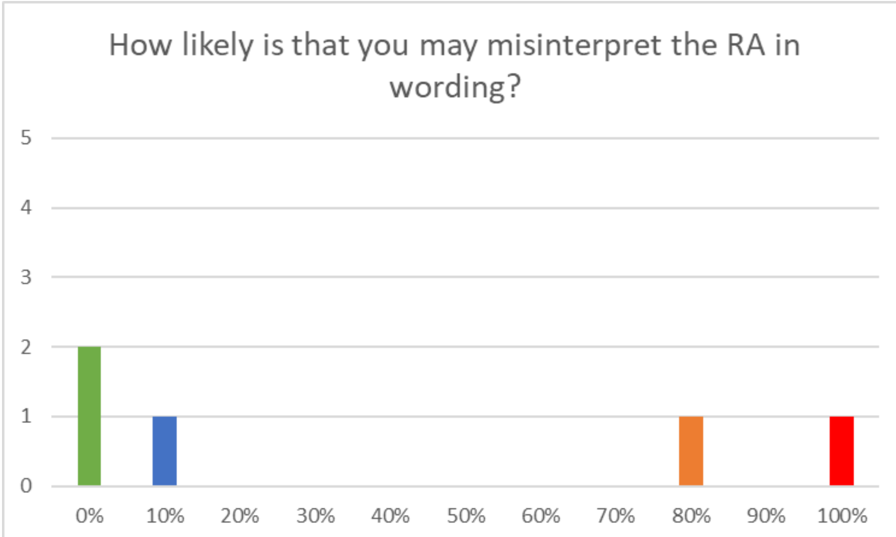

Graph 15 – likeliness of misleading of intruder symbol

Pilots have been asked on *the likeliness of misinterpret the RA as a command to ownship*. 3 out of 5 pilots expressed low likeliness (0%, 10% and 30%). 1 out of 5 pilots expressed the likeliness is 50%. 1 out of 5 pilots expressed, that the likeliness is 80% with a note, that *familiarity with TSAA+ is the key*:



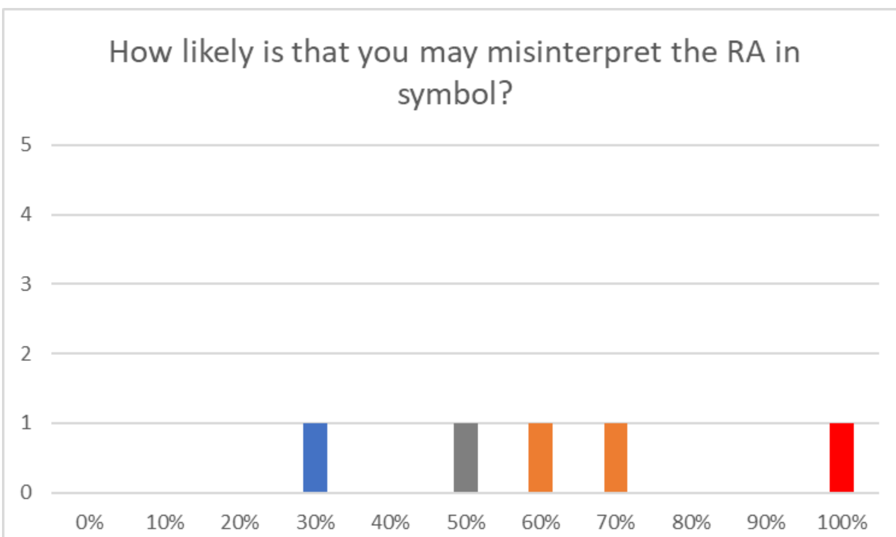

Graph 16 – likeliness of misinterpretation of RA as a command to ownship

Pilots have been asked on *the likeliness of misinterpret the RA in wording*. 3 out of 5 pilots expressed low likeliness (t0% and 10%) 2 out of 5 pilots expressed high likeliness (80% and 100%):




Graph 17 – likeliness of misinterpretation of RA in wording

Pilots have been asked on *the likeliness of misinterpret the RA in symbol*. 1 out of 5 pilots expressed low likeliness (30%). 1 pilot expressed neutral attitude to this statement. 3 out of 5 pilots expressed high likeliness (60%, 70% and 100%):

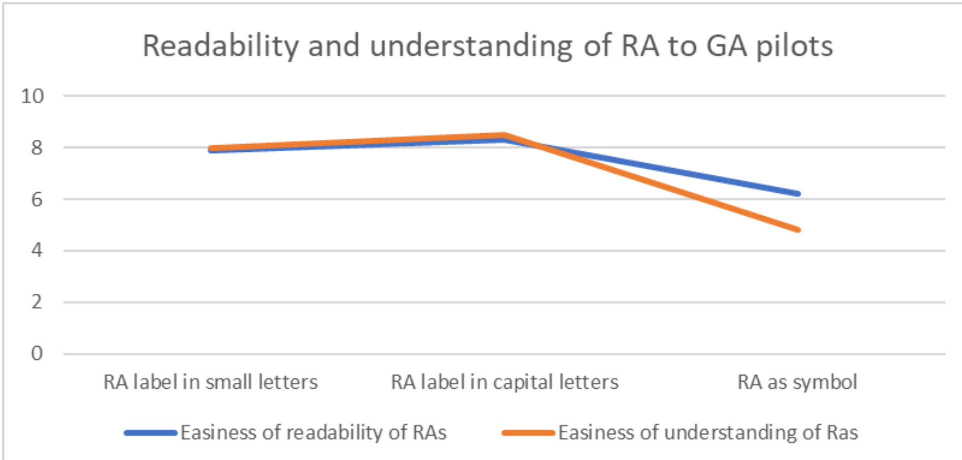



Graph 18 - likeliness of misinterpretation of RA as symbol

**RA fixation session:**

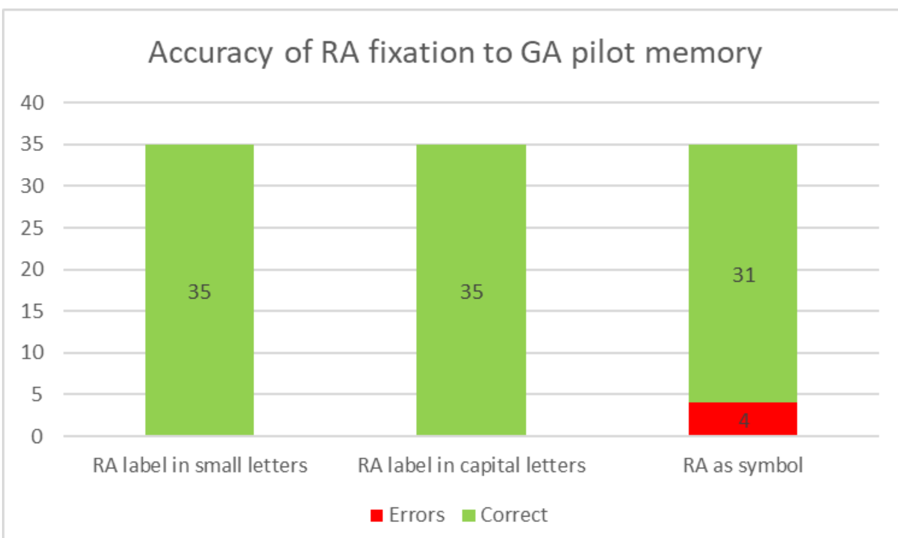
After the simulator session pilots were asked to run application which was prepared to evaluate the accuracy of fixation of RA to pilot memory. We were than able to objectively evaluate the previously expressed statements regarding the readability and understanding of the RA as it is written as a word or as a symbol.

Graph confirms the above-mentioned statement plus it gives us the cue for how the label should be displayed. The RA presented as a word in CAPITAL letters has been rated as most understandable and readable for pilots. The RA as symbol has been rated as less understandable and readable for pilots:



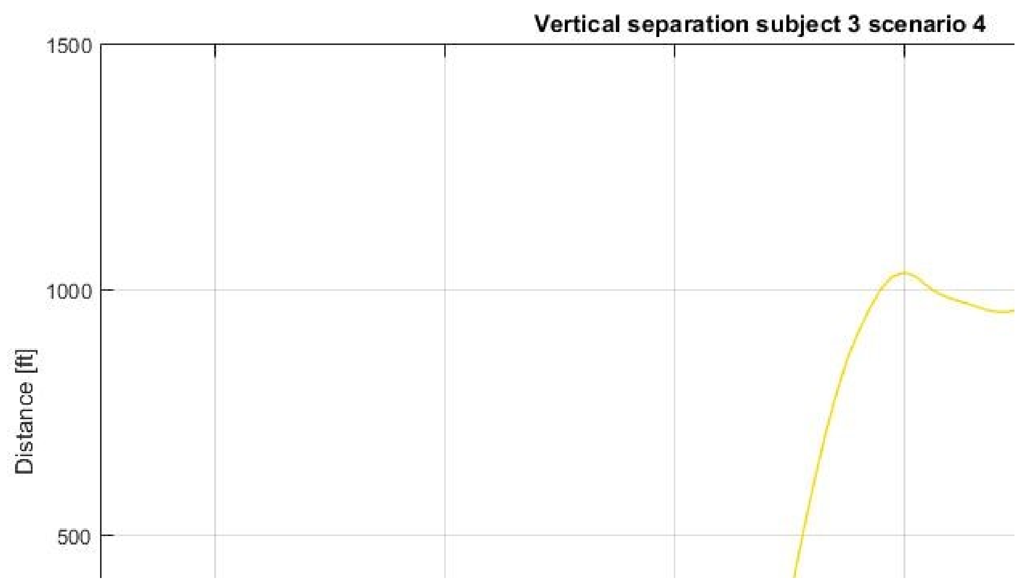

Graph 19 – readability and understanding of RA

The accuracy of fixation of RA to pilot memory confirms, that from the overall number of 35 RAs, the 4 errors were made only in case of RA presented as symbol. The error has been caused by the RA symbol misinterpretation:




Graph 20 – accuracy of RA fixation to pilot´s memory

To fully depict the potential for error in case of TSAA+, we provide an example of data that has been recorded during one of the simulator session flight. On the graph you can see that when GA pilot had no device in cockpit (red line), the separation with intruder resulted in MAC because the pilot had no chance to spot the aircraft that has been coming from behind the ownship. The ownship pilot tried to solve the other intruder and so he get into trajectory of the second one. In the case of TSAA+ (yellow line) the potential error in interpretation of situation has been mitigated by traffic display and resulted in sufficient separation with intruder in the end:




Graph 21 – vertical separation example

**EX04-CRT-PJ.11-A4-V2-VALP-007**

To asses that end user is able to perceive and interpret task relevant information and anticipate future actions, we have prepared the post-scenario questionnaire with set of questions to identify the level of pilot situation awareness. After each scenario, pilot had to answer the following questions. We were measuring the accuracy of the information to evaluate if and how much has the pilot been aware of the situation:

*1) What was the traffic action?*

*2) What was the position of the intruder when you detected it?*

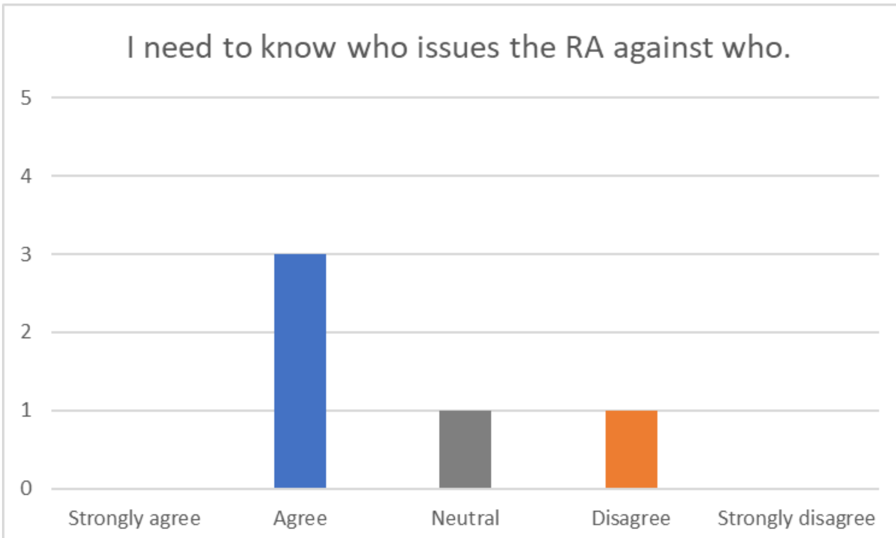
After the simulator session the folllowing set has been included in questionnaire to depict the complete picture of perceiving and interpreting the task relevant information:

*3) I need to know who issues the RA against who.*

*4) In which case, do you think you could evaluate your situation with number of surrounding traffic more easily to decide manoeuvre?*

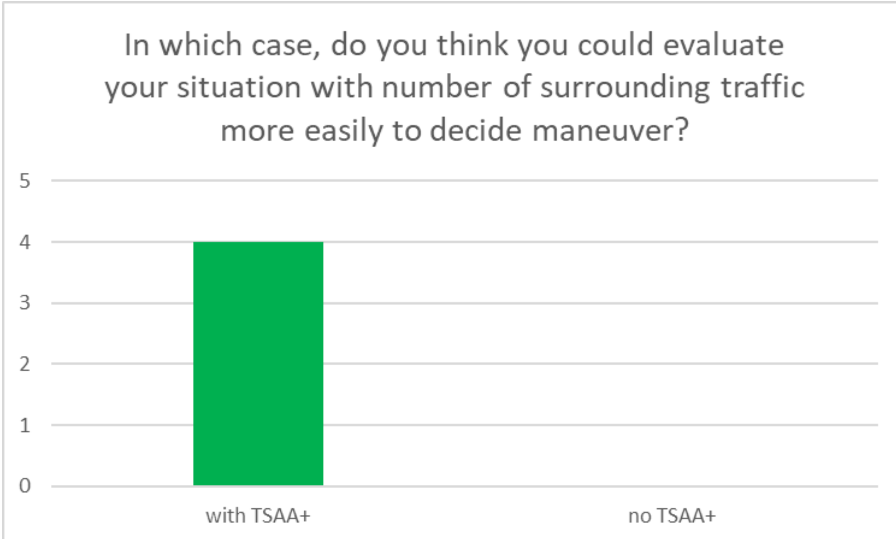
**Questionnaire:**

3 out of 5 pilots expressed positive attitude ("agree") to the statement that they *need to know who issues the RA against who*. 1 out of 5 pilots expressed neutral attitude to this statement. 1 out of 5 pilots expressed negative attitude ("disagree") to this statement with a note that *it could be than too complex and will depend on how it will be displayed to the pilot:*




Graph 22 – need to know issuer of RA

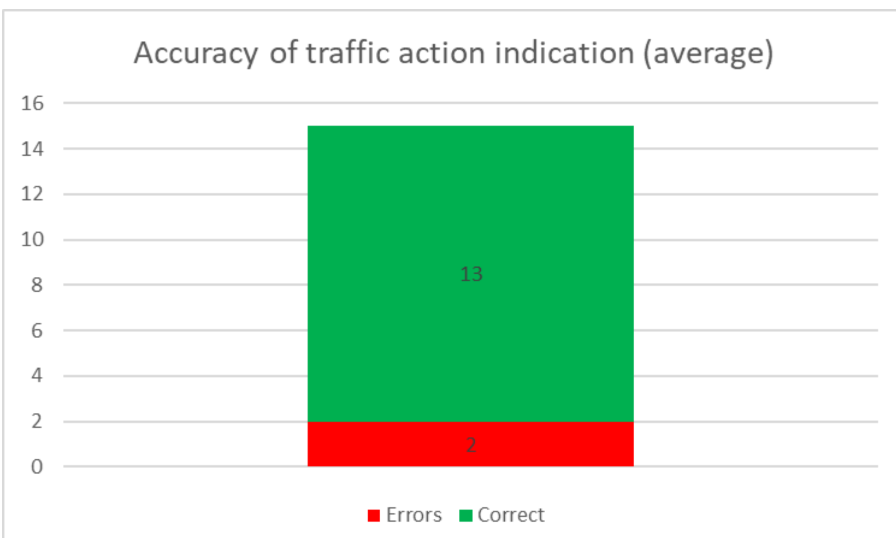
4 out of 5 pilots expressed that *in case of TSAA+ in comparison to no TSAA+ they could evaluate their situation more easily* with a note *that it improved their scanning and cause less fixation of pilot attention on intruder (staring).* 1 pilot did not vote but expressed that *the situation is same for both cases where the TSAA+ information is considered by this pilot as FYI info*:




Graph 23 – easiness of decision

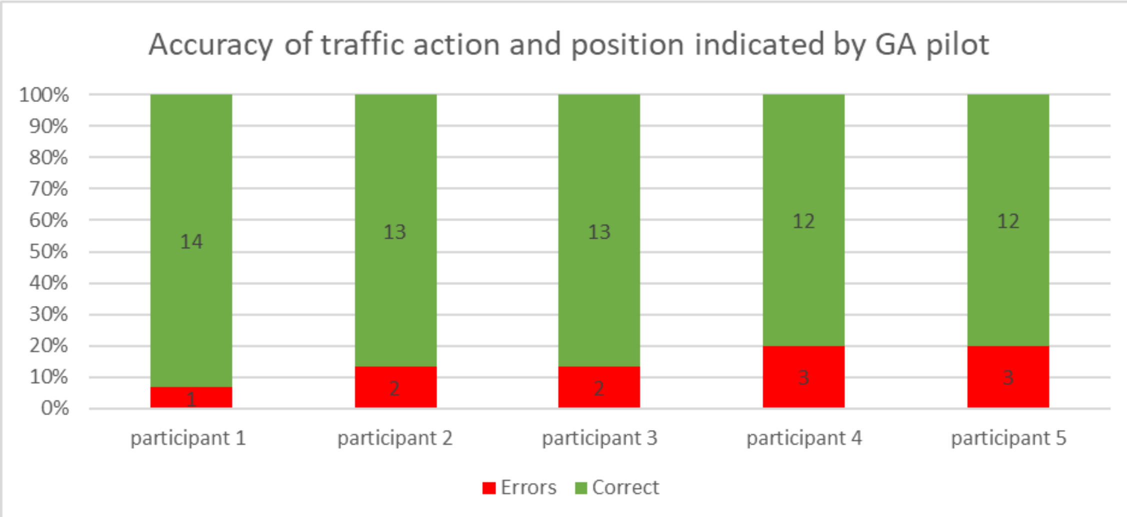
**Post-scenario accuracy session:**

Part of the exercise was also observation of pilot behaviour focused on accuracy of traffic action indication. We have measured the average error rate. Measured average error rate has been low. The following graph shows that from 15 scenarios (75 cases total) where the accuracy has been measured, pilots have made only 2 errors in average (11 cases total). Errors were made within every type of scenario (baseline, TSAA, TSAA+). Observation showed up that when there were 2 aircraft coming from different sides to ownship, pilot noticed the first threat and started with mitigation action and in this case, pilot did not notice another traffic that was going from different side:




Graph 24 – accuracy of traffic action indication (average)

Accuracy of traffic indication in detail:



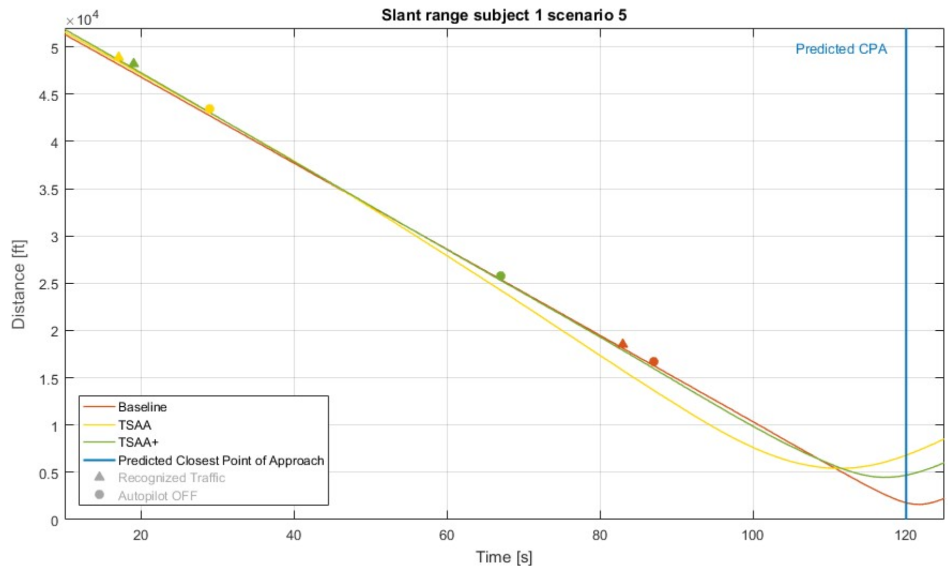

Graph 25 – accuracy of traffic indication (detail)

**EX04-CRT-PJ.11-A4-V2-VALP-008**

During the simulation, pilots have often expressed positive attitude to the level of situation awareness. Pilots expressed that they feel the situation awareness increases when using TSAA+ (notes provided to question "I consider TSAA+ information beneficial"). Pilots expressed that TSAA+ definitely gives a better situation awareness and allows to smooth the workload (notes provided to question "In which case, do you think you could evaluate your situation with number of surrounding traffic more easily to decide maneuver?"), helps with decision making and rection time (notes provided to question "TSAA+ application is acceptable for GA purposes").

Together with the outcomes of previous situation awareness exercise (EX04-CRT-PJ.11-A4-V2-VALP-007) we assume, the situation awareness with TSAA+ will increase or will likely stay in acceptable limits.

This assumption could be also depicted on example of bahavior of pilot with TSAA+ in situation with 2 traffic coming to CPA on diferent fligh level from one side on the following graph. With TSAA+ GA pilot spotted the traffic earlier than TSAA and much eralier than in baseline scenarios. Pilot stayed calm, had enough time to decide the approriate maneuver, pilot was aware of the situation and waited how the situation will develop, pilot switched off the autopilot and still did not start maneuvre since having all the necessary information on display. In the very end the separation from intruder resulted in more than 5000 ft:




Graph 26 – slant range separation example

On the other side, when we were asking "What do you think can limit the acceptance of TSAA+ in GA environment?" we have found out that the overration of TSAA+ display could lead to decreased situation awareness because pilot could loose track of outside visual scanning and tend to stay head down in tricky situation. This could make situation even trickier with some unspotted/undisplayed traffic.

**EX04-CRT-PJ.11-A4-V2-VALP-009**

To assess whether pilots do not predict negative impact with regard to changes in roles and that the responsibilities or means for mitigating negative impacts have been identified, we have prepared the following set of questions:

*1) TSAA+ application is acceptable for GA purposes.*

*2) TSAA+ associated operations are acceptable for GA purposes.*

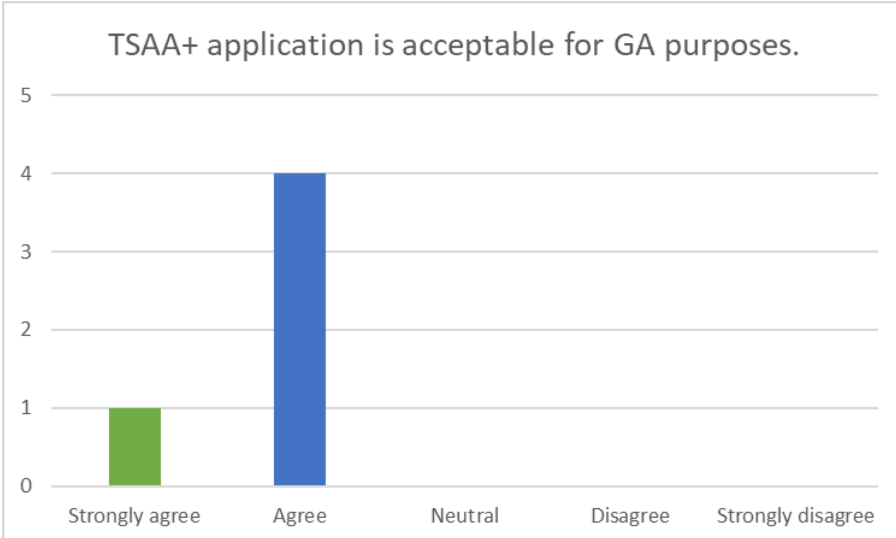
*3) What do you think can limit the acceptance of TSAA+ in GA environment?*

*4) The usage of TSAA+ in GA assumes understanding of TCAS functionality.*

*5) GA environment operations are going to change with expansion of TSAA+ to GA.*

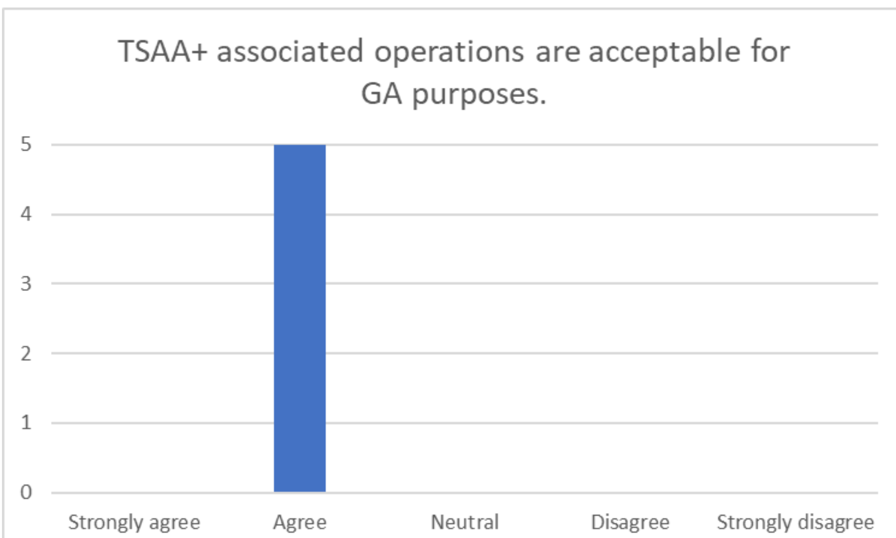
**Questionnaire:**

5 out of 5 pilots expressed positive attitude ("strongly agree" and "agree") to the statement that *TSAA+ application is acceptable for GA purposes*:




Graph 27 – acceptability of TSAA+ for GA

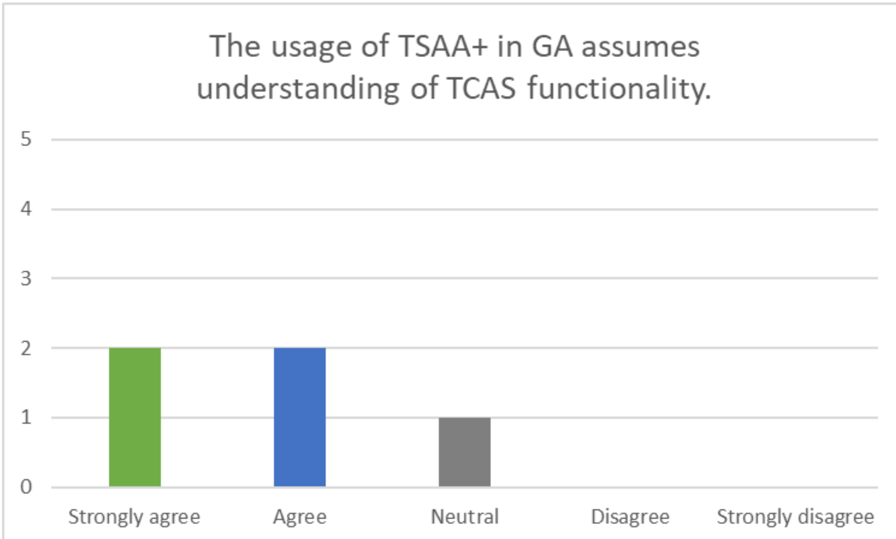
5 out of 5 pilots expressed positive attitude ("agree") to the statement that *TSAA+ associated operations are acceptable for GA purposes*:




Graph 28 – acceptability of TSAA+ operations for GA

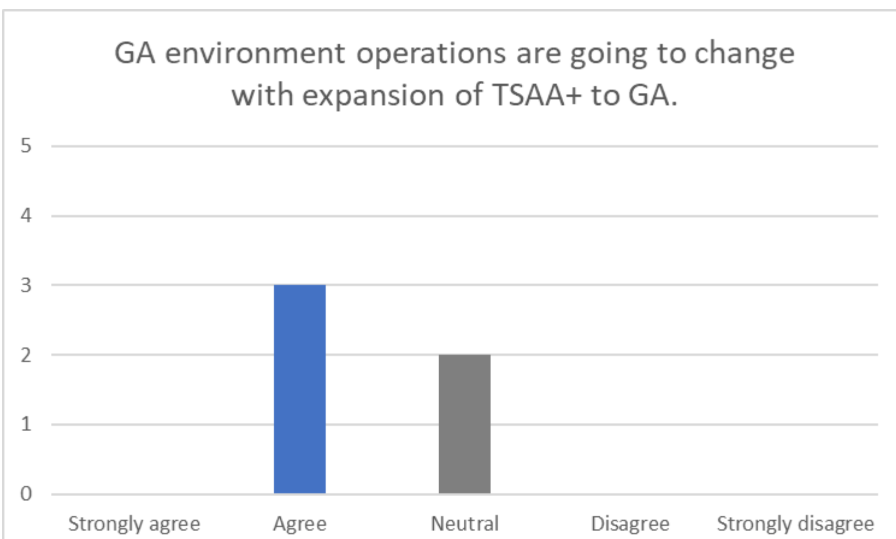
Pilots have stated, that lack of ADS-B equipage within GA aircraft (low penetration of ADS-B technology to GA environment) *may limit the acceptance of TSAA+ in GA environment* as well as initial cost of technology, initial mistrust to the technology and its overall adoption.

4 out of 5 pilots expressed positive attitude ("strongly agree" and "agree") to the statement that *the usage of TSAA+ in GA assumes understanding of TCAS functionality*. 1 out of 5 subjects expressed neutral attitude with a note that *pilot would likely need to know what the crew of second aircraft will do:*




Graph 29 – TSAA+ understanding versus TCAS knowledge

3 out of 5 pilots expressed positive attitude ("agree") to the statement that *GA environment operations are going to change with expansion of TSAA+ to GA*. 2 out of 5 subject expresed neutral attitude to this statement with a note *that TSAA+ improves safety but pilot still has to look out and follow the VFR rules and maybe include TSAA+ in checklist, pilots expressed concernes about what actions is GA pilot supposed to perform in case of RA against ownship*:




Graph 30 – impact of TSAA+ operations on GA

**EX04-CRT-PJ.11-A4-V2-VALP-010**

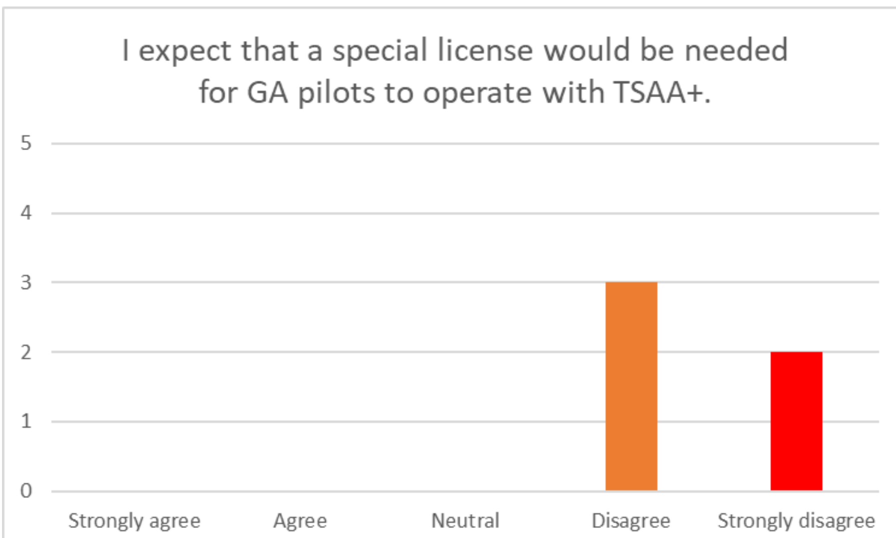
To identify preliminary training needs, initial knowledge skills and experience requirements, we have prepared the following set of questions in questionnaire:

*1) I expect that a special license would be needed for GA pilots to operate with TSAA+.*

*2) I expect pilots will need to be trained to use TSAA+.*

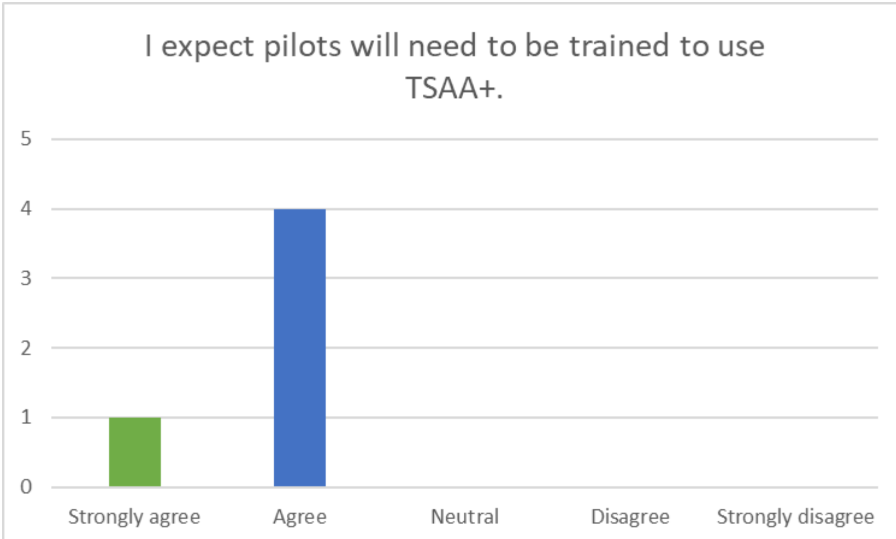
*3) Please suggest the method of training you would prefer to be able to use TSAA+ safely (physical training, e-learning, short how-to as a part of application).*

5 out of 5 pilots expressed negative attitude ("disagree" and "strongly disagree") to the statement that a *special license would be needed for GA pilots to operate with TSAA+* with a note that *no special license is needed even for GPS tracking apps and so should be for TSAA+*:




Graph 31 – impact of TSAA+ on pilot license

5 out of 5 pilots expressed positive attitude ("strongly agree" and "agree") to the statement that *pilots will need to be trained to use TSAA+*:

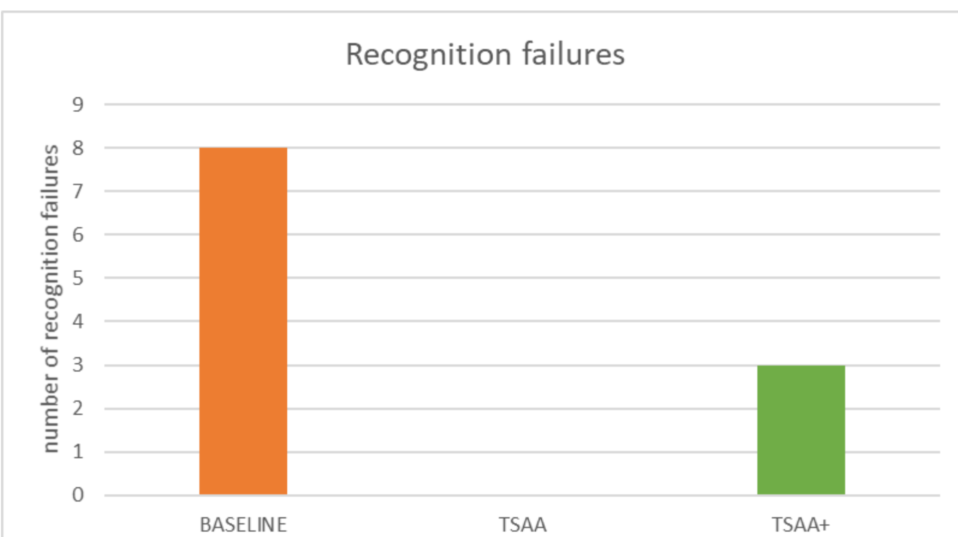



Graph 32 – TSAA+ training needs

When we were asking on the suggested method of training pilots would prefer, the suggestions were wobbling around training in a form of *e-learning or video demonstration*. Pilots also suggested *classroom theory and practice on simulator with different cases and geometry* as the possible training method for TSAA+.

**EX04-CRT-PJ.11-A4-V2-VALP-011**

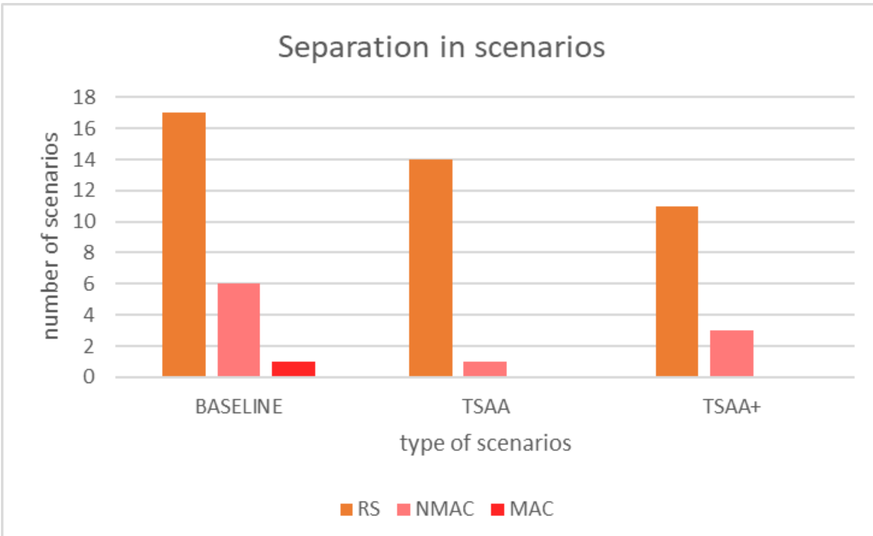
To asses whether see and avoid failures involving GA aircraft were reduced bu about 3 %, we compared number of recognition failures throughout the types of scenarios. As a recognition failure we understand not seeing all traffic , seeing traffic after the potential crash. On the graph below, we can see, that by using TSAA or TSAA+ the avoid failures were decreased by more than 3 %.



**EX04-CRT-PJ.11-A4-V2-VALP-012**

We understand conflict situation as a lower separation between ownship and an intruder. RS = Reduced Separation, NMAC = Near Mid-Air Collision, MAC = Mid-Air Collision, defined in this document.

We can see that the separation in scenarios shows improvement when using TSAA+ system. The difference was made mostly by displayed intruders (both TSAA and TSAA+) and by showed RAs and changing the maneover based on the newly received information (only TSAA+).




### A.3.3 Unexpected Behaviours/Results

N/A

### A.3.4 Confidence in Results of Validation Exercise 4

#### 1. Level of significance/limitations of Validation Exercise Results

The scenario set and the number of participants were limited, which is a standard limitation in workshop exercise. The scenarios were not dynamic.

#### 2. Quality of Validation Exercises Results

Exercise was performed in simulator with limited conditions enabling simulation of real flight situations.

Rotorcraft simulation flying model was customized small GA aircraft model. This was feasible because of the nearly identical behaviour of small aircraft and rotorcraft in higher speed we used for our scenarios.

### 3. Significance of Validation Exercises Results

The applied methodology was adapted to the known limitations of the validation exercises. In this context, the qualitative results of TSAA+ operational evaluation and pilots' workshop should be considered as significant high confidence results.

## A.3.5 Conclusions

### 1. Conclusions on concept clarification

The expansion of TSAA+ to GA will have impact on current GA operations / procedures. Current rules for GA pilots when in proximity of TCAS equipped traffic could be affected by the expansion of TSAA+ (i.e. GA pilot that is used to not to manoeuvre when in proximity of TCAS equipped traffic is – due to TSAA+ - able to avoid manoeuvre that is in contradiction to RA).

GA pilots are often not very familiar with TCAS behaviour and following operations and advisories (TA, RA) that are common for non-GA aircraft crew. For GA pilot with no previous TCAS experience it took some time to accommodate the rules of TCAS and use it for decision on appropriate manoeuvre. Information from TSAA+ influences the manoeuvre already performed by GA pilot. Ought to say, that in many cases the manoeuvre performed by GA pilot is not focused on having largest separation between ownship and traffic but to perform manoeuvre that keeps the traffic always in sight to meet the VFR rules. This manoeuvre is also often driven by the type of aircraft and various conditions of view from cockpit.

Pilots will need to be informed of how to use TSAA+ at least in a means of e-learning / how-to or video demonstration on simulator. The use of TSAA+ will not expect any special license for GA pilots.

### 2. Conclusions on technical feasibility

TSAA+ brings certain benefits to pilots. The benefits of TSAA+ may be pronounced together with other ADS-B data (at least position, altitude and vertical speed of traffic) and potentially the whole TSAA logic. Potential contradiction between current vertical trend of aircraft taken from ADS-B data as part of TSAA logic (↑↓) and issued RA (i.e. CLIMB) as part of TSAA+ logic must be considered in design stage.

In comparison to no device in GA cockpit, the benefit of TSAA+ is significant. The penetration of ADS-B in GA environment is crucial for the credibility of TSAA+ device in GA cockpit.

### 3. Conclusions on performance assessments

The content of information provided by TSAA+ on display is enough to determine the future path of aircraft to take proper/correct action to avoid collision. The GA pilot´s information needs have been filled by TSAA+ (but involving also other ADS-B data such as position, altitude and vertical speed of traffic). The form of presentation of TSAA+ content expects minor HMI adjustments. There is no significant discrepancy between system-provided information and user-required information. Pilot´s interpretation of all system states (based on the symbols and the information provided by TSAA and TSAA+) brings some questions and concerns (please see recommendations).

We have detected several issues with other traffic RAs, that have been classified by GA pilot as a command to ownship. An increased workload of pilots might be expected due to the novelty and amount of TSAA+ information in comparison to baseline (no device).

### A.3.6 Recommendations

The overall concept (providing RA information to pilots) was assessed as beneficial and useful. However, future work on HMI development is necessary.

Here we provide several suggestions that could be considered for future work:

- More striking colour of RA.
- The list of RAs included in TSAA+ for GA pilots could be limited to these RAs: climb, descent, do not climb, do not descent and level off.
- Both textual and graphical representations of RA to be considered to avoid confusion over the meaning.

# Appendix B Validation Exercise #05 Report

This appendix concludes validation report for EXE-PJ11.A4-V2-VALP-005, exercise performed by Thales.

## B.1 Summary of the Validation Exercise #05 Plan

As in the VALP PJ.11-A4_V2_VALP_SA+ (D6.1.010).

### B.1.1 Validation Exercise description, scope

This exercise for V2 maturity level was performed as FTS (Fast Time Simulation) on Thales simulation platform SIMPLY using TCAS II model according to [39].

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

The objective was to assess quantitatively, the benefits of TCAS II information broadcast ("+") on TSAA-equipped aircraft, in terms of probability of near mid-air collision (NMAC), reversal RAs and increase/decrease rate RAs.

Data received from EUROCONTROL (10^6 encounters) was generated by CAFÉ encounter model and were filtered to eliminate equipped-equipped or unequipped-unequipped encounters. Such filter eliminated 68% of the encounters, leaving a sample of 320000.

Encounter data from CAFÉ was sampled every second and interpolation has been done using MATLAB software to get data every 100 milliseconds.

CAFÉ Encounters included one unequipped aircraft (ownship) and one TCASII equipped aircraft (intruder).

Two scenarios have been used to analysis TSAA+ performances versus TSAA:

3. TCASII versus TSAA,
4. TCASII versus TSAA+.

In the first scenario original trajectories from EUROCONTROL have been used with the assumption that aircraft were equipped respectively with TCASII and TSAA (cf. B.2).

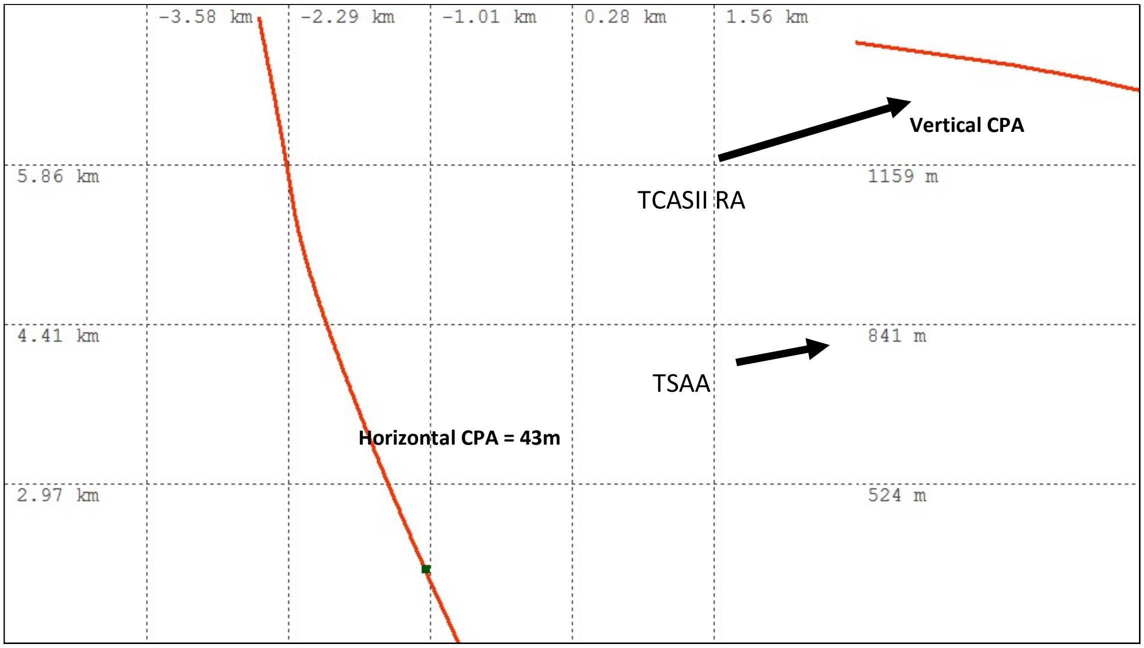



**Figure 6-14: Example of TCAS II vs TSAA**

In the second scenario 4 manoeuvres have been defined for the ownship aircraft [40] in order to implement TSAA+ function:

1. **Level Off**: The logic on the GA aircraft issues a level-off advisory that requires the pilot to manoeuvre to maintain a vertical speed equal to 0 ft/min.

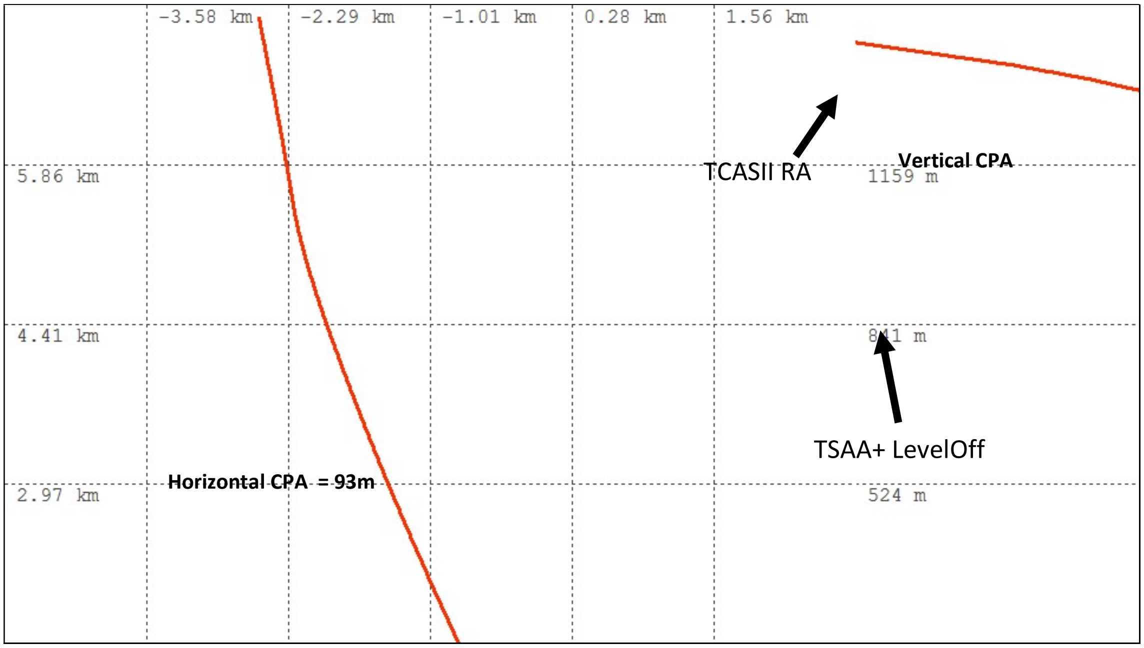



**Figure 6-15: Level Off manoeuver in TCASII vs TSAA+ encounter**

2. **Do Not Descend/Do Not Climb**: The logic of the GA aircraft issues an advisory to maintain a vertical speed that complies with the sense of intruder RA. If the sense is **Upward**, then vertical speed less or equal to 0 ft/min complies with the advisory. Thus, if the GA aircraft is climbing the pilot must level off. If the GA aircraft is already descending, then the pilot must maintain current vertical speed.

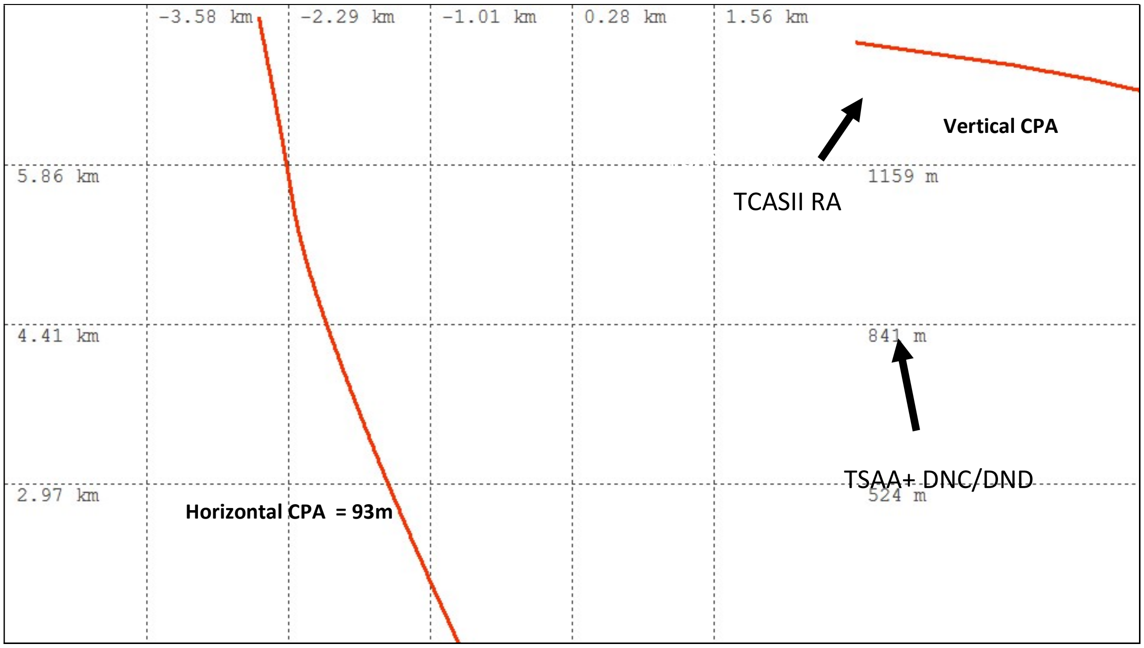



**Figure 6-16: DoNotClimb/DoNotDescend manoeuver in TCASII vs TSAA+ encounter**

3. **Descend/Climb**: The logic of the GA aircraft issues an advisory to maintain a vertical speed of 500 ft/min in the direction that complies with the sense of RA. If the sense is Upward, then descent rate equal to 500 ft/min complies with the advisory. We assume the aircraft is always able to achieve 500 ft/min.

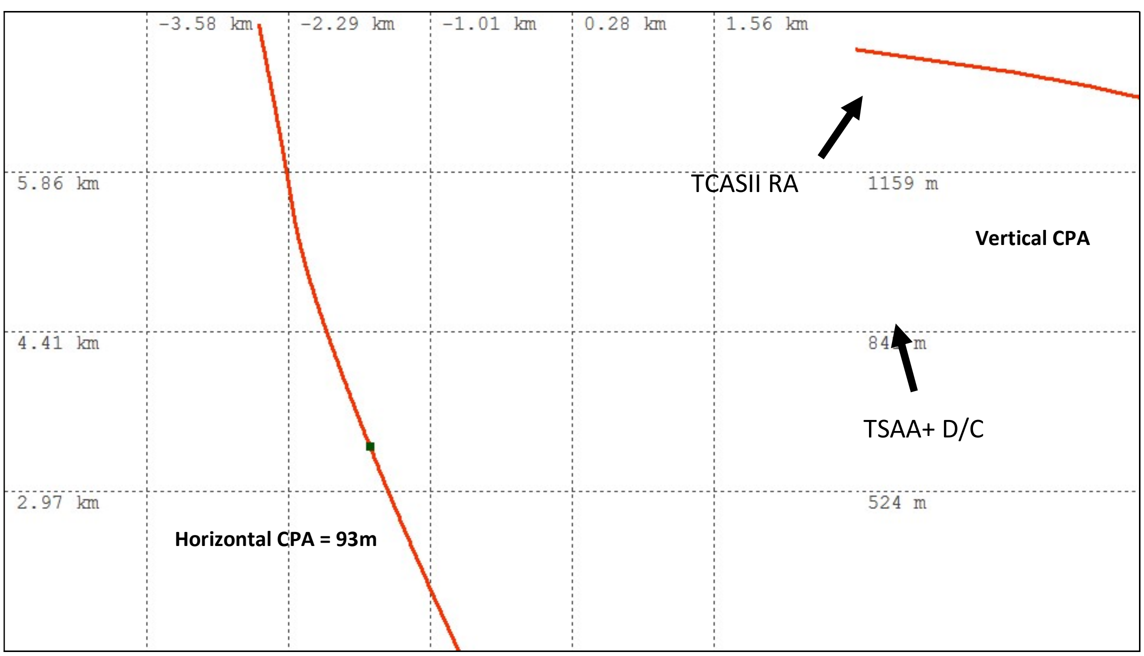



**Figure 6-17: Descend/Climb manoeuvre in TCASII vs TSAA+ encounter**

4. **Maintain Vertical Speed**: The pilot maintains the current vertical speed of the aircraft.

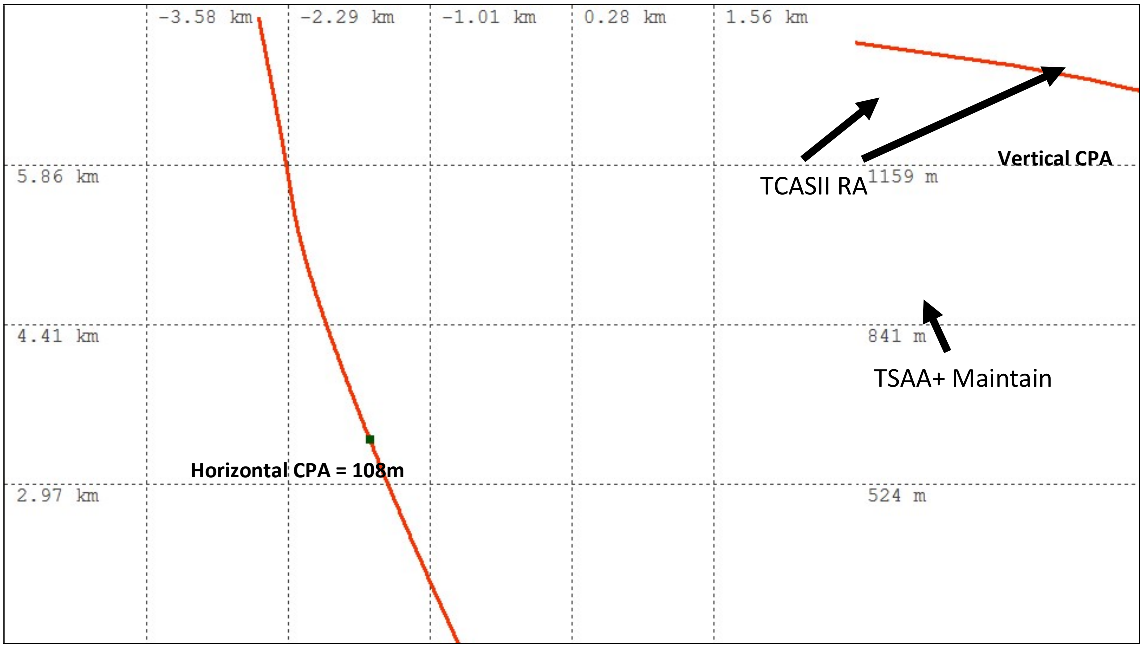



**Figure 6-18: Maintain vertical speed manoeuver in TCASII vs TSAA+ encounter**

The ownship aircraft in scenario 1 is supposed to react to intruder as a TSAA equipped aircraft and its original trajectory has not been modified unlike in V1 exercise where the ownship trajectory has been modified according preliminary pilot reaction model that has been discarded for V2 exercise.

The ownship aircraft in scenario 2 reacts to Active Resolution Advisory (ARA) field in TCAS squitter from intruder aircraft according 4 manoeuvers defined in [40], unlike in V1 exercise where TSAA+ aircraft has been supposed not to react to ARA field reception.

Aircraft (ownship and intruder) performances used for manoeuvers are:

- Maximum vertical rate: 6000 fpm
- Maximum vertical acceleration: 500 fpm/s
- Banking angle: 25°
- Banking angle rate: 1 °/s
- Maximum turn rate: 3 °/s

Reaction delays used for TSAA+ have been 3s and 5s.

Reaction delay for TCASII has been 5s.

### B.1.2 Summary of Validation Exercise #05 Validation Objectives and success criteria

| | |
|---|---|
| Identifier | **OBJ-PJ.11.A4-VALP-0001** |
| Objective | To evaluate the NMAC probability in the following encounter scenarios:<br>• TSAA/TCAS II<br>• TSAA+/TCAS II |
| Title | TSAA/TSAA+ NMAC probability assessment |
| Category | <safety> |
| EX5-CRT-PJ.11-A4-V2-VALP-001 | The NMAC probability is better in the TSAA+/TCAS II scenario than in the TSAA/TCAS II scenario. |

| | |
|---|---|
| Identifier | **EX5-OBJ-PJ.11.A4-VALP-0002** |
| Objective | To reduce cases of compromising RA with TSAA+ than with TSAA |
| Title | TSAA/TSAA+ Compromising intruder RA assessment |
| Category | <safety> |
| EX5-CRT-PJ.11-A4-V2-VALP-002 | The risk of avoidance invalidated by other aircraft with TSAA+ is at most 3% |

### B.1.3 Summary of Validation Exercise #05 Validation scenarios

Following scenarios have been applied in the validation:

- **TCAS II-equipped intruder vs. unequipped ownship**. The ownship has been supposed to react to intruder as a TSAA equipped aircraft because encounters provided have been generated according to controlled airspace features (cf. B.2) and its original trajectory has not been modified. The intruder has been equipped with *TCASII*, *Mode S transponder* and *ADS-B OUT*. The ownship has been equipped with *Mode C transponder*.

- **TCAS II-equipped intruder vs. TSAA+ equipped ownship** with the assumption, that TSAA+ aircraft, after the reception of ARA information from intruder, performs 4 types of manoeuver with 3s or 5s reaction delay. The intruder has been equipped with *TCASII*, *Mode S transponder* and *ADS-B OUT*. The ownship has been equipped with *Mode C transponder* and *ADS-B IN*.

### B.1.4 Summary of Validation Exercise #05 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| EX5-ASS-PJ.11-A4-001 | Pilot behaviour | Aircraft Equipage | Pilot behaviour is not repetitive for the same situation. | Pilot behaviour is based on time to react. Thus, the pilot behaviour depends on this factor, and it is not repetitive. | N/A | HP | Expert judgement | N/A | THALES | Low |
| EX5-ASS-PJ.11-A4-002 | Encounter Model | Environment constrains | Simulations will be limited to 2 aircraft: 1 ownship and 1 intruder. | Validation with more than 2 aircraft will be performed in V3. | N/A | Safety | Expert judgement | N/A | THALES | Low |
| EX5-ASS-PJ.11-A4-003 | Encounter Model | Aircraft Equipage | TSAA+ pilot in all encounters is aware that intruder is equipped with TCAS II, by Aircraft Operational status squitter reception | TSAA+ aircraft receive intruder TCAS II capability (Aircraft Operational Status squitter) before RA | N/A | Safety | Expert judgement | N/A | THALES | High |
| EX5-ASS-PJ.11-A4-004 | ARA Reception | Aircraft Technology | Each manoeuvre assumes that the GA aircraft is able to receive the Active Resolution Advisory (ARA) subfield from the TCAS-equipped aircraft | TSAA+ is based on RA awareness and ARA field in RA is received by ownship | N/A | Interoperability | Expert judgement | N/A | 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:

- Unequipped aircraft in Equipped-Unequipped encounters flight in controlled airspace and they are considered TSAA-equipped because this function has been performed by ATC.

## B.3 Validation Exercise #05 Results

### B.3.1 Summary of Validation Exercise #05 Results

| Validation Exercise #05 Validation Objective ID | Validation Exercise #05 Validation Objective Title | Validation Exercise #05 Success Criterion ID | Validation Exercise #05 Success Criterion | Sub-operating environment | Exercise #05 Validation Results | Validation Exercise #05 Validation Objective Status |
|---|---|---|---|---|---|---|
| OBJ-PJ.11.A4-VALP-0001 | TSAA/TSAA + NMAC probability assessment | EX5-CRT-PJ.11-A4-V2-VALP-001 | The NMAC probability is better in the TSAA+/TCAS II scenario than in the TSAA/TCAS II scenario | En-Route, TMA – various from high to low complexity | | |
| EX5-OBJ-PJ.11.A4-VALP-0002 | TSAA/TSAA + Compromising intruder RA assessment | EX5-CRT-PJ.11-A4-V2-VALP-002 | The risk of avoidance invalidated by other aircraft with TSAA+ is at most 3% (50% of current value) | En-Route, TMA – various from high to low complexity | | |

Table 17: Validation Results for Exercise 5

### B.3.2 Analysis of Exercise 5 Results per Validation objective

EUROCONTROL has provided 1 million safety encounters (i.e. with HMD<500ft) from CAFÉ Encounter Model. All encounters last 70 seconds.

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 is given every second. X and Y positions are distances respect to an unspecified origin whose location is not necessary for the successful outcome of the exercise.

Only Equipped-Unequipped encounters (approximately 32% of encounters) were filtered.

Such data has been post processed to MATLAB in order to have 100 milliseconds position, velocity and turn rate interpolation.

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

OBJ-PJ.11-A4-V-VALP-0002 for V2 validation phase refers to evaluation of safety of TSAA+ system during mixed equipage encounters. 3s and 5s reaction delays for TSAA+ have been used.

**OBJ-PJ.11.A4-VALP-0001:** *Evaluate the NMAC probability in the following encounter scenarios:*

- *TCAS II vs TSAA*
- *TCAS II vs TSAA+*

According to the TCAS MOPS [39], Near Mid Air Collision (NMAC) occurs when two aircraft come within 100ft vertically (VMD) and 500ft horizontally (HMD). The number of encounters used in simulations is too low for high level confident results.

Based on observations of European radar data, EUROCONTROL found that when HMD < 3000ft and VMD < 400ft there is a uniform distribution of observed encounters so NMAC conditions were extended to 400ft vertically (the maximum HMD is already less than 3000ft for all encounters) in order to have representative value of NMAC.

Results for TCAS II vs TSAA scenario are based on the assumption in B.2.

The computed PNMAC in TSAA scenarios is the reference for TSAA+ scenarios. The value is 0.83%.

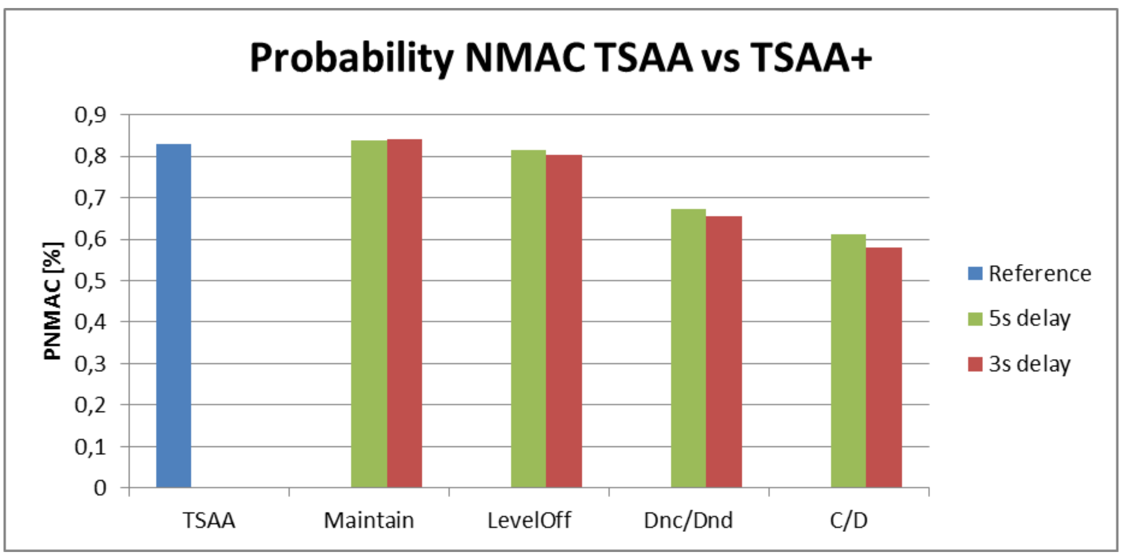



**Figure 6-19: Probability NMAC TSAA vs TSAA+**

In the figure on the top the best manoeuver among the four ones described in B.1.1 in order to reduce PNMAC is Climb/Descent. The reduction is 30%. Differences between 5s and 3s pilot reaction delays are negligible.

**EX5-OBJ-PJ.11.A4-VALP-0002:** ***Reduction of cases of compromising RA with TSAA+ than with TSAA***

RA compromising occurs when a manoeuvre (instigated by ATC or Pilot) leads to a new conflict situation (with a different aircraft) that would not have occurred without the manoeuvre. In this case TSAA/TSAA+ manoeuver could compromise intruder RA, generating an increase/decrease rate RA or reversal RA.

Results for TCAS II vs TSAA scenario are based on the assumption in B.2.

The computed ratio in TSAA scenarios is the reference for TSAA+ scenarios. The value is 0.44%.

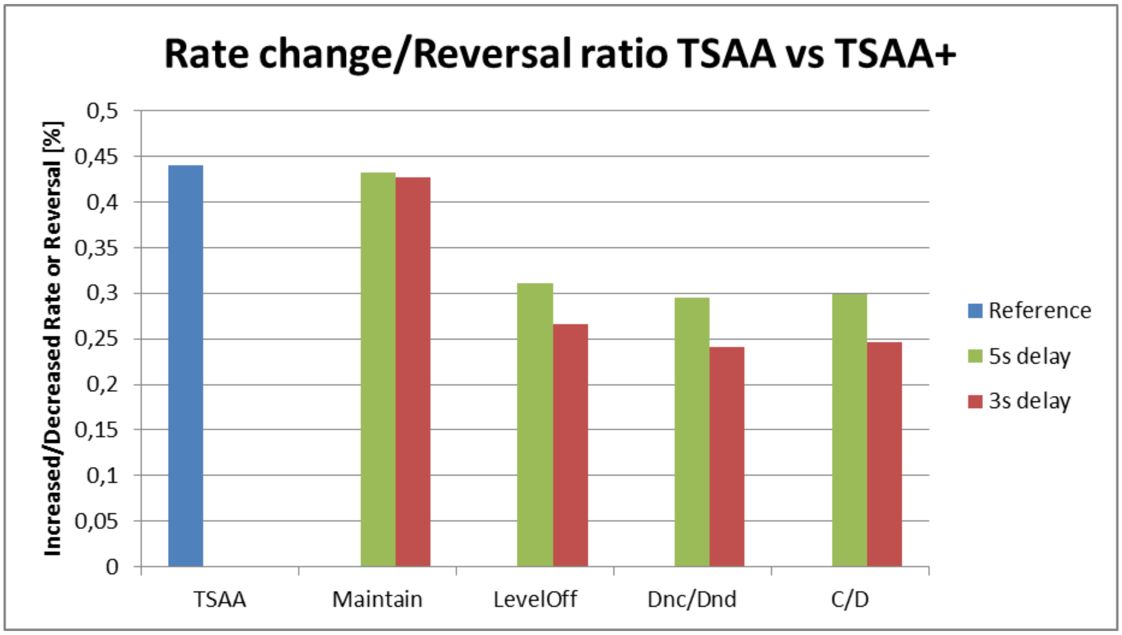



**Figure 6-20: Rate change/Reversal ratio TSAA vs TSAA+**

According to RA compromising definition (cf. 1), Climb/Descend and DoNotClimb/DoNotDescend manoeuver (cf. manoeuver 2 in B.1.1) are the safest with 44% of reduction compared to TSAA. Differences between 5s and 3s pilot reaction delays are negligible.

This result doesn't satisfy **EX5-CRT-PJ.11-A4-V2-VALP-002** successful criterion but it is important to keep in mind that the low number of analyzed encounters (370000) could decrease the real value and so larger number (e.g. several millions) should give a representative result.

### B.3.3 Unexpected Behaviours/Results

No unexpected behaviours/results found during V2 simulations.

### B.3.4 Confidence in Results of Validation Exercise 5

1. **Level of significance/limitations of Validation Exercise Results**

TSAA Pilot reaction model used in V1 exercise is discarded for V2 activities according to EUROCONTROL expert judgements. The results provided in this appendix are obtained using the assumption that TSAA function is approximated by ATC that is already taken into account in encounters from CAFÉ model.

All encounters are composed by only two aircraft and the impact of other neighbour aircraft on manoeuvers is not taken into account.

Equipped aircraft from CAFÉ model are supposed to have a TCAS II equipped aircraft behavior but sometimes this behavior doesn't comply TCASII MOPS [39].

In all encounters there is no separation between airspace classes (A,C,F and G) and between aircraft environments (TMA, En route).

### 2. Quality of Validation Exercises Results

V2 simulations have been performed with SIMPLY simulator with an increased sampling rate based on an interpolating point factor of 10 (e.g. 100ms sampling rate).

All TCASII/TSAA+ manoeuvers have been performed with constant parameters defined in B.1.1.

### 3. Significance of Validation Exercises Results

CAFÉ encounters have been used only for safety purpose. The metric used in V2 exercise is probability of NMAC and Rate change/Reversal but the number of Equipped-Unequipped encounters available for simulations (320000 encounters) has been too low for high confidence probability results.

Based on observations of European radar data, EUROCONTROL found that when HMD < 3000ft and VMD < 400ft there is a uniform distribution of observed encounters so NMAC conditions were extended horizontally (3000ft) and vertically (400ft) in order to have representative value of NMAC.

## B.3.5 Conclusions

The obtained results for TSAA vs TSAA+ show that the broadcast of equipage status of intruder aircraft is beneficial for GA pilots in case of intruder RAs.

Among the four manoeuvers tested in V2 simulations for TSAA+, Climb/Descend one (cf. manoeuver 3 in B.1.1) is the safest in terms of NMAC probability with 30% of reduction compared to TSAA. Differences between 5s and 3s pilot reaction delays are negligible.

According to RA compromising definition (cf. B.3.21), Climb/Descend and DoNotClimb/DoNotDescend manoeuvers (cf. manoeuvers 2 and 3 in B.1.1) are the safest with 44% of reduction compared to TSAA. Differences between 5s and 3s pilot reaction delays are negligible.

### 1. Conclusions on concept clarification

The obtained results indicate that the broadcast of equipage status of intruder aircraft may be beneficial for GA pilots in case of intruder RAs.

### 2. Conclusions on technical feasibility

Technical feasibility was not assessed at this stage.

# 3. Conclusions on performance assessments

PNMAC and Rate change/Reversal assessment is described in B.3.5.

## B.3.6 Recommendations

Obtaining results with higher significance would require new real time simulations with human in loop. Scenarios shall be also extended to several intruders to have more realistic use cases.

In addition, the obtained results indicate that the broadcast of equipage status of intruder aircraft is beneficial for GA pilots in case of intruder RAs.

All encounter data is not sorted by airspace classes (A, C, F and G) and aircraft environments (TMA, En-route) so results cannot give details about differences in airspace classes and environment. For next maturity phase more information in encounter data could show limits of TSAA+ in specific scenarios.

# Appendix C Validation Exercise #06 Report

TSAA is an application based on ADS-B aimed to provide an alerting to General Aviation (GA) pilots for surrounding traffic for which the algorithm detects a future conflict. The application has been specified in RTCA DO-317B/DO348 standards, which have been adopted by EUROCAE as equivalent ED-194A/ED-232. TSAA algorithm and application requirements have been tuned against encounter models representative of the US airspace and, while recognizing "state aircraft could potentially utilize this application to reduce the risk of a mid-air collision" considered only GA.

SESAR2020 PJ11-A4 has in its scope the study of possible benefit of providing to TSAA Pilot the information of a TCAS RA in case of a TCAS intruder (TSAA+). As part of this activity the TSAA performance has been preliminarily evaluated as a baseline for the TSAA+ improvements, considering:

- SSR radar tracks gathered in central Europe over 1 year (2015/16)
- mixed encounters (i.e. TSAA ownship and TCAS intruder)
- in which ownship were a mix of GA Fixed Wing, Rotary wing and state aircraft (with no TCAS)

While established methodology has been adopted for TSAA performance assessment, a different set of key performance indicators have been used, as considered more suitable for Safety and Operational Performance acceptability (Missed Alert %[4] and Outlying Alert %[5]). Results of preliminary assessment performed in V1 Validations on this initial set of EU encounters and comparison with similar results obtained for US airspace as described in RTCA/EUROCAE specifications, have highlighted some anomalies which have been presented to SC-186 experts. While the PJ11-A4 results are still incomplete, mainly due to the European encounters set under development (e.g. no GA-GA encounters, very few state encounters, no separate helicopters encounters) it is anticipated that an update of RTCA/EUROCAE standards may be necessary.

This appendix includes validation report for Validation Objective EXE-PJ.11-A4-VALP-0001 which is addressed by EXE06.

EXE06 has been performed by Leonardo in order to improve evaluation of the behaviour of currently defined Traffic Situation Awareness and Alerting (i.e. TSAA) using European representative encounters for GA Fixed Wing, Rotorcraft and State (as provided by EUROCONTROL).

## C.1 Summary of the Validation Exercise #06 Plan

Leonardo exercise (EXE-06) comprises a fast-time simulation complementing EXE-03 of V1 validation, by refining evaluation of TSAA alerting performance through differentiation between GA fixed wing and helicopter scenarios, High altitude and Low altitude operations, and evaluation of additional state mixed-equipage encounters. The need for refined evaluation has been identified during V1 validation.

[4] Missed alerts % includes both late alerts and events when no alert is issued; a late alert is any required alert issued less than 12.5 seconds before Closest Point of Approach (CPA)

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

## C.1.1 Validation Exercise description, scope

Considering that EUROCONTROL will not make available radar tracks of Uneq-Uneq close encounters in a timeframe compatible with V2 validations, V2 Validation objectives are:

- Encounter Modelling:
  - continue filtering out anomalous/unsuitable encounters from existing encounter set (e.g. split tracks, military parallel flights)
  - identification of «Helicopter encounters» from the Encounter Data set
  - analysis and validation of additional encounters from other ANSP
- V2 FTS Simulation Runs objectives:
  - Validation of new corrected ED-194A / DO-317B (Change 1) under development within WG-51 / SC-186
  - TSAA alerting performance assessment differentiated between GA Fixed Wing and Helicopter scenarios
  - TSAA alerting performance assessment differentiated between Airport /Low En-route

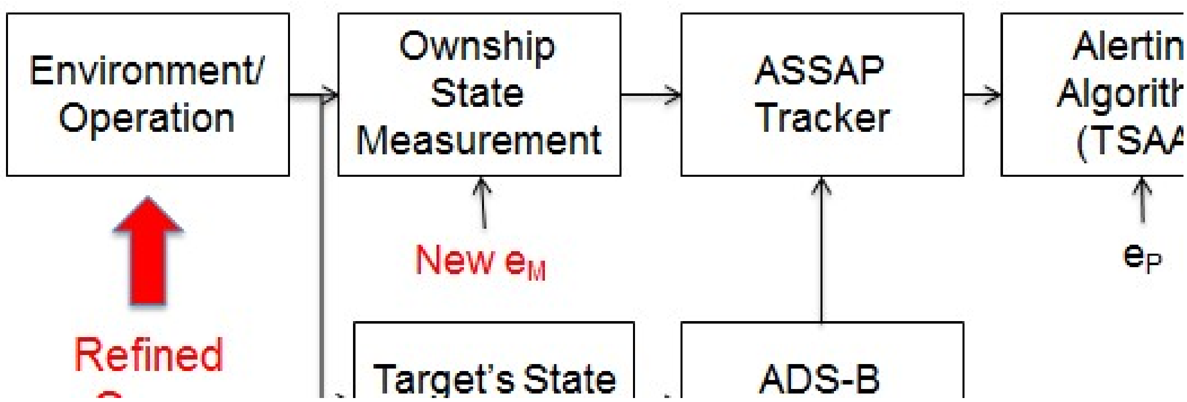



**Figure 6-21:** EXE06 concept diagram

## C.1.2 Summary of Validation Exercise #06 Validation Objectives and success criteria

Validation objective defined for this exercise is as follows:

| 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-V- | CRT-PJ.11-A4- | Partially (1 of 4 OBJ | EX6-0BJ-PJ.11- | EX6-CRT-PJ.11- |

| | | | | |
|---|---|---|---|---|
| VALP-0001 | VALP-0001-001 | SC's are fully covered, the rest is covered by EXE-04 and EXE-05) | A4-V2-VALP-001 | A4-V2-VALP-001 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-002 | EX6- CRT -PJ.11-A4-V2-VALP-002 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-003 | EX6- CRT -PJ.11-A4-V2-VALP-003 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-004 | EX6- CRT -PJ.11-A4-V2-VALP-004 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-005 | EX6- CRT -PJ.11-A4-V2-VALP-005 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-006 | EX6- CRT -PJ.11-A4-V2-VALP-006 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-007 | EX6- CRT -PJ.11-A4-V2-VALP-007 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-008 | EX6- CRT -PJ.11-A4-V2-VALP-008 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-009 | EX6- CRT -PJ.11-A4-V2-VALP-009 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-010 | EX6- CRT -PJ.11-A4-V2-VALP-010 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-011 | EX6- CRT -PJ.11-A4-V2-VALP-011 |
| | | | EX6-OBJ-PJ.11-A4-V2-VALP-012 | EX6- CRT -PJ.11-A4-V2-VALP-012 |

**Table 18: Validation Objectives addressed in Validation Exercise EXE06**

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-001 |

| | |
|---|---|
| Objective | Evaluate TSAA alerting performance of GA Fixed Wing aircraft against TCAS equipped Intruders in central EU Low Altitude operational environment |
| Title | Missed Alert in GA–TCAS Low Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-001 | Missed Alert % is <5% for GA Fixed Wing encounters in Low Altitude environment |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-002 |
| Objective | Evaluate TSAA alerting performance of Rotorcrafts against TCAS equipped Intruders in central EU Low Altitude operational environment |
| Title | Missed Alert in R–TCAS Low Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-002 | Missed Alert % is <5% for Rotorcraft encounters in Low Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-003 |
| Objective | Evaluate TSAA alerting performance of State Aircraft against TCAS equipped Intruders in central EU Low Altitude operational environment |
| Title | Missed Alert in StA–TCAS Low Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-003 | Missed Alert % is <5% for StA encounters in Low Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-004 |
| Objective | Evaluate TSAA alerting performance of GA Fixed Wing aircraft against TCAS equipped Intruders in central EU Low Altitude operational environment |
| Title | Outlying Alert in GA–TCAS Low Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-004 | Outlying Alert % is <5% for GA Fixed Wing encounters in Low Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-005 |
| Objective | Evaluate TSAA alerting performance of Rotorcrafts against TCAS equipped Intruders in central EU Low Altitude operational environment |
| Title | Outlying Alert in R–TCAS Low Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-005 | Outlying Alert % is <5% for Rotorcraft encounters in Low Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-006 |
| Objective | Evaluate TSAA alerting performance of State Aircraft against TCAS equipped Intruders in central EU Low Altitude operational environment |
| Title | Outlying Alert in StA–TCAS Low Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-006 | Outlying Alert % is <5% for StA encounters in Low Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-007 |
| Objective | Evaluate TSAA alerting performance of GA Fixed Wing aircraft against TCAS equipped Intruders in central EU High Altitude operational environment |
| Title | Missed Alert in GA–TCAS High Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-007 | Missed Alert % is <5% for GA Fixed Wing encounters in High Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-008 |
| Objective | Evaluate TSAA alerting performance of Rotorcrafts against TCAS equipped Intruders in central EU High Altitude operational environment |
| Title | Missed Alert in R–TCAS High Altitude |
| Category | <safety> |

| | |
|---|---|
| EX6-CRT-PJ.11-A4-V2-VALP-008 | Missed Alert % is <5% for Rotorcraft encounters in High Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-009 |
| Objective | Evaluate TSAA alerting performance of GA Fixed Wing aircraft against TCAS equipped Intruders in central EU High Altitude operational environment |
| Title | Outlying Alert in GA–TCAS High Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-009 | Missed Alert % is <5% for StA encounters in High Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-010 |
| Objective | Evaluate TSAA alerting performance of Rotorcrafts against TCAS equipped Intruders in central EU High Altitude operational environment |
| Title | Outlying Alert in R–TCAS High Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-010 | Outlying Alert % is <5% for GA Fixed Wing encounters in High Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-011 |
| Objective | Evaluate TSAA alerting performance of Rotorcrafts against TCAS equipped Intruders in central EU High Altitude operational environment |
| Title | Outlying Alert in R–TCAS High Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-011 | Outlying Alert % is <5% for Rotorcraft encounters in High Altitude |

| | |
|---|---|
| Identifier | EX6-OBJ-PJ.11-A4-V2-VALP-012 |
| Objective | Evaluate TSAA alerting performance of State Aircraft against TCAS equipped Intruders in central EU High Altitude operational environment |

| | |
|---|---|
| Title | Outlying Alert in StA–TCAS High Altitude |
| Category | <safety> |
| EX6-CRT-PJ.11-A4-V2-VALP-012 | Outlying Alert % is <5% for StA encounters in High Altitude |

### C.1.3 Summary of Validation Exercise #06 Validation scenarios

Figure below provides a pictorial view of the different class of encounters, distinguished between aircraft equipped with TCAS II (Equipped) and not (Unequipped).

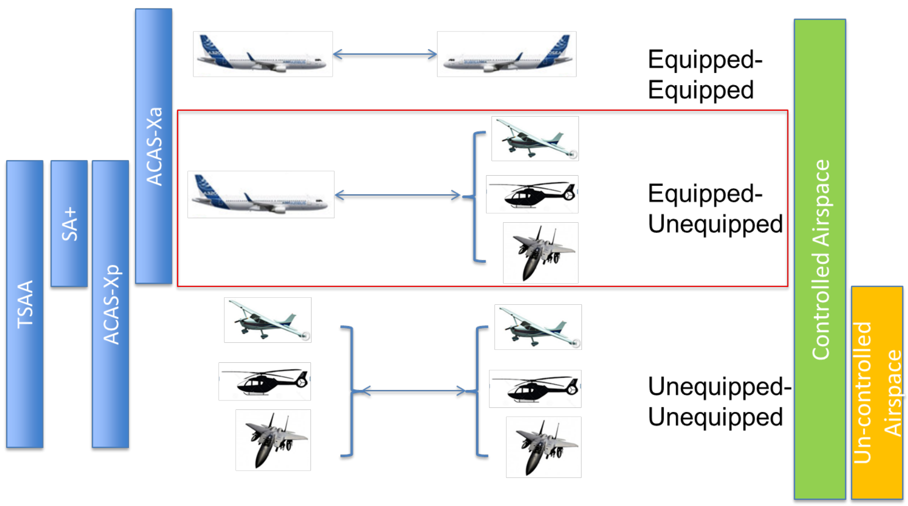



**Figure 6-22: Encounter types**

Encounter set used in PJ11-A4 V2 Validations will use the same Encounter sets derived from SSR Radar tracks recorded in core Europe during 1-year time frame (2015/2016) by 3 ANSP, representing a de-identified sample of European mixed equipage encounters (TCAS equipped / TCAS unequipped). This encounter set has been provided by EUROCONTROL as sub-product of ACAS-Xa encounter modelling activity.

A total of 8389 Radar tracks of close encounters have been scrutinized and anomalous data have been filtered out (a total of 4551 encounters, i.e. 54.2% of the initial data), leaving a sample of 3838 validated encounters (3726 GA/R and 112 StA 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. aircraft 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 StA, intentional proximity, or other SUR anomalies.

#### Reference Scenario(s)

Reference scenarios are typical mixed encounters (i.e. ownship TCAS unequipped / intruder TCAS equipped) as gathered as SSR radar tracks in representative central Europe controlled airspace during 2015/2016.

Reference scenarios will be characterized by Operational environment and Airspace user category (as described below).

### Operational environments

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.

10.000 ft MSL can be considered the maximum altitude for unpressurized aircraft (for FAR 91 ops you can legally fly up to 12,500' without any supplemental oxygen & between 12,500'-14,000' for less than 30 minutes). Furthermore 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.

Similarly, to previous EXE03, the criteria to associate an encounter to an operational environment will be the altitude and distance from airport (if made available as part of encounter data) of the ownship at the Closest Point of Approach (CPA).

### Airspace user category

Airspace user categories considered as ownship will be:

- General Aviation Fixed Wing aircraft
- Rotorcrafts (including state rotorcrafts)
- State aircraft (non-transport type)

### Solution Scenario(s)

Solution scenario will consider:

- all General Aviation and StA aircraft with ADS-B receiver i.a.w. DO-260B, and an ASSAP processing and TSAA application i.a.w. DO-317B;
- all General Aviation and StA aircraft with navigation Position and Velocity accuracy category of NACp=8 and NACv=1 or better;
- all TCAS equipped aircraft with a GNSS Navigation source with NACp=8 and NACv=1 or better;

For background on Navigation source chosen accuracies (NACp/NACv) see VALP V2 sect 5.3.4.2.

### C.1.4 Summary of Validation Exercise #01 Validation Assumptions

| Identifier | Title | Type of Assumption | Description | Justification | Flight Phase | KPA Impacted | Source | Value(s) | Owner | Impact on Assessment |
|---|---|---|---|---|---|---|---|---|---|---|
| EX6-ASS-PJ.11-A4-001 | Single Alert | Aircraft Equipage | 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 | ED-194A/DO-317B | N/A | PJ.11 | Low |
| EX6-ASS-PJ.11-A4-002 | Helicopter encounters characteristics | Encounters | Helicopter encounters will be identified by means of track characteristics (e.g. curvature radius 0.25 NM at level flight; change in altitude with no change in position; stall speed below min threshold, etc) | No information present in encounter set on type of aircraft (Rotorcraft/Fixed Wing) | ALL | Safety | PJ11 | N/A | PJ.11 | Low |
| EX6-ASS-PJ.11-A4-003 | Airprox definition | Safety | Airprox is defined as equivalent to penetration of HAZ volumes | FAA/MITRE HF study at the basis of HAZ/HAZ' volumes (see sect.3.4 of [44]) indicate that pilot feels in danger if another aircraft enters in HAZ volume | ALL | Safety | FAA | see sect.3.4 of [44] | PJ.11 | Low |

| Identifier | Title | Type of Assumption | Description | Justification | Flight Phase | KPA Impacted | Source | Value(s) | Owner | Impact on Assessment |
|---|---|---|---|---|---|---|---|---|---|---|
| EX6-ASS-PJ.11-A4-004 | Pilot reaction | Safety | On issuance of a correct TSAA Alert a pilot is capable to avoid an Airprox with a probability of 0.5 | In accordance to the study in [45], the probability of a pilot to see an intruder within his FoV is 0.5.[6] | ALL | Safety | Lincoln Lab study [45] | P(Airpox avoidance\|alert) =1 | PJ.11 | High |
| EX6-ASS-PJ.11-A4-005 | Induced Airprox | Safety | TSAA induced Airprox are negligible | In case of Outlying alerts, the pilot must always visually acquire the intruder before doing any manoeuvre | ALL | Safety | PJ11-A4 | N/A | PJ.11 | Low |

Table 19: Validation Assumptions overview

## C.2 Deviation from the planned activities

During the Validation Planning phase new state encounters extracted from other ANSP Radar tracks were envisioned, which did not materialise due to lack of resources from Eurocontrol.

## C.3 Validation Exercise #06 Results

[6] This study placed pilots in a near passing case (altitude separation 500 ft and horizontal separation as small as manageable – typically a few tenths of a mile) while taking great care that they were not aware that the flight they were performing was out of the ordinary (this is actual flight trial – not simulation). The overall outcome of the study showed about 50% failure rate to see the other aircraft in good weather conditions in spite that the approaching aircraft was within the surveillance field of view.

The assumption considers that if the pilot is alerted by TSAA, then he always visually acquires the intruder, and manoeuvring in accordance to Rule of the Air, he is able to avoid an Airprox.

### C.3.1 Preparation of Validation Exercise #06

**Ownship and ADS-B improved error models**

In the EXE03 the errors of position and speed were modeled as Gaussian noise with zero mean and standard deviation depending for NACp and NACv. ADS-B Gaussian error model for Position and Velocities has been considered too pessimistic (suggestion by SC-186):

Alternative error models were identified, analysed, implemented and validated for Horizontal Position and Velocity (based on Gauss-Markov model) and for Altitude (ICAO Annex 10 error model).

A degradation Run of ALL Pseudo True Tracks encounters used for EXE03 (with the same NACp=8 and NACv=1) was performed. A first comparison (only one degraded Run) showed that the results of the TSAA with these degraded encounters were better than those obtained with previous Gaussian model degrader, so we derived the indication that more realistic error models could potentially resolve the Outlying Alerts % issue seen in V1.

**Identification of Helicopter encounters**

Initially criteria based on the shape of trajectory in XY plane was developed: the encounter with a change in heading of at least 180 deg with a curvature radius < 0.25 NM with not excessive vertical speed were selected as possible helicopter encounter. 0.4 NM was identified as the curvature radius for a piper aircraft at 80 knots and 3 deg/s standard maneuver, 0.25NM radius threshold was chosen. At the end of this inspection 122 encounters of 3838 were selected.

A second possible complementary/alternative selection criterion was identified based on the ground speed, which has been evaluated and implemented. The criterion was: encounters which have a minimum ground (gs) speed less than 40knots and are not on-ground. The rationale of the 40knots threshold was based on the stall speed for Piper aircraft. Using this criterion 844 encounters of 3838 were selected.

After discussion with PJ11-A4 Partners it was decided to use only the second criteria based on gs (and discard previous based on curvature radius).

**High/Low altitude Encounters classification**

Due to lack of information of Airport vicinity of Encounters it was only possible to differentiate between Low Altitude airspace (EnRoute + Airport) and High Altitude airspace (High EnRoute).

The criteria used for selecting Low Altitude airspace and High Altitude airspace was based on ownship altitude @CPA:

- Altitude @CPA >=10.000 feet => High Altitude airspace
- Altitude @CPA <10.000 feet => Low Altitude airspace

Classification Results:

- 203 High Altitude airspace Encounters
- 3557 Low Altitude airspace Encounters

**Continuous filtering of defective operational encounters**

Starting from EXE03 Operational Encounter set:

- 77 Encounters have been excluded as proposed by Eurocontrol
- 3 Encounters (2 already included in previous point) have been excluded from V1 Encounter Set following Leonardo visual inspection
  - ansp6_2015-08-29_00886
  - ansp3_2015-09-28_01106 (already included in previous point)
  - ansp3_2015-10-01_00620 (already included in previous point)
- Based on the analysis of EXE06 preliminary simulations on True Tracks, it was decided to remove the following encounters:
  - ansp6_2015-08-10_0708 (StA Low raising Outlying Alert)
  - ansp6_2015-07_10_00655 (RO Low raising Late Alert)

In addition, 2 encounters of EXE03 were modified to remove spurious parts identified in the course of EXE06 activities:

- ansp3_2015-06-03_01818 (StA Low raising Outlying Alert);
- ansp6_2015-08-29_00312 (FW Low raising Outlying Alert)

Total of 3758 Encounters have been be used for EXE06 (were 3838 in EXE03 set).

**DO-317B ASA MOPS (incl. TSAA) under revision**

Leonardo has been part of the effort for DO-317B Change 1, necessary for the correction of material errors identified in DO-317B Test Tracks.

Leonardo (and Honeywell) participated to the SC-186 / WG-51 Joint Virtual Plenary meeting held on the 7th September (webex) and received upgraded test vectors on 22nd of Sept.

Upgraded tracks has been tested with Leonardo's TSAA simulator which implements DO-317B (optional) Velocity tracker function.

Only «truth» and «1090/ADS-B» test tracks tested (Must, Must Not, Non Accel). No abnormal behaviours found:

- All MUST test track raise an Alert before 12.5 sec to the CPA
- All MUST NOT test track DO NOT raise an Alert
- All NonAccel test track raise an Alert before 35 sec to the CPA

| CLASS | Encounter Classification | Number of Encounters |
|---|---|---|
| FW Low | Could Alert | 1819 |
| FW Low | Must Alert | 16 |
| FW Low | Must Not Alert | 872 |

| | | |
|---|---|---|
| | **Total** | **2707** |
| RO Low | Could Alert | 550 |
| RO Low | Must Alert | 12 |
| RO Low | Must Not Alert | 222 |
| | **Total** | **784** |
| StA Low | Could Alert | 42 |
| StA Low | Must Alert | 1 |
| StA Low | Must Not Alert | 21 |
| | **Total** | **64** |
| FW High | Could Alert | 80 |
| FW High | Must Alert | 5 |
| FW High | Must Not Alert | 67 |
| | **Total** | **152** |
| RO High | Could Alert | 21 |
| RO High | Must Alert | 1 |
| RO High | Must Not Alert | 8 |
| | **Total** | **30** |
| StA High | Could Alert | 4 |
| StA High | Must Alert | 1 |
| StA High | Must Not Alert | 16 |
| | **Total** | **21** |
| Not in EXE06 | Could Alert | 71 |
| Not in EXE06 | Must Alert | 7 |
| Not in EXE06 | Must Not Alert | 2 |
| | **Total** | **80** |
| **TotalEncounter EXE03** | | **3838** |
| **TotalEncounter EXE06** | | **3758** |

Table 20: Encounters classification (MA, MNA, CA)

## C.3.2 Summary of Validation Exercise #06 Results

| Validation Exercise #06 Validation Objective ID | Validation Exercise #06 Validation Objective Title | Validation Exercise #06 Success Criterion ID | Validation Exercise #06 Success Criterion | Sub-operating environment | Exercise #06 Validation Results | Validation Exercise #06 Validation Objective Status |
|---|---|---|---|---|---|---|
| EX6-OBJ- | Missed | EX6-CRT- | Missed Alert | Low Altitude | **2,5%** | **OK** |

| | | | | | | |
|---|---|---|---|---|---|---|
| PJ.11-A4-V2-VALP-001 | Alert in GA–TCAS encounters | PJ.11-A4-V2-VALP-001 | is <5% | | **+/- 1,2%** | |
| EX6-OBJ-PJ.11-A4-V2-VALP-002 | Missed Alert in R–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-002 | Missed Alert is <5% | Low Altitude | **0%** <br> **+/- 0%** | **OK** |
| EX6-OBJ-PJ.11-A4-V2-VALP-003 | Missed Alert in StA–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-003 | Missed Alert is <5% | Low Altitude | **0%** <br> **+/- 0%** | **OK** |
| EX6-OBJ-PJ.11-A4-V2-VALP-004 | Outlying Alerts in GA–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-004 | Outlying Alert is <5% | Low Altitude | **5%** <br> **+/- 0,3%** | **NOK** |
| EX6-OBJ-PJ.11-A4-V2-VALP-005 | Outlying Alert in R–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-005 | Outlying Alert is <5% | Low Altitude | **0,5%** <br> **+/- 0,2%** | **OK** |
| EX6-OBJ-PJ.11-A4-V2-VALP-006 | Outlying Alert in StA–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-006 | Outlying Alert is <5% | Low Altitude | **29,5%** <br> **+/- 2,4%** | **NOK** |
| EX6-OBJ-PJ.11-A4-V2-VALP-007 | Missed Alert in GA–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-007 | Missed Alert is <5% | High Altitude | **0%** <br> **+/- 0%** | **OK** |
| EX6-OBJ-PJ.11-A4-V2-VALP-008 | Missed Alert in R–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-008 | Missed Alert is <5% | High Altitude | **0%** <br> **+/- 0%** | **OK** |
| EX6-OBJ-PJ.11-A4-V2-VALP-009 | Missed Alert in StA–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-009 | Missed Alert is <5% | High Altitude | **0%** <br> **+/- 0%** | **OK** |
| EX6-OBJ-PJ.11-A4-V2-VALP-010 | Outlying Alerts in GA–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-010 | Outlying Alert is <5% | High Altitude | **5%** <br> **+/- 1%** | **NOK** |

| | | | | | | |
|---|---|---|---|---|---|---|
| EX6-OBJ-PJ.11-A4-V2-VALP-011 | Outlying Alert in R–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-011 | Outlying Alert is <5% | High Altitude | **0%** **+/- 0%** | **OK** |
| EX6-OBJ-PJ.11-A4-V2-VALP-012 | Outlying Alert in StA–TCAS encounters | EX6- CRT - PJ.11-A4-V2-VALP-012 | Outlying Alert is <5% | High Altitude | **5.2%** **+/- 6%** | **NOK** |

**Table 21: Validation Results for Exercise 6**

### C.3.3 Analysis of Exercise 6 Results per Validation objective

In a similar way as what has been done in V1 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.

| Name | TotReq Alr | *OkAlr* | *LateAlr* | *NoAlr* | TotRaised Alr | Req Alr | RepReq Alr | Perm Alr | RepPerm Alr | Outlying Alr | Missed Alert % | Mean CPA | Outlying Alert % | Repeat Alert % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FW Low | 23 | 22 | 1 | 0 | 306 | 20 | 10 | 259 | 7 | 10 | 4,3% | 32 | 3,3% | 5,6% |
| RO Low | 12 | 12 | 0 | 0 | 195 | 12 | 0 | 178 | 5 | 0 | 0,0% | 34 | 0,0% | 2,6% |
| StA Low | 2 | 2 | 0 | 0 | 8 | 1 | 0 | 5 | 0 | 2 | 0,0% | 35 | 25,0% | 0,0% |
| FW High | 14 | 14 | 0 | 0 | 21 | 7 | 1 | 9 | 3 | 1 | 0,0% | 33 | 4,8% | 19,0% |
| RO High | 1 | 1 | 0 | 0 | 4 | 1 | 0 | 3 | 0 | 0 | 0,0% | 35 | 0,0% | 0,0% |
| StA High | 1 | 1 | 0 | 0 | 3 | 1 | 0 | 2 | 0 | 0 | 0,0% | 26 | 0,0% | 0,0% |
| **TOT** | **53** | **52** | **1** | **0** | **537** | **42** | **11** | **456** | **15** | **13** | | | | |

**Table 22: Results for Pseudo True Tracks**

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

**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

As it can be seen from Table 22, only Outlying Alert% for State Aircraft in Low Airspace is above 5% threshold.

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 described in Appendix H Pseudo True Track degradation model, considered a Gaussian error distribution both for position and speed for ownship and intruder.

As described in VALR V1 C1.3, EXE06 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 7 times to capture the effect of the random errors on the system performance, thus requiring in total 7x3838 encounter simulations[7].

It was then taken the average values of the Alert counts for the 7 degradation runs, as reported in Table 23.

| Name | TotReq Alr | OkAlr | LateAlr | NoAlr | TotRaised Alr | Req Alr | RepReq Alr | Perm Alr | RepPerm Alr | Outlying Alr | Missed Alert % | Mean CPA | Outlying Alert % | Repeat Alert % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FW Low | 23,0 | 22,4 | 0,6 | 0,0 | 384,3 | 20,1 | 12,3 | 317,3 | 15,3 | 19,3 | 2,5% | 32 | 5,0% | 7,2% |
| RO Low | 12,0 | 12,0 | 0,0 | 0,0 | 203,1 | 12,0 | 0,7 | 183,1 | 6,3 | 1,0 | 0,0% | 33 | 0,5% | 3,4% |
| StA Low | 2,0 | 2,0 | 0,0 | 0,0 | 7,6 | 1,1 | 0,3 | 4,0 | 0,0 | 2,1 | 0,0% | 35 | 29,5% | 4,4% |
| FW High | 14,0 | 14,0 | 0,0 | 0,0 | 31,0 | 7,4 | 2,1 | 10,9 | 9,0 | 1,6 | 0,0% | 33 | 5,0% | 35,8% |
| RO High | 1,0 | 1,0 | 0,0 | 0,0 | 3,9 | 1,0 | 0,0 | 2,9 | 0,0 | 0,0 | 0,0% | 35 | 0,0% | 0,0% |
| StA High | 1,0 | 1,0 | 0,0 | 0,0 | 5,3 | 1,0 | 0,1 | 3,7 | 0,1 | 0,3 | 0,0% | 25 | 5,2% | 5,2% |
| TOT | 53 | 52 | 1 | 0 | 635 | 43 | 16 | 522 | 31 | 24 | | | | |

**Table 23:Results for Degraded Tracks**

As it can be seen from Table 22, Outlying Alert% for State Aircraft both in Low and High Airspace are above 5% threshold.

**Comparison with previous V1 results**

*We have performed a comparison of results between 2017 degrader and 2018 degrader.*

The results of V1 and V2 exercises cannot be compared directly since the encounter set for each family are different. So, in order to better understand the result difference due to the different degradation error model, we decide to reorganize the results of the V1 EXE03 with the encounters sets used for V2 EXE06 (obviously pseudo true track results are identical since the TSAA algorithm is not modified).

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

| | V1 Results | | | | | V2 Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Name | Missed Alert % | Alr Time to CPA mean [sec] | Outlying Alert % | Repeat Alert % | Outlying Alr/# HAZ penetr. | Missed Alert % | Alr Time to CPA mean [sec] | Outlying Alert % | Repeat Alert % | Outlying Alr/# HAZ penetr. |
| FW Low | 0,0% | 33 | 12,4% | 14,5% | 3,5 | 2,5% | 32 | 5,0% | 7,2% | 0,8 |
| RO Low | 0,0% | 33 | 3,4% | 14,4% | 0,8 | 0,0% | 33 | 0,5% | 3,4% | 0,1 |
| StA Low | 0,0% | 35 | 17,8% | 41,7% | 1,8 | 0,0% | 35 | 29,5% | 4,4% | 1,1 |
| FW High | 0,0% | 33 | 8,2% | 65,8% | 0,7 | 0,0% | 33 | 5,0% | 35,8% | 0,1 |
| RO High | 0,0% | 33 | 0,0% | 0,0% | 0,0 | 0,0% | 35 | 0,0% | 0,0% | 0,0 |
| StA High | 0,0% | 26 | 3,7% | 28,1% | 0,3 | 0,0% | 25 | 5,2% | 5,2% | 0,3 |

**Table 24: Degraded Tracks results (3 Runs only) comparison with V1 and V2 degraders**

If for some of the encounter sets Outlying alert % get worse with 2018 degrader (e.g. StA Low 17.2% to be compared with 29.5%, StA High 3.6% to be compared with 5.2%) as it has been already pointed out in DO-348, % increase due to the fact that denominator decreases (i.e. number of raised alerts), as it can be noticed comparing TotRaisedAlr and OutlyingAlr.

Encounters with 2017 Degrader have always obtained a number of outlying alert higher or equal to those of 2018 Degrader.

Encounters with 2017 Degrader have always obtained a total number of raised alert higher or equal to those of 2018 Degrader.

Also, percentage of late alerts is higher with 2018 degrader, notwithstanding always within limits.

In reality this is not due to the degradation method used because the pseudo true tracks already have a late alert. Some Runs of degradation 2018 do not present any late alert (so that on average on the 7 runs we have 0.6 occurrences of late alert) but from this point of view 2017 degrader seems to provide better results.

In summary, it can be said that looking at the number of outlying alerts it is confirmed that for the 2018 degrader the situation improves considerably.

### C.3.4 Unexpected Behaviours/Results

No unexpected behaviours of the simulation platform, nor simulation results have been experienced.

### C.3.5 Confidence in Results of Validation Exercise 6

#### 1. Level of significance/limitations of Validation Exercise Results

In encounter modelling the assumption is that of the whole population of possible encounters of a certain category (e.g. historical encounters of General Aviation and Transport aircraft in airspace below 10.000 feet not in airport environment), the subset of encounters captured (e.g. by radar) are sufficiently representative of the whole population (i.e. with same characteristics in terms of mean and standard deviation of a certain property).

It is reasonable to assume that if we take different sets of sample encounters all with the same count of encounters, the average value for each set follow a gaussian distribution, centred on the whole population average value.

The problem is how large should be an encounter set so that if we take different sets the average values are with a certain probability (confidence level) within a certain interval from the population average (confidence interval).

As an example, with 100 encounters belonging to a certain category of encounters (e.g. GA-TCAS Must Alert encounters), using a certain Alerting Algorithm we observe 8% of Missed Alerts. We would like to know with a confidence level of 95% the confidence interval, to see if it is less than 3%, so to conclude that with 95% confidence level the population average would be above the 5% threshold.

Considering Annex 1 as the theoretical framework, we would have 8 observations (Missed Alert) on average for each degradation RUN out of 100 Must Alert encounters of each encounter set, i.e. 0,08 mean value, with a standard deviation calculated as:

$$\mu_1 = \frac{O_1}{N}$$

$$\sigma_1 - \sqrt{\mu_1(1-\mu_1)/N}$$

Where:

$N$ is the number of simulated encounters (# of runs x number of encounters in each sample)

$O_1$ $O_1$ *and* $O_2$ are the # of observations of Missed Alerts with Algorithm 1

$\mu$ is the mean of the Missed Alert % with Algorithm 1

$\sigma_1$ $\sigma_1$ *and* $\sigma_2$ is the standard deviation of the Missed Alert % Algorithm 1

or 8% +/- 2,7%. At 2 sigma (95%) the interval would be 2,6% - 13,4%. So we could not conclude with 95% confidence that Outlying Alerts are above 5%.

# 2. Quality of Validation Exercises Results

This validation exercise used an improved dataset as 80 encounters previously used in V1 Validations, has been found faulty and not usable for various reasons, and 2 encounter tracks have been corrected.

Better and more realistic error models for Ownship and Intruder's position and velocity data have been used.

Furthermore 7 degradation Runs have been performed instead of the previous 3 Runs of V1, increasing the number of overall data set and reducing confidence interval.

More specific data set have been used separating GA FW from Rotorcrafts encounters and High/Low Airspace encounters.

Having said this, the following validation limitations still remain:

- We have been using only encounters with TCAS intruders, which is a subset of the whole possible encounters.
- We have assumed that the operational encounters recorded by three ANSP in central Europe are representative of the whole European airspace.
- The sample encounters set used in EXE06 where not representative enough, e.g. most of them having only 1 Must Alert encounter tracks.
- Low Airspace scenarios included both En-route and Airport scenarios, which we can expect to have quite different characteristics in terms of frequency of airproxy.

# 3. Significance of Validation Exercises Results

If we look at the Missed Alert % and Outlying Alerts % of Table 23, we calculate the standard deviation, and consider the 95% confidence interval (2 sigma), we see that:

| **Missed Alert %** | avrg | sigma | confidence interval lower limit (95%) | confidence interval higher limit (95%) | |
|---|---|---|---|---|---|
| FW Low | 2,5% | 1,2% | 0,0% | 4,9% | YES |
| RO Low | 0,0% | 0,0% | 0,0% | 0,0% | YES |
| StA Low | 0,0% | 0,0% | 0,0% | 0,0% | YES |
| FW High | 0,0% | 0,0% | 0,0% | 0,0% | YES |
| RO High | 0,0% | 0,0% | 0,0% | 0,0% | YES |
| StA High | 0,0% | 0,0% | 0,0% | 0,0% | YES |

**Table 25: Missed Alert % confidence interval @95%**

For all encounter types and scenarios, the Missed Alert % is below 5% with a confidence level of 95%.

| **Outlying Alert %** | Avrg | sigma | confidence interval lower limit (95%) | confidence interval higher limit (95%) | |
|---|---|---|---|---|---|
| FW Low | 5,0% | 0,3% | 4,5% | 5,6% | NO |
| RO Low | 0,5% | 0,2% | 0,1% | 0,9% | YES |
| StA Low | 29,5% | 2,4% | 24,7% | 34,4% | YES |
| FW High | 5,0% | 1,0% | 3,0% | 7,0% | NO |

| | | | | | |
|---|---|---|---|---|---|
| RO High | 0,0% | 0,0% | 0,0% | 0,0% | YES |
| StA High | 5,2% | 6,0% | -6,7% | 17,1% | NO |

**Table 26: Outlying Alert % confidence interval @95%**

Only for Rotorcraft Low Airspace and High Airspace we can conclude that Outlying Alert is below 5% acceptability Threshold.

For State Aircraft Low Airspace, we can state that Outlying Alert is above 5% threshold with 95% confidence.

## C.3.6 Conclusions

Table below compare the different TSAA performance assessments performed for DO-348, PJ11-A4 V1 validation (EXE03) and the PJ11-A4 V2 validation (EXE06):

| | DO-348 | PJ11-A4 (EXE03) | PJ11-A4 (EXE06) |
|---|---|---|---|
| **Airspace** | NAS | 3 EU ANSP | 3 EU ANSP |
| **Encounter type** | Eq-Uneq<br>Uneq-Uneq | Eq-Uneq | Eq-Uneq |
| **Operat.al Scenarios** | Airport<br>Low Enroute<br>High Enroute | Combined | - Low Airspace<br>- High Airspace |
| **Ownship** | Combined GA (FW + RW)<br>+ GA RW only (*) | Combined GA (FW + RW)<br>+ Military | - GA Fixed Wing<br>- Rotocrafts (incl. StA)<br>- State Aircrafts FW |
| **Encounter source** | TIS-B (radar) + ADS-B tracks<br>Historical MAC/NMAC<br>Encounter Models (LLCEM) | SSR Radar tracks | SSR Radar tracks |
| **Accept. Criteria** | Total Alert Periods (>TAS)<br>Outlying Alert Periods (> TAS) | Missed Alert % (<5%)<br>Outlying Alert % (<5%) | Missed Alert % (<5%)<br>Outlying Alert % (<5%) |

**Table 27: comparison of DO-348, EXE03 (V1) and EXE06 (V2) TSAA performance assessments**

Previous V1 Validation exercise arrived at the following conclusions:

- Missed Alerts % (sum of Late % and No Alerts %) are within the 5% threshold, for both GA (fixed wing and rotorcraft) and State 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 State 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%)[8]
- Mean time to Alert was ~ 45 sec (with 20sec standard deviation)[9], which is sensibly greater than the one indicated in DO-348 for NAS encounters (26÷30 sec depending on specific operational scenario).

A direct comparison with new EXE06 results cannot be made as:

a) the encounter set are different (different scenarios, different set for GA FW and Rotorcraft)

b) Some (80) of the encounters used in V1 has been eliminated in encounter set used for V2

c) Position and velocity error model (degrader) have been used

Nevertheless, we have performed a comparison of TSAA performance results considering different error models with same V2 encounter sets, to appreciate what changes have introduced.

# 1. Conclusions on concept clarification

There are no indications from this validation exercise on TSAA concept itself. Indeed, a reference conceptual framework for utilizing Validation results for estimating benefits in the CBA is provided in the following.

In order to compare the solution scenario (i.e. GA/R/StA aircraft have ADS-B In and TSAA) with reference scenario (i.e. GA/R/StA aircraft DO NOT have ADS-B In and TSAA), the following conceptual framework can be applied:

- from EUROCONTROL closed encounters (i.e. two radar tracks with the potential of triggering an STCA alert) are identified Airprox encounters. AIRPROX is defined by ICAO as: "*A situation in which, in the opinion of a pilot or a controller, the distance between aircraft as well as their relative positions and speed have been such that the safety of the aircraft involved was or may have been compromised*"
- on the basis of FAA/MITRE HF study referenced in sect 3.4 of [18], an AIRPROX could be quantitatively defined as a penetration of HAZ volume (for Airport / Low En-route / High En-route)
- hence the number of AIRPROX's within the EUROCONTROL Close Encounter set for the reference scenario can be derived as the number of Must Alert encounter

[8] 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)

[9] 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

- assuming that majority of AIRPROX are due to lack of visual acquisition by pilots of intruding aircraft in due time, it can be considered that TSAA would be able to avoid a large fraction of AIRPROX's in these situations (80% could be assumed)
- the benefit of TSAA is then measured in terms of estimated reduction of AIRPROX's, when GA/R/StA are equipped with ADS-B In and TSAA application (directly derived from Missed Alert %)
- TSAA induced Airprox's can be assumed negligible, as in case of Outlying alerts (i.e. Alerts raised when considered not necessary), the pilot must always visually acquire the intruder before doing any manoeuvre (so Outlying alerts % is used only as an Operational Suitability metric).

# 2. Conclusions on technical feasibility

Previous V1 validation results showed Outlying Alerts % above 5% threshold. A possible explanation was identified to the possible presence of helicopter encounters 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 (high density and low speed) does not perform as well as TSAA for the general flying population of aircraft.

Indeed, V2 validation have shown that with available helicopter encounter set no issue exists both in terms of Missed Alert % and Outlying Alert %. This could be possibly due to the fact that in the available encounter set there are no "heliport like encounters", even if this could not be verified (as the encounters have been de-geolocalized).

# 3. Conclusions on performance assessments

Missed Alerts:

Also with new differentiated encounter sets and new error models, Missed Alert % has been confirmed below 5% acceptability threshold, with a confidence level of 95%.

Outlying Alerts:

Only for Rotorcraft Low Airspace and High Airspace we can conclude that Outlying Alert is below 5% acceptability Threshold.

For State Aircraft Low Airspace we have observed an average Outlying Alert % of 29,5% and can state that Outlying Alert is above 5% threshold with 95% confidence.

For General Aviation Fixed Wing (GA) High/Low Airspace and State Aircraft Fixed Wing (StA) High Airspace we have observed an average Outlying Alert % of approx. 5% but in neither case we can conclude anything with respect to the 5% threshold.

For General Aviation Fixed Wing (GA) High/Low Airspace if a threshold of 7% is considered, we can conclude that Outlying Alert % is below 7% with a confidence level of 95%.

### C.3.7 Recommendations

For future TSAA performance evaluations in European airspace the following recommendations can be made:

- Extend assessment to unequipped/unequipped encounters
- Extend assessment considering more ANSP data, in order to increase representativeness of European airspace and have more encounters to increase confidence on results
- Separate assessment for airport environment, and in particular for helicopters in heliport environment

# Appendix D Validation Exercise #07 Report

## D.1 Summary of the Validation Exercise #07 Plan

### D.1.1 Validation Exercise description, scope

The key objective of this validation exercise was to assess, in terms of interoperability and reusability aspects, the operational acceptability of Airborne Collision Avoidance System designed for remotely piloted aircraft – ACAS Xu – for GA/R operations; in particular:

1. Acceptability/feasibility of ACAS Xu RA instructions for GA/R pilots when installed on GA/rotorcraft platform (ownship),
2. Acceptability of ACAS Xu behaviour when installed on drone during encounters with GA aircraft.

This exercise was performed in three consecutive steps:

1. First, simulations with ACAS Xu-equipped GA/R ownship encountering cooperative intruder using set of real European encounters provided by EUROCONTROL. In this step alerting performance of ACAS Xu when installed on board of GA/R was evaluated.
2. Second, simulations with unequipped GA/R ownship encountering ACAS Xu equipped intruder using set of theoretical encounters based on geometrical considerations of possible conflicts among any aircraft (worst cases). In this step, alerting performance of the two systems was evaluated.
3. Then, results of the first two steps were consolidated, representative sample of the encounters will be selected and presented to GA/R pilots participating EXE-04 in order to obtain feedback on ACAS Xu acceptability and feasibility from operational point of view.

**Validation technique:**

Honeywell fast-time simulation platform (CASCARA) with ACAS Xu Run4.2 integrated was used for both simulations using EUROCONTROL real European encounters and set of artificial encounters as an input.

Second technique used was a workshop with Honeywell internal GA pilots, using results obtained through FTS as a basis for the discussion. Set of 18 representative scenarios was selected to support the discussion.

**What is ACAS Xu and why is it the subject of evaluation?**

ACAS Xu is an extension of the ACAS Xa/Xo system (subject of PJ.11-A1 and PJ.11-A3 solutions) which is designed for vehicles with new surveillance technologies and different characteristics, such as Unmanned Aircraft Systems (UAS). It is a DAA solution that provides both DWC and CA functionality. In comparison to existing collision avoidance system for manned aviation (TCAS II or ACAS Xa), for ACAS Xu, Tas have been replaced by DWC alerting and guidance and RAs are considered to be a combination of the DAA Warning Alert and Directive Guidance (continue to be referred as RAs to keep terminology consistent with ACAS Xa/Xo standards). RAs are indications given to the flight crew recommending manoeuvres intended to avoid collisions with all threats or restrict manoeuvres to maintain existing separation. In case of collision risk (intruder poses a threat), a recommended course of action is selected and provided to the pilot. That action can be in **both vertical and horizontal plane**. Vertical and horizontal manoeuvres are guidance are depicted independently of one another on the display and their timing may not coincide. However, if the timing does coincide, the pilot responds to both recommended manoeuvres, resulting in a **blended manoeuvre** (a combination of both vertical and horizontal response).

Since there is currently no collision avoidance solution tailored for General Aviation, the re-use of already available systems should be considered and analysed. As a first step, ACAS Xu which is currently under development, was chosen to be assessed for its re-usability, feasibility and acceptability by GA pilots.

### D.1.2 Summary of Validation Exercise #07 Validation Objectives and success criteria

| | |
|---|---|
| Identifier | **EX7-OBJ-PJ.11.A4-V2-VALP-0001** |
| Objective | Assess acceptability of ACAS Xu RA instructions for GA/R pilots when installed on GA/R platform, and acceptability of ACAS Xu behaviour when installed on drone during encounters with GA/R aircraft. |
| Title | Interoperability with and reusability of ACAS Xu for GA/R |
| Category | <safety> |
| EX7-CRT-PJ.11-A4-V2-VALP-001 | Majority of ACAS Xu RAs are considered as feasible and acceptable for GA/R/StA pilots. |
| EX7-CRT-PJ.11-A4-V2-VALP-002 | All ACAS Xu manoeuvres are compatible with rules of the air. |
| EX7-CRT-PJ.11-A4-V2-VALP-003 | Drones' manoeuvring is predictable and acceptable for GA/R pilots. |

### D.1.3 Summary of Validation Exercise #07 Validation scenarios

**Reference scenario:** N/A [10]

**Solution scenarios:**

- One ACAS Xu-equipped GA/R ownship and one cooperative intruder during real European mixed-equipage en-route and TMA encounters to assess Acceptability/feasibility of ACAS Xu RA instructions for GA pilots when installed on GA/rotorcraft platform (ownship),

[10] Due to the nature of the validation exercise, both simulated situations are considered as a solution scenario. Goal of the exercise is to get the first impression whether GA pilots accept and ACAS Xu RA instructions and find them feasible, and whether they find acceptable when an ACAS Xu equipped drone follows the ACAS Xu RAs.

- One unequipped GA ownship and one ACAS Xu equipped intruder during artificial "worst-case" encounters developed within PJ.11-A2 to assess acceptability of ACAS Xu behaviour when installed on drone during encounters with GA aircraft.

## D.1.4 Summary of Validation Exercise #07 Validation Assumptions

| Identifier | Title | Type of Assumption | Description | Justification | Flight Phase | KPA Impacted | Source | Value(s) | Owner | Impact on Assessment |
|---|---|---|---|---|---|---|---|---|---|---|
| EX7-ASS-PJ.11-A4-001 | Encounter set | Traffic Characteristics | Encounter set will consist of real European encounters involving GA/ R encountering TCAS II equipped intruders. | Honeywell is not addressing StA aspects. | N/A | N/A | EUROCONTROL | 3622 encounters | HONEYWELL | Medium |
| EX7-ASS-PJ.11-A4-002 | One intruder only | Traffic characteristics | Simulation will involve only one intruder | Encounter set limitation. | All | Safety | EUROCONTROL | 1 | HONEYWELL | Low |
| EX7-ASS-PJ.11-A4-003 | Surveillance errors | Traffic Characteristics | Surveillance errors won't be considered within this exercise. | This is initial analysis of ACAS Xu logic behaviour and its applicability for GA/R aircraft in terms of operational acceptability of conflict resolutions. | All | Safety | HONEYWELL | N/A | HONEYWELL | Low |

| Identifier | Title | Type of Assumption | Description | Justification | Flight Phase | KPA Impacted | Source | Value(s) | Owner | Impact on Assessment |
|---|---|---|---|---|---|---|---|---|---|---|
| EX7-ASS-PJ.11-A4-004 | No pilot reaction considered | Human Performance | No pilot reaction model is to be used during simulations for GA aircraft. | The aim of this exercise is to assess what kind of RA at what time would be provided to ownship pilot. Feasibility of these RAs will be consequently discussed with real pilots. | All | HP | HONEYWELL | N/A | HONEYWELL | Low |
| EX7-ASS-PJ.11-A4-005 | RWC alerting | Traffic Characteristics | Manoeuvring based on Remain Well Cleared function is not considered within the operational scenarios. | RWC function has rather traffic advisory character, at this stage the objective of the exercise is interested in RAs. | All | HP | HONEYWELL | N/A | HONEYWELL | Low |
| EX7-ASS-PJ.11-A4-005 | No StA | Traffic Characteristics | No StA encounters will be addressed in this exercise | Honeywell does not address StA aspects | N/A | N/A | HONEYWELL | N/A | HONEYWELL | Low |

Table 28: Validation Assumptions overview

## D.2 Deviation from the planned activities

Following deviations from the planned activities occurred during EXE-07:

- According to VALP, GA/R pilots participating on EXE-04 were supposed to be used for discussion about Xu scenarios. Since fast-time simulations were not completed at the time of EXE-04 execution, planned per-pilot discussion was changed into dedicated workshop with Honeywell internal GA pilots. This deviation, however, allowed more consistent and better focused execution of EXE-07 itself involving higher number of GA pilots.

- Second fast-time simulation (aiming to assess acceptability of ACAS Xu behaviour when installed on drone during encounters with GA aircraft) did not simulate TSAA+ equipped ownship, but the ownship was considered unequipped. This deviation had no impact on the objective. Deviation was driven by the goal not to confuse pilots with two new systems (TSAA+ & ACAS Xu) they are not familiar with, keeping the focus on ACAS Xu behaviour while flying unequipped GA aircraft.

- Data set for second fast-time simulation, as described in the VALP, envisaged altitude values of 29000 and 29200 ft what was shown inappropriate for GA operations. Data set executed during the evaluation was simulated for altitude of 3,000 ft.

## D.3 Validation Exercise #07 Results

### D.3.1 Summary of Validation Exercise #07 Results

| Validation Exercise #07 Validation Objective ID | Validation Exercise #07Validation Objective Title | Validation Exercise #07 Success Criterion ID | Validation Exercise #07 Success Criterion | Sub-operating environment | Exercise #07 Validation Results | Validation Exercise #07 Validation Objective Status |
|---|---|---|---|---|---|---|
| EX7-OBJ-PJ.11.A4-V2-VALP-0001 | Interoperability with and reusability of ACAS Xu for GA/R | EX7-CRT-PJ.11-A4-V2-VALP-001 | Majority of ACAS Xu RAs are considered as feasible and acceptable for GA/R/StA pilots. | En-route and TMA (all complexities) | | NOK |
| | | EX7-CRT-PJ.11-A4-V2-VALP-002 | All ACAS xu manoeuvres are compatible with rules of the air. | En-route and TMA (all complexities) | | NOK |
| | | EX7-CRT-PJ.11-A4-V2-VALP-003 | Drones' manoeuvring is predictable and acceptable for GA/R pilots. | En-route and TMA (all complexities) | | NOK |

Table 29: Validation Results for Exercise 7

## D.3.2 Analysis of Exercise 7 Results per Validation objective

### 1. EX7-OBJ-PJ.11.A4-V2-VALP-0001 Results

**1st Step: Fast-time simulations of ACAS Xu equipped GA/R ownship vs. cooperative intruder**

**Purpose:**

The purpose of these fast-time simulations was to evaluate alerting performance of ACAS Xu when installed on board of GA/R, during encounters with cooperative intruders. From the obtained results, representative set of scenarios was selected and presented to pilots with the goal to assess/discuss how acceptable and feasible ACAS Xu Resolution Advisories (RAs) are for GA pilot.

**Data set used:**

Real European mixed-equipage[11] encounters provided by EUROCONTROL. The same set of encounters was already used for V1 validations (EXE-01) in 2018 [42]. The total set of 3628 mixed-equipage encounters was simulated.

Passive surveillance only, based on receiving ADS-B messages, was considered as a surveillance input for ACAS Xu installed on board of GA/R.

**Simulation approach:**

3628 encounters were simulated applying ACAS Xu Run4.2 model on GA/R aircraft side. Alerting performance of ACAS Xu was assessed by focusing on the number of generated RAs and type issued RA. Since simulations were not dynamic (trajectories did not change based on given RA on either ownship or intruder side), focus was given on:

- the type of 1st RA (assuming that pilot would react, what would in reality change the sequence of all other potential RAs), and
- type & sequence of RA during first 1 seconds of the advisory (assuming that standard pilot reaction duration is 5 seconds).

Based on results obtained in 1st step of FTS, nine scenarios were selected as candidates for the workshop discussion. Set of scenarios was selected based on expert judgement, to allow various types of possible RAs, including both nominal (which pilot might find to be straightforward) and worst-case situations (when rather unexpected, or combination of more different RAs is given by the system within a short time). In particular, the goal of the scenario set was to include:

[11] By mixed-equipage encounters, encounters between unequipped GA/R aircraft and TCAS II equipped aircraft are meant.

1. Scenarios with horizontal RA;
2. Scenario with vertical RA;
3. Reverse scenario which changes RA sense within first 5 seconds (both horizontal and vertical);
4. Scenario where provided RA does not comply with rules of the air;

To allow pilots to better understand the encounter and ACAS Xu suggested behaviour, selected scenarios were simulated in Cesium ion, a scalable and secure platform for streaming 3D geospatial data.

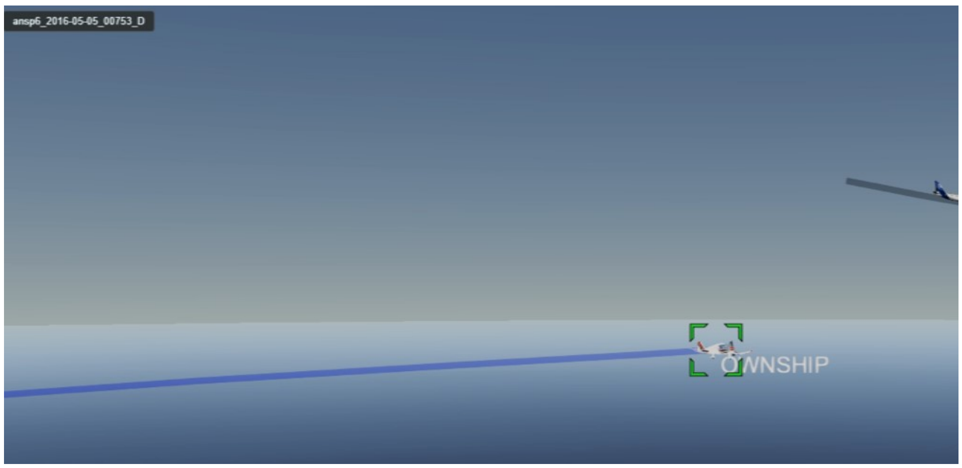



**Figure 6-23: Exemplar scenario as presented in Cesium ion video during the workshop**

With each scenario, workshop participants were asked to fill the following questionnaire:

| Question | Your answer | Your note |
|---|---|---|
| Did you understand the meaning of RA? | Yes / No | |
| What would be your action (what maneuvre)? | | |
| If not having ACAS Xu - what would you do? (how would you maneuvere in this situation?) | | |
| Was the RA [provided sufficiently in advance to execute maneuver? | Yes / No | |
| Do you consider the behavior of ACAS Xu trustworthy / acceptable? (if not trustworthy - In what conditions would you decide to disobey the RA?) | Yes / No = Conditions to disobey: | |
| Do you find the maneuver compliant with GA flying rules? | Yes / No = why: | |

**Figure 6-24: Questionnaire for 1st step FTS scenarios**

**<u>Simulation outcome:</u>**

In 1270 (35%) of cases out of 3628 encounters, ACAS Xu generated an RA. Figures below indicate type of first RA (Figure 6-25) and type and sequence of RA during first 5 seconds of RA (Figure 6-26).

Results of 1st step FTS indicate that majority of RAs issued on board of ACAS Xu equipped GA/R ownship are horizontal and of “right” sense (~43%), i.e. compliant with rules of the air. Approximately 80% of all issued RAs are of horizontal sense. This result is influenced by the altitude and corresponds to lower altitude operations, which are typical for mixed-equipage encounters.

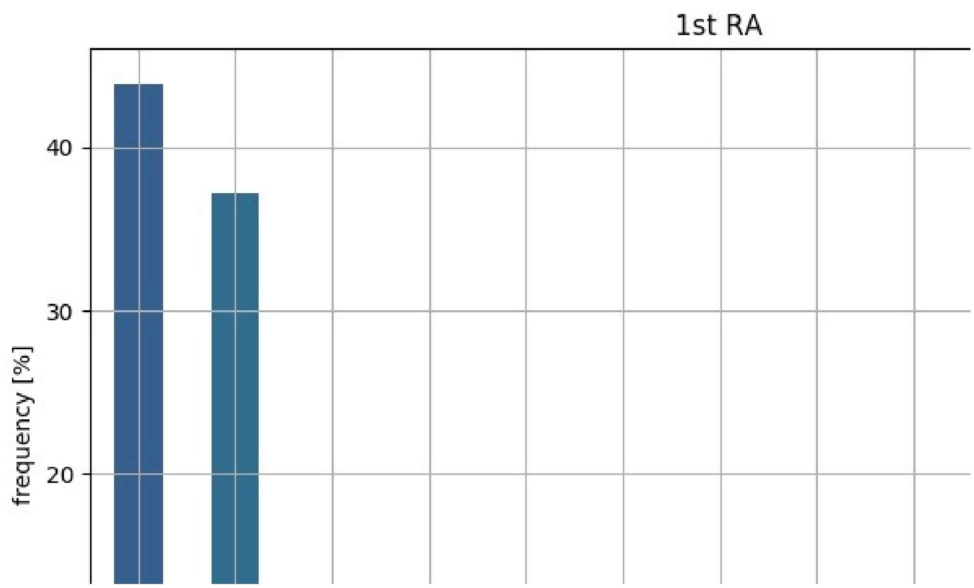



**Figure 6-25: EXE-07 (1st Step FTS) - type of 1st RA**

Second graph confirms that even when looking at first 5 sec of the issued manoeuvre, in most of the cases the horizontal sense is consistent (Pure R, Pure L), then the third most common manoeuvre is horizontal reversal followed by consistent, purely vertical senses and then blended manoeuvres.

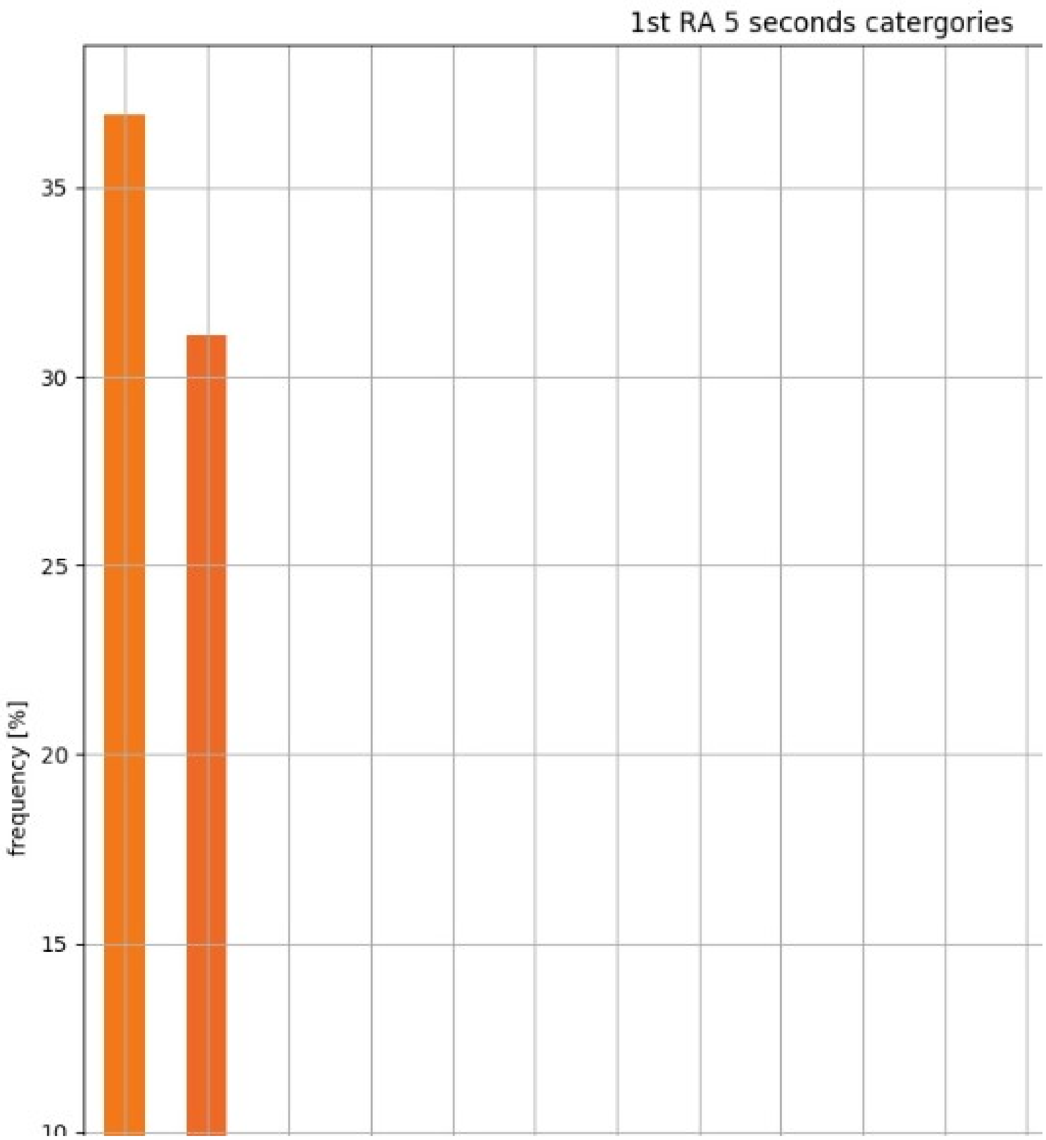



**Figure 6-26: EXE-07 (1st Step FTS) - type and sequence of RA during first 5 seconds**

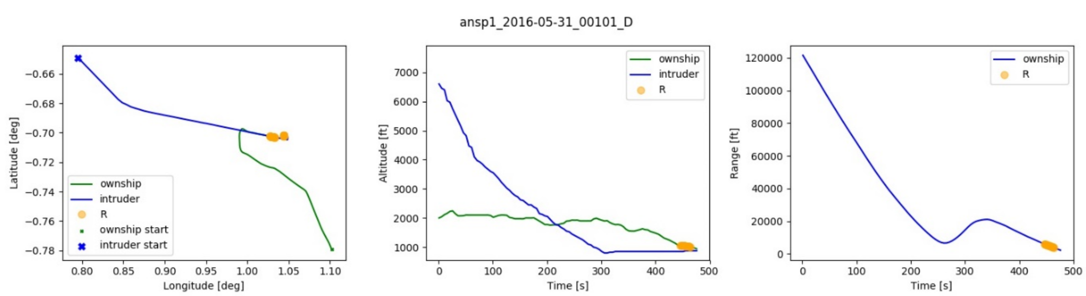
| Type of RA (1s) abbreviation | Meaning of the abbreviation | Type of 5sec category abbreviation | Meaning of the abbreviation |
|---|---|---|---|
| **R** | Right | **Pure R** | Right only |
| **L** | Left | **Pure L** | Left only |
| **D** | Descend | **H reversal** | Right -> Left, Left -> Right |
| **C** | Climb | **Pure D** | Descend only |
| **DNC** | Do Not Climb | **Pure C** | Climb only |

| Type of RA (1s) abbreviation | Meaning of the abbreviation | Type of 5sec category abbreviation | Meaning of the abbreviation |
|---|---|---|---|
| **RC** | Right Climb | **Hor2Bl** | Horizontal changing to blended manoeuvre (i.e. vertical sense added) |
| **LC** | Left Climb | **Ver2Bl** | Vertical changing to blended manoeuvre (i.e. horizontal sense added) |
| **DND** | Do Not Descend | **Pure DNC** | Do Not Climb only |
| **LD** | Left Descend | **Pure RC** | Right & Climb blended manoeuvre |
| **RD** | Right Descend | **Pure LC** | Left & Climb blended manoeuvre |
| **LDNC** | Left Do Not Climb | **V strengthening** | Vertical only, strengthening manoeuvre |
| **RDNC** | Right Do Not Climb | **Pure LD** | Left & Descend blended manoeuvre |
| **LDND** | Left Do Not Descend | **Pure DND** | Do not Descend only |
| - | - | **Pure RD** | Right & Descend blended manoeuvre |
| - | - | **Pure LDNC** | Left & Do Not climb only |
| - | - | **V reversal** | Climb -> Descend, Descend -> Climb |
| - | - | **Pure LDND** | Left & Do Not Descend only |

**Table 30: Legend for EXE-07 graphs**

Based on results obtained in 1st step of FTS, following nine scenarios were selected as candidates for the workshop discussion.

On the graphs below, first row depicts full length of the scenario, while second row focuses on first 5 seconds of the RA, which is the most relevant since in normal operation it is expected that pilot would react within the 5 seconds.



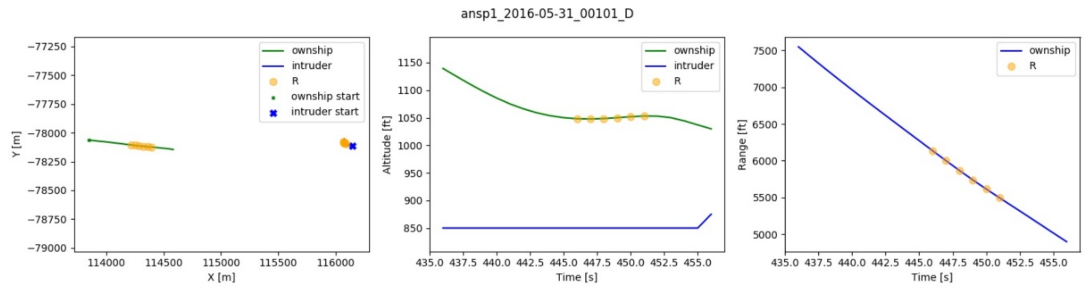



**Figure 6-27: EXE-07 - Workshop candidate scenario no.1**

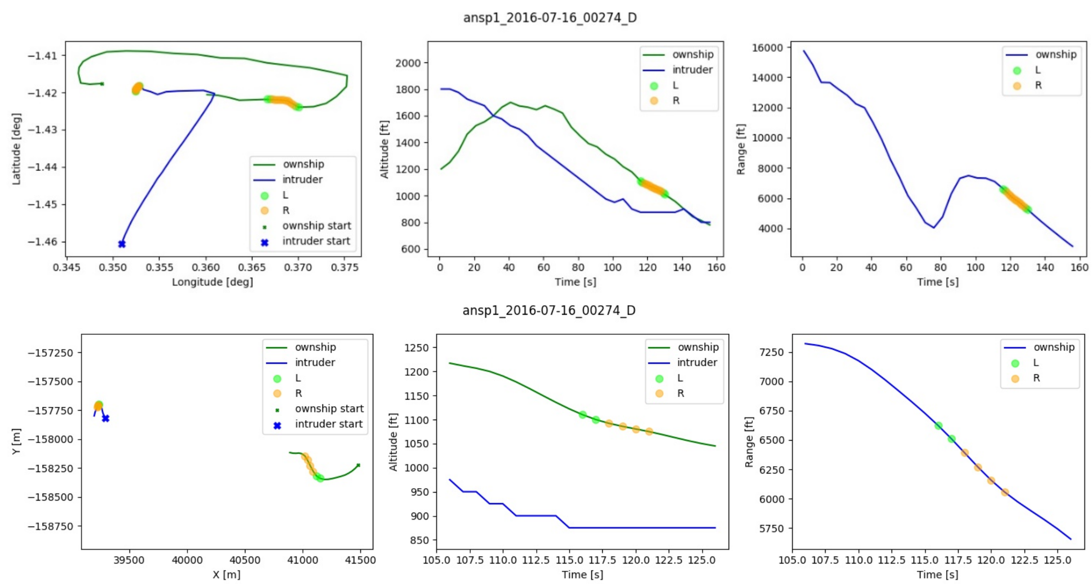
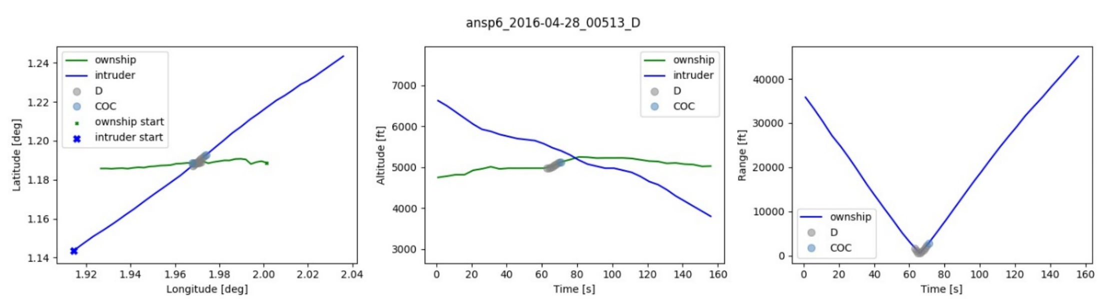



**Figure 6-28: EXE-07 - Workshop candidate scenario no.2**



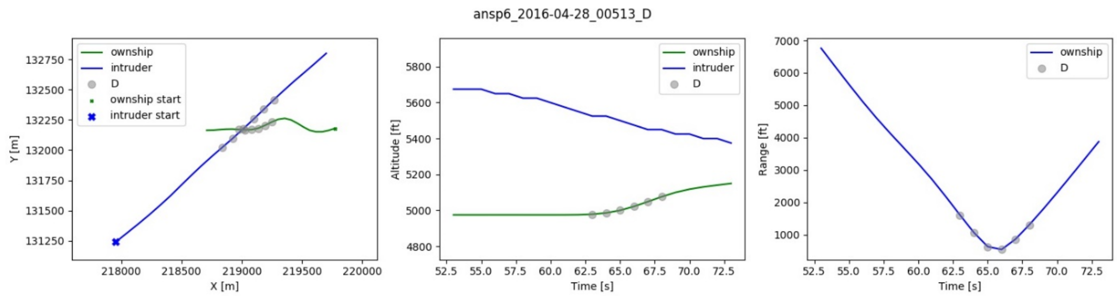



Figure 6-29: EXE-07 - Workshop candidate scenario no.3

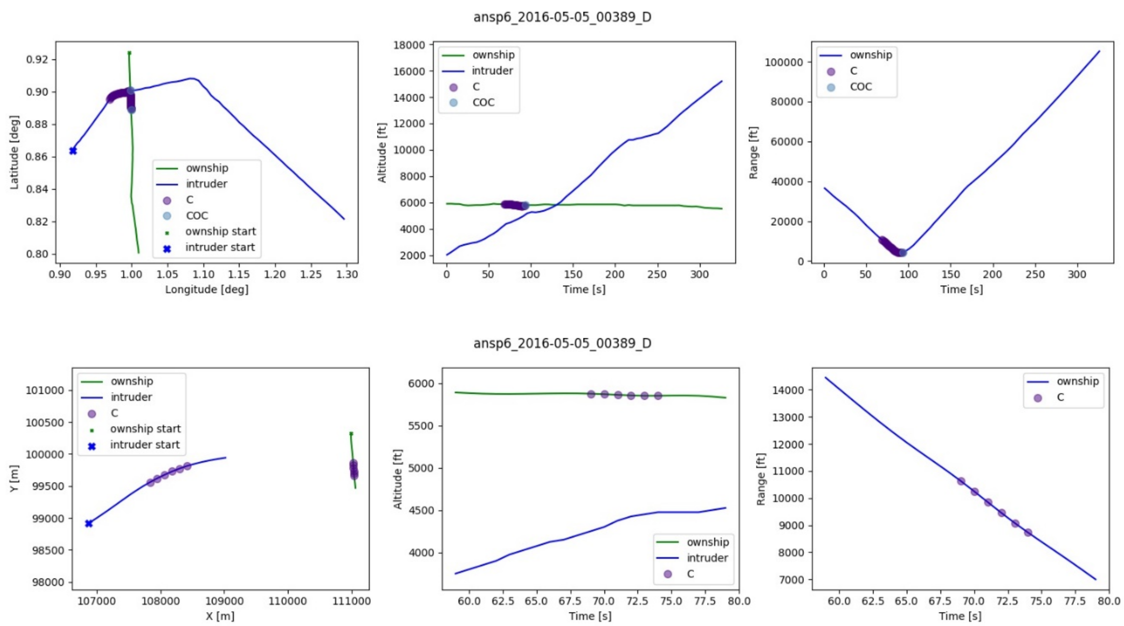
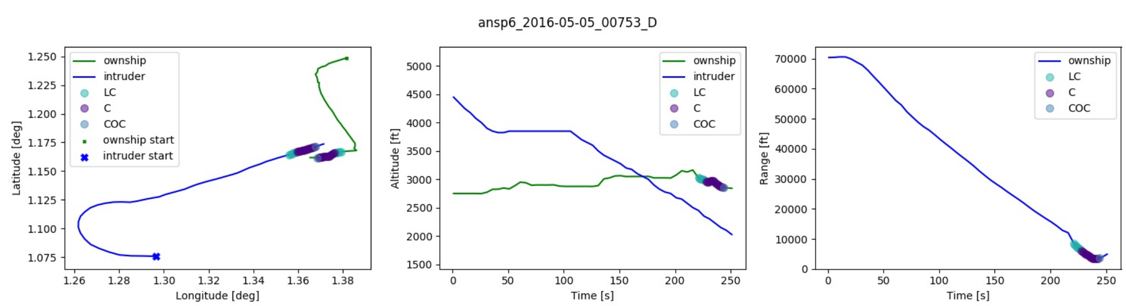



Figure 6-30: EXE-07 - Workshop candidate scenario no.4



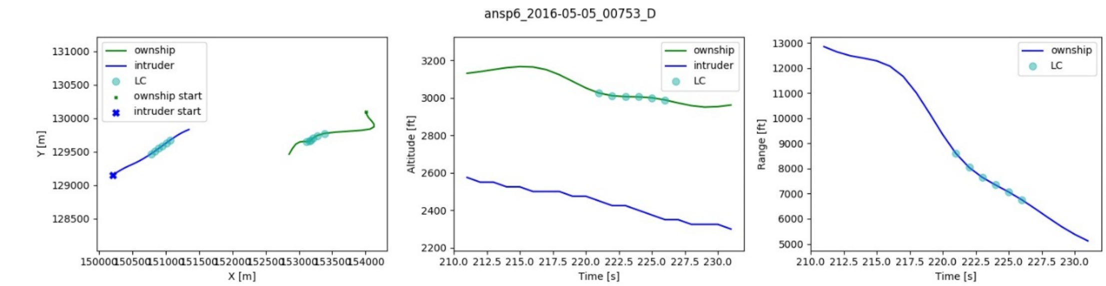



**Figure 6-31: EXE-07 - Workshop candidate scenario no.5**

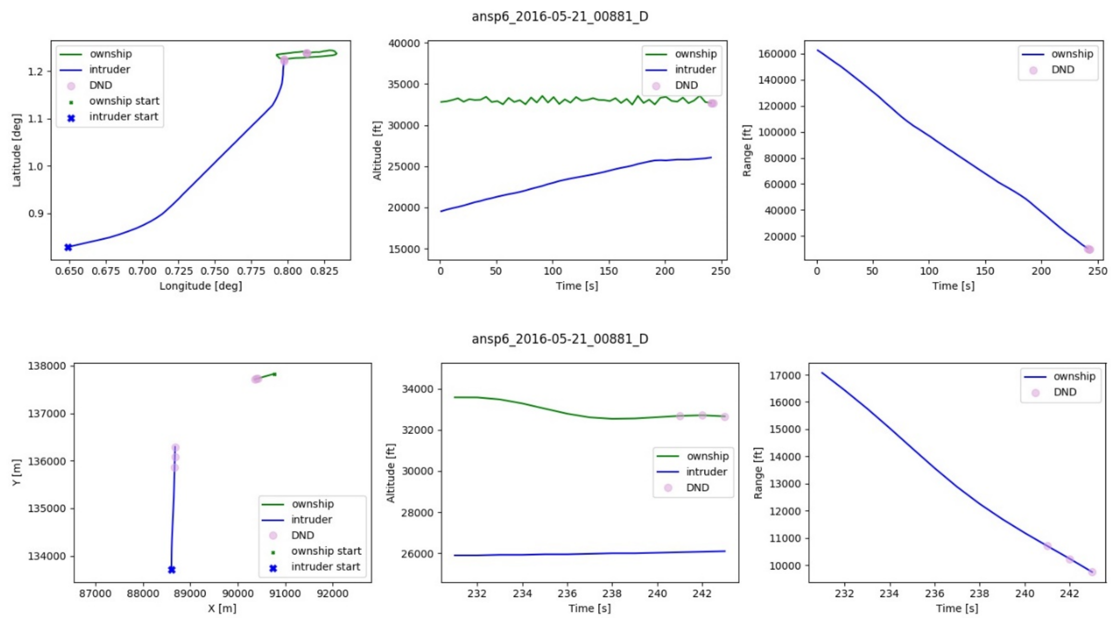
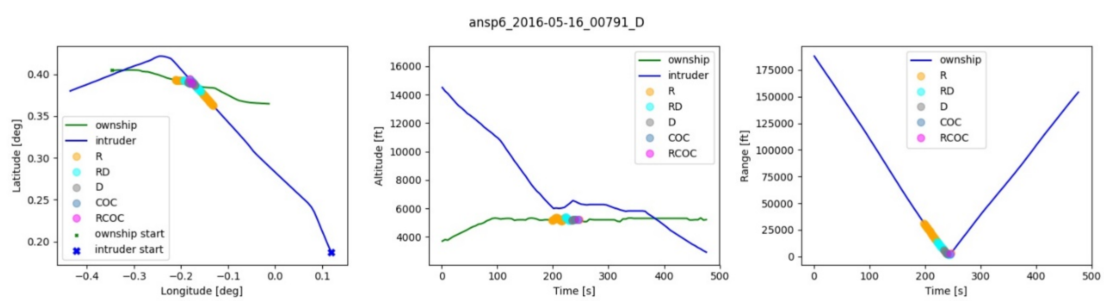



**Figure 6-32: EXE-07 - Workshop candidate scenario no.6**



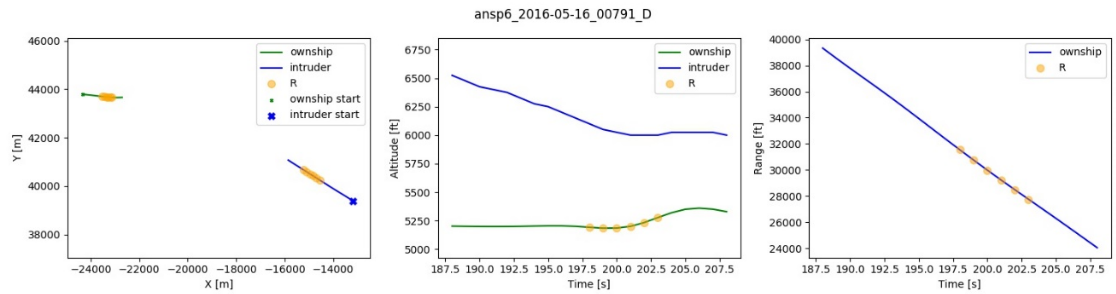



**Figure 6-33: EXE-07 - Workshop candidate scenario no.7**

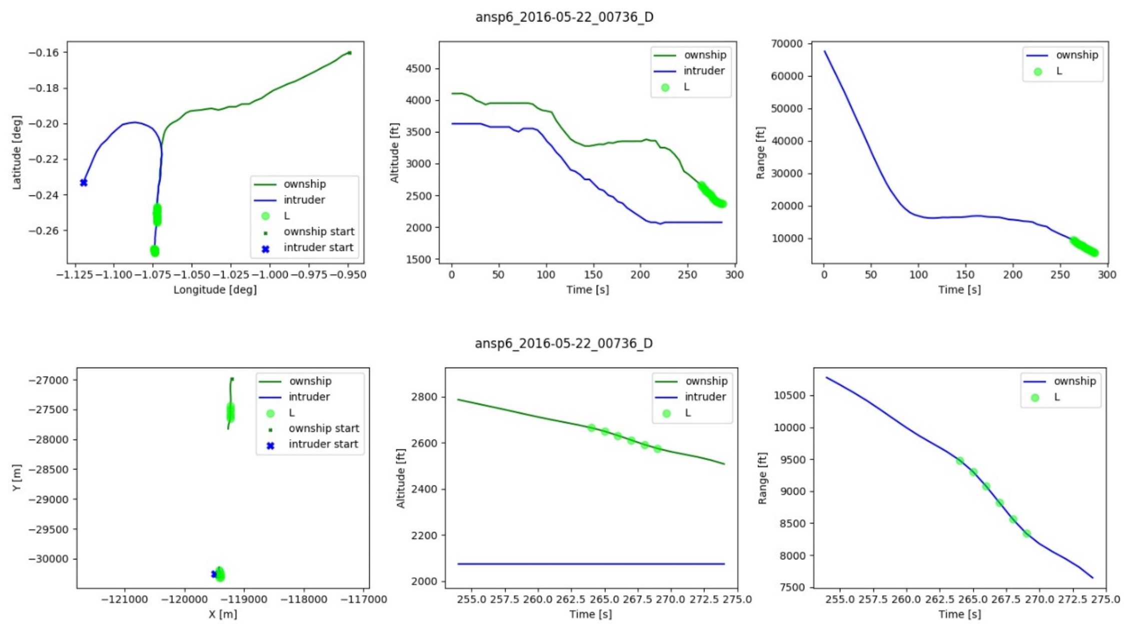
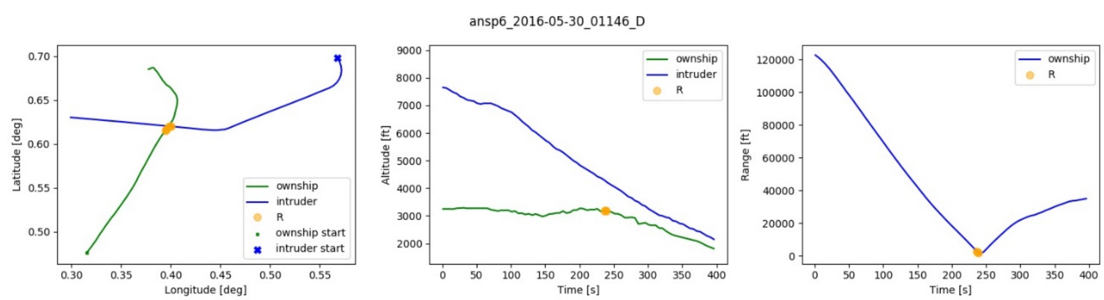



**Figure 6-34: EXE-07 - Workshop candidate scenario no.8**



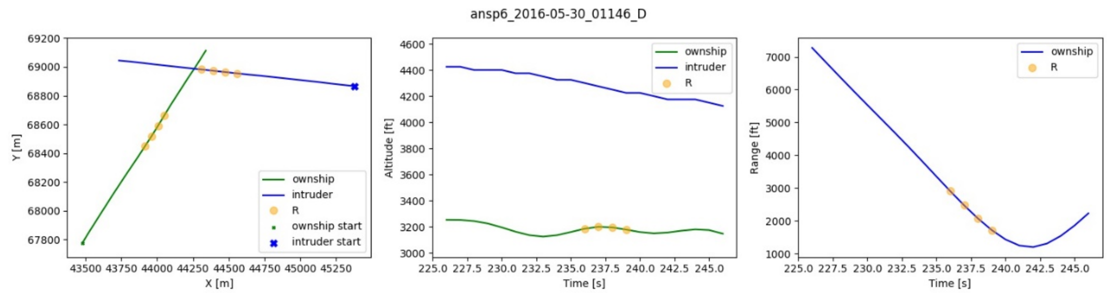



**Figure 6-35: EXE-07 - Workshop candidate scenario no.9**

### 2nd Step: Fast-time simulations of unequipped GA/R ownship vs. ACAS Xu equipped drone intruder

**Purpose:**

The purpose of these fast-time simulations was to evaluate alerting performance of ACAS Xu when installed on drone during encounter with unequipped GA. From the obtained results, representative set of scenarios was selected and presented to GA pilots with the goal to assess/discuss how acceptable is for them the Resolution Advisory (RAs) issued ACAS Xu equipped drone.

**Data set used:**

Theoretical “worst case” scenarios created by Honeywell, and already used for V1 evaluations in PJ.11-A2 were re-used for this purpose. The total set of 110 scenarios was simulated with different variables as shown in the table below.

Basic scenario was a head on encounter, ownship flying with speed of 200kt at 3000ft altitude to the north. Intruder is at the same altitude, same speed flying to the south. The other scenarios are derived from this basic one by changing some parameter, adding vertical or horizontal manoeuvres of ownship and/or intruder.

| Name | min_time [s] | max_time [s] | x_time [s] | lat_own [deg] | lon_own [deg] | hdg_own [deg] | speed_own [kt] | alt_own [ft] | vrate_own [fps] | turnrate_own [deg/s] | lat [deg] | lon [deg] | hdg_tgt [deg] | speed_tgt [kt] | alt_tgt [ft] | vrate_tgt [fps] | target_turn_rate | Name | alt_own [ft] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario01 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 100 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario56 | 3200 |
| Scenario02 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario57 | 3200 |
| Scenario03 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 300 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario58 | 3200 |
| Scenario04 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 10 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario59 | 3200 |
| Scenario05 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 25 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario60 | 3200 |
| Scenario06 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 30 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario61 | 3200 |
| Scenario07 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | -10 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario62 | 3200 |
| Scenario08 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | -25 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario63 | 3200 |
| Scenario09 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | -30 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario64 | 3200 |
| Scenario10 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario65 | 3200 |
| Scenario11 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 2 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario66 | 3200 |
| Scenario12 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 4 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario67 | 3200 |
| Scenario13 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | -1 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario68 | 3200 |
| Scenario14 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | -2 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario69 | 3200 |
| Scenario15 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | -4 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 0 | Scenario70 | 3200 |
| Scenario16 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 30 | 200 | 3000 | 0 | 0 | Scenario71 | 3200 |
| Scenario17 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 60 | 200 | 3000 | 0 | 0 | Scenario72 | 3200 |
| Scenario18 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 90 | 200 | 3000 | 0 | 0 | Scenario73 | 3200 |
| Scenario19 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 120 | 200 | 3000 | 0 | 0 | Scenario74 | 3200 |
| Scenario20 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 150 | 200 | 3000 | 0 | 0 | Scenario75 | 3200 |
| Scenario21 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 100 | 3000 | 0 | 0 | Scenario76 | 3200 |
| Scenario22 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 300 | 3000 | 0 | 0 | Scenario77 | 3200 |
| Scenario23 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3500 | 0 | 0 | Scenario78 | 3200 |
| Scenario24 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 2500 | 0 | 0 | Scenario79 | 3200 |
| Scenario25 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 10 | 0 | Scenario80 | 3200 |
| Scenario26 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 25 | 0 | Scenario81 | 3200 |
| Scenario27 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 30 | 0 | Scenario82 | 3200 |
| Scenario28 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | -10 | 0 | Scenario83 | 3200 |
| Scenario29 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | -25 | 0 | Scenario84 | 3200 |
| Scenario30 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | -30 | 0 | Scenario85 | 3200 |
| Scenario31 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 1 | Scenario86 | 3200 |
| Scenario32 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 2 | Scenario87 | 3200 |
| Scenario33 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 4 | Scenario88 | 3200 |
| Scenario34 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | -1 | Scenario89 | 3200 |
| Scenario35 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | -2 | Scenario90 | 3200 |
| Scenario36 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | -4 | Scenario91 | 3200 |
| Scenario37 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 30 | 200 | 3000 | 0 | 1 | Scenario92 | 3200 |
| Scenario38 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 60 | 200 | 3000 | 0 | 1 | Scenario93 | 3200 |
| Scenario39 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 90 | 200 | 3000 | 0 | 1 | Scenario94 | 3200 |
| Scenario40 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 120 | 200 | 3000 | 0 | 1 | Scenario95 | 3200 |
| Scenario41 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | 1 | Scenario96 | 3200 |
| Scenario42 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | -1 | Scenario97 | 3200 |
| Scenario43 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 30 | 200 | 3000 | 0 | -1 | Scenario98 | 3200 |
| Scenario44 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 60 | 200 | 3000 | 0 | -1 | Scenario99 | 3200 |
| Scenario45 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 90 | 200 | 3000 | 0 | -1 | Scenario100 | 3200 |
| Scenario46 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 120 | 200 | 3000 | 0 | -1 | Scenario101 | 3200 |
| Scenario47 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 1 | 49.17 | 16.675 | 180 | 200 | 3000 | 0 | -1 | Scenario102 | 3200 |
| Scenario48 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 25 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 25 | 0 | Scenario103 | 3200 |
| Scenario49 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 25 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | -25 | 0 | Scenario104 | 3200 |
| Scenario50 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | -25 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | 25 | 0 | Scenario105 | 3200 |
| Scenario51 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | -25 | 0 | 49.17 | 16.675 | 180 | 200 | 3000 | -25 | 0 | Scenario106 | 3200 |
| Scenario52 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 0 | 200 | 3000 | 25 | 0 | Scenario107 | 3200 |
| Scenario53 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | 49.17 | 16.675 | 0 | 200 | 3000 | -25 | 0 | Scenario108 | 3200 |
| Scenario54 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | 25 | 0 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | Scenario109 | 3200 |
| Scenario55 | 0 | 120 | 90 | 49.17 | 16.675 | 0 | 200 | 3000 | -25 | 0 | 49.17 | 16.675 | 0 | 200 | 3000 | 0 | 0 | Scenario110 | 3200 |

**Table 31: List of different geometries included in the worst-case set of scenarios.**

**Simulation approach:**

110 encounters were simulated applying ACAS Xu Run4.2 model on drone intruder side. Alerting performance of ACAS Xu was assessed by focusing on the number of generated RAs and type issued RA. Since simulations were not dynamic (trajectories did not change based on given RA on either ownship or intruder side), focus was given on:

- the type of 1st RA (assuming that system or drone operator would react, what would in reality change the sequence of all other potential RAs), and
- type & sequence of RA during first 5 seconds of the advisory (assuming that standard pilot reaction duration is 5 seconds).

Based on results obtained in 2nd step of FTS, eight scenarios were selected as candidates for the workshop discussion. Set of scenarios was selected based on expert judgement, to allow various types of possible RAs, including both nominal (when GA pilot might find Xu behaviour expectable) and worst-case situations (with rather unexpected Xu drone manoeuvring). In particular, the goal of the scenario set was to include:

1. Scenarios with vertical RA;
2. Scenarios with horizontal RA;
3. Reverse scenarios which changes RA sense within first 5 seconds (both horizontal and vertical);
4. Scenario where provided RA does not comply with rules of the air;

With each scenario, workshop participants were asked to fill the following questionnaire:

| Question | Your answer | Your note |
|---|---|---|
| Would you expect that UAV will do such maneuvre? If not, what maneuvre of UAV would you expect it to do in this situation? | Yes / No = expected maneuvre: | |
| Do you find proposed UAV maneuver acceptable? | Yes / No = why: | |
| Is this UAV maneuver compliant with flying rules? | Yes / No = why: | |

**Figure 6-36: Questionnaire for 2nd step FTS scenarios**

**Simulation outcome:**

Figures below indicate type of first RA (Figure 6-37) and type and sequence of RA during first 5 seconds of RA (Figure 6-38).

Around 35 cases (~31%) of cases out of 110 artificial encounters, ACAS Xu installed on drone intruder issued vertical - climb RA against GA. It is assumed that this result is to big extent driven by the low altitude at which the encounter occurred. More than 50% of the scenarios then generated horizontal manoeuvre (~26% issued Right RA, ~25% issued Left RA).

Results of 2nd step FTS indicate that if horizontal manoeuvre is issued by drone, **Right** (Right + blended Right Climb) sense RA is given in more often than **Left** sense, however, the left sense still occurs quite often (25% or all the alerts), what introduces a safety risk since it does not comply with rules of the air, that GA pilot involved in the encounters might execute to avoid the collision. Moreover, if we look at the type and sequence of first 5 seconds of the issued RA, the amount of **Left** sense RAs is even higher than **Right** sense RAs.

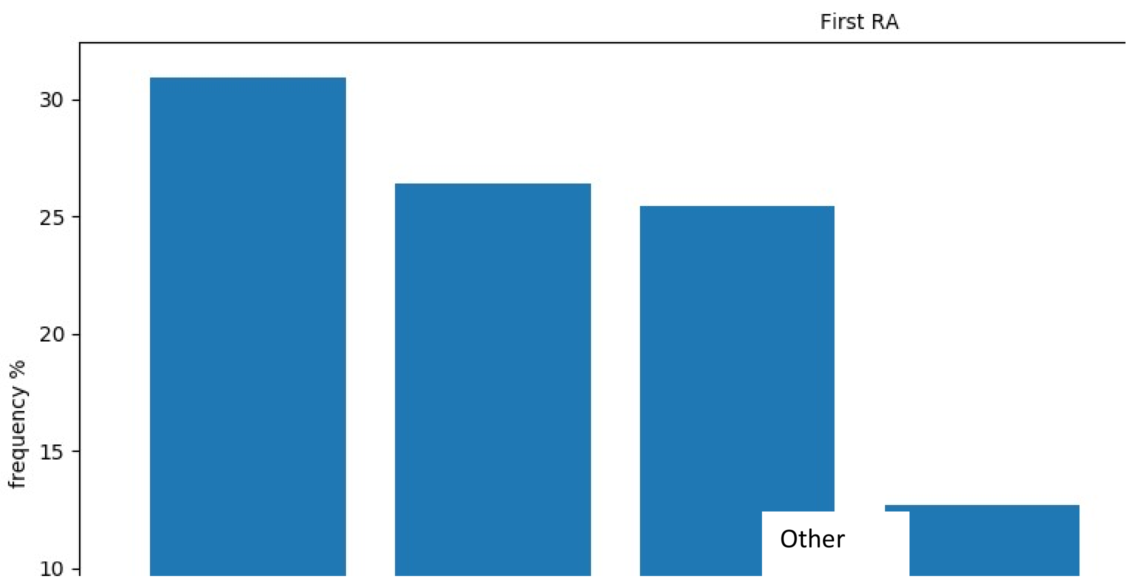



Figure 6-37: EXE-07 (2nd Step FTS) - type of 1st RA

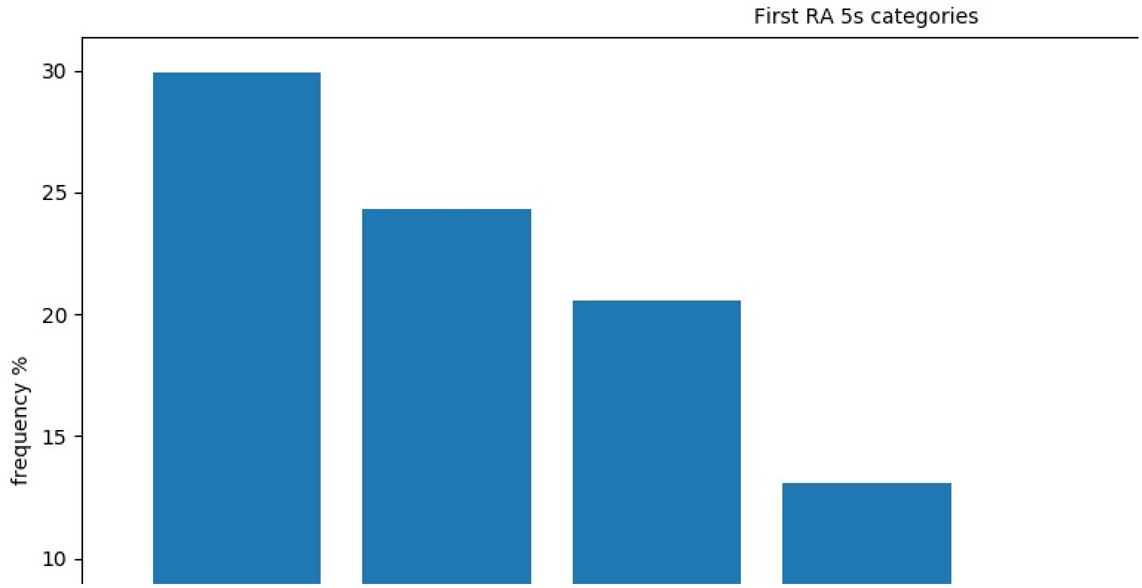



**Figure 6-38: EXE-07 (2nd Step FTS) - type and sequence of RA during first 5 seconds**

Based on results obtained in 2nd step of FTS, following eight scenarios were selected as candidates for the workshop discussion.

On the graphs below, first row depicts full length of the scenario, while second row focuses on first 5 seconds of the RA, which is the most relevant since in normal operation it is expected that pilot would react within the 5 seconds.

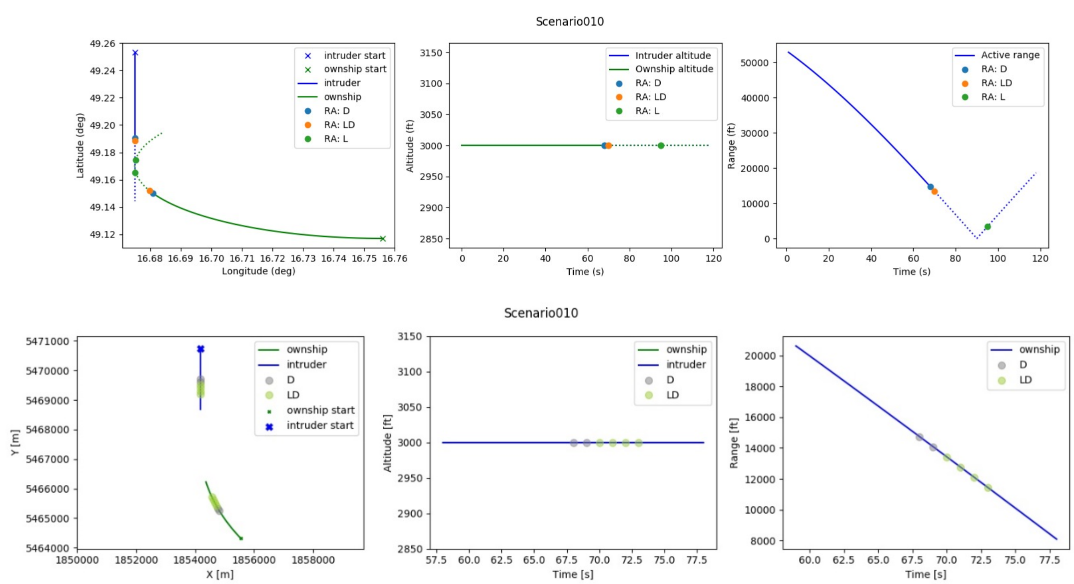



**Figure 6-39: EXE-07 - Workshop candidate scenario no.10**

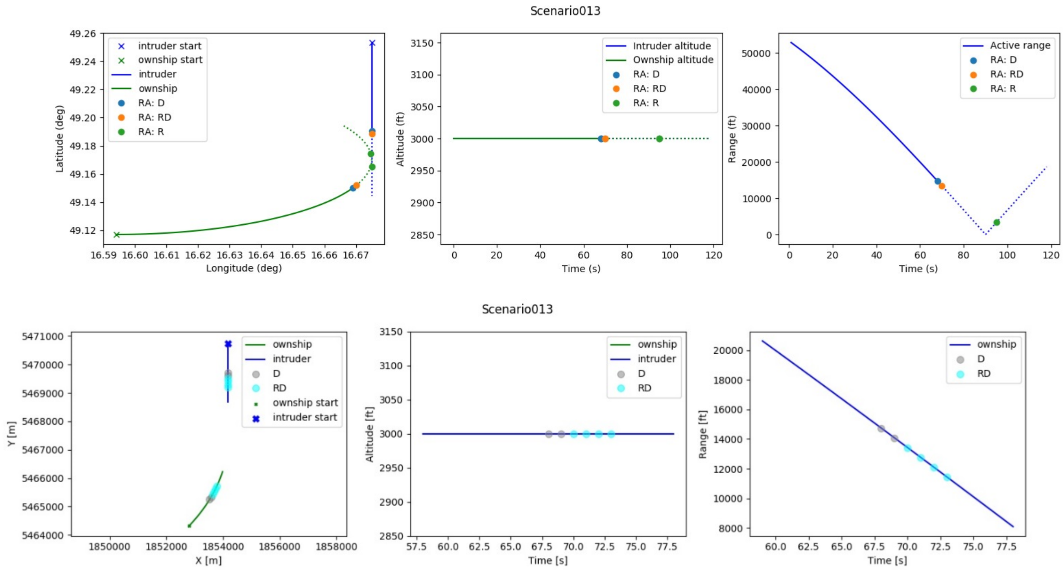



**Figure 6-40: EXE-07 - Workshop candidate scenario no.11**

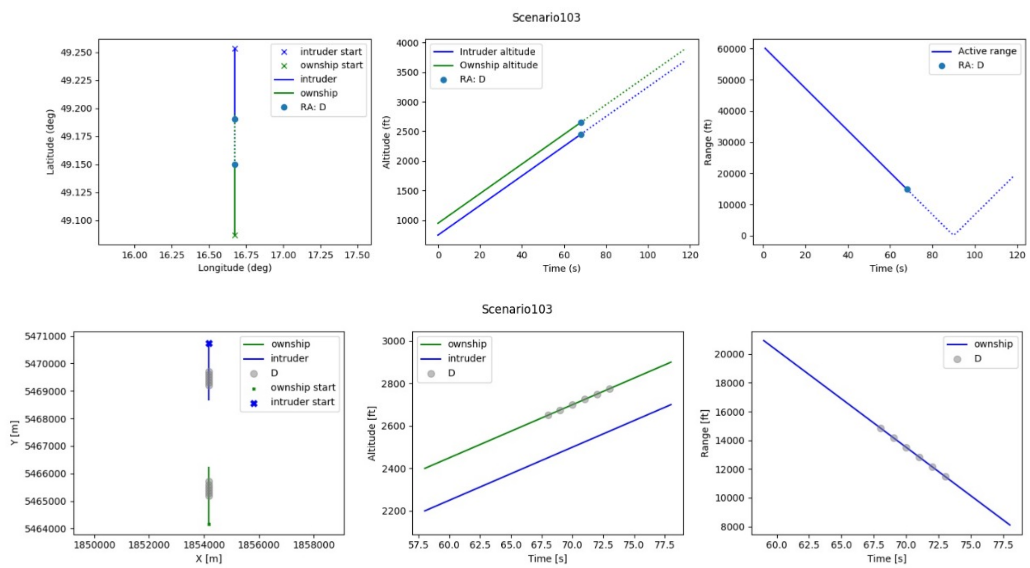
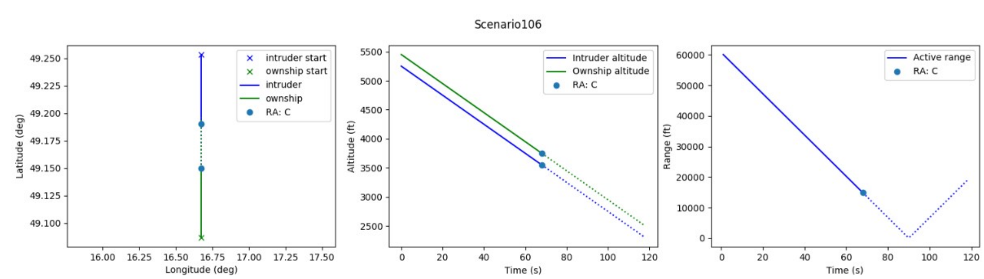



**Figure 6-41: EXE-07 - Workshop candidate scenario no.12**



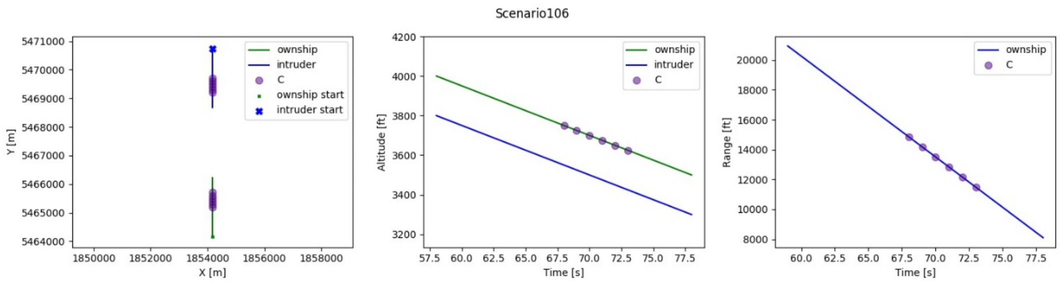



**Figure 6-42: EXE-07 - Workshop candidate scenario no.13**

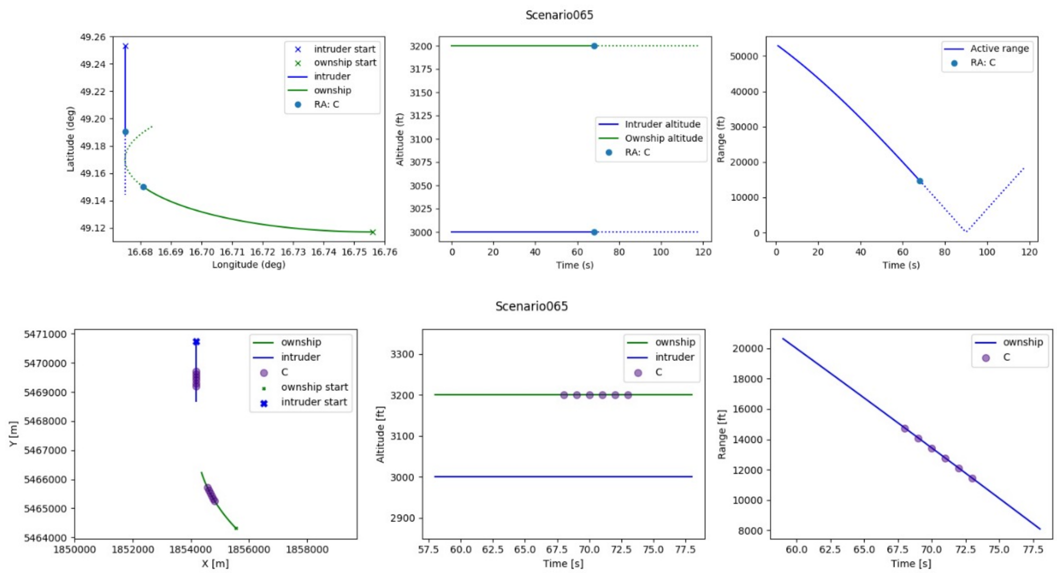
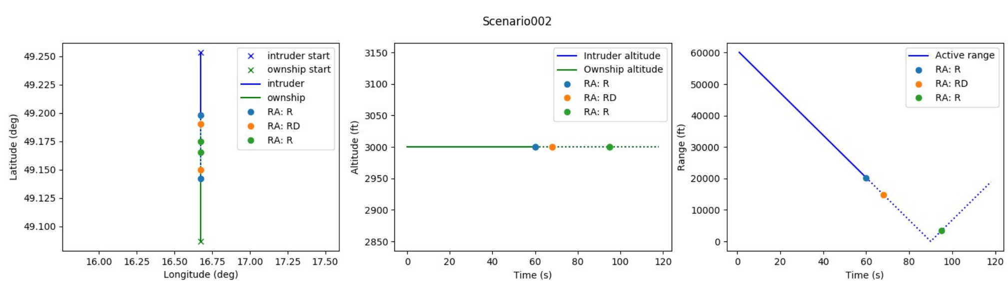



**Figure 6-43: EXE-07 - Workshop candidate scenario no.14**



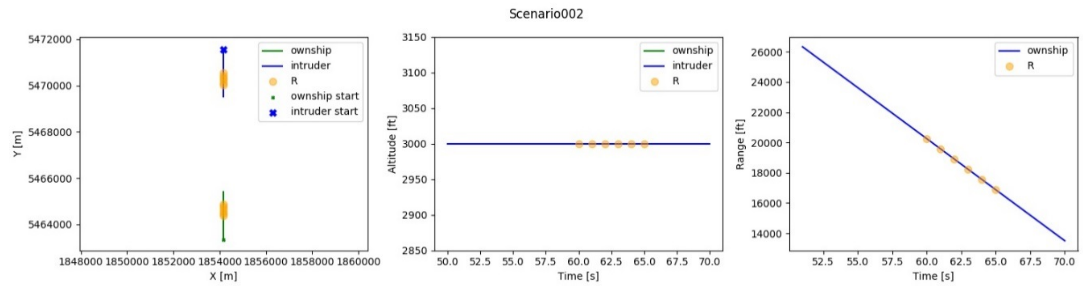



**Figure 6-44: EXE-07 - Workshop candidate scenario no.15**

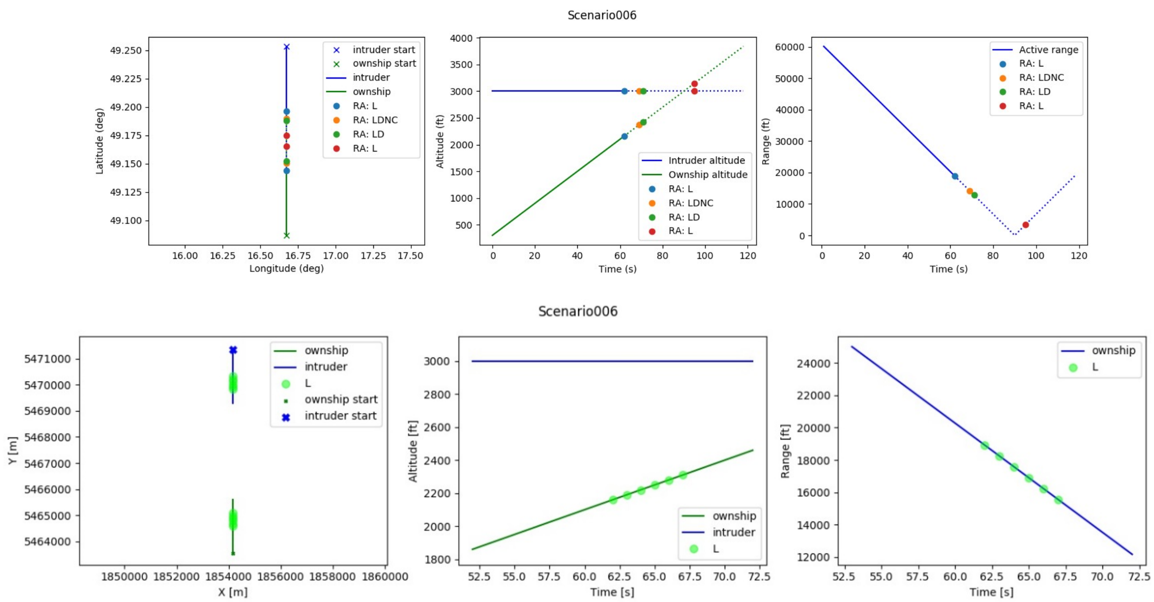
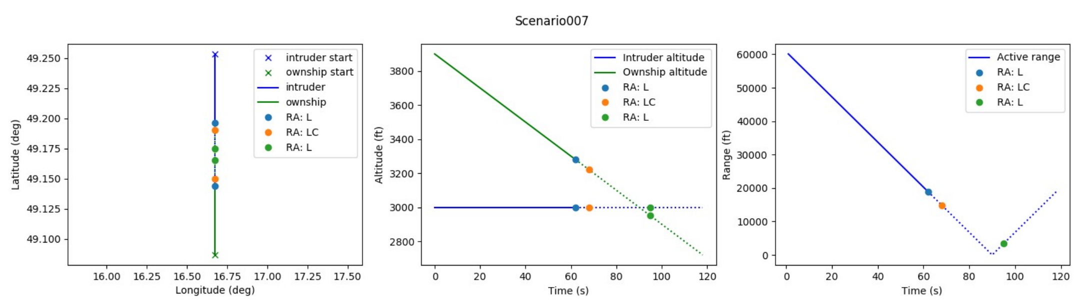



**Figure 6-45: EXE-07 - Workshop candidate scenario no.16**



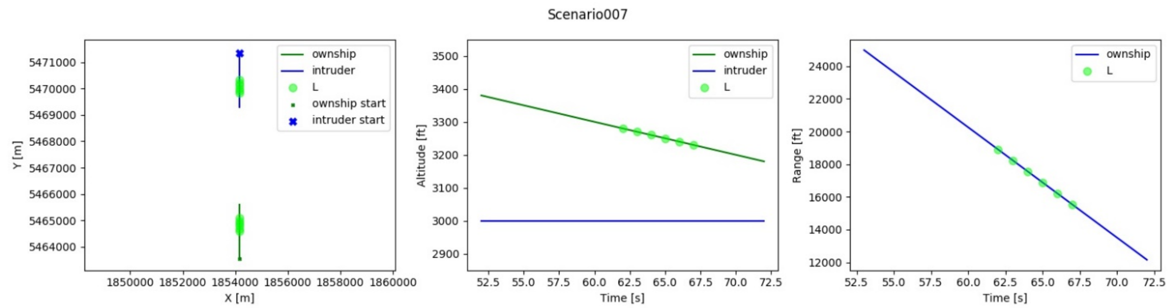



**Figure 6-46: EXE-07 - Workshop candidate scenario no.17**

## 3rd Step: Internal Workshop with GA pilots

**Purpose:**

The aim of the workshop was to obtain GA pilots' feedback to acceptability and feasibility of proposed ACAS Xu manoeuvres in two situations:

- ACAS Xu used on GA ownship (9 selected scenarios from 1st step)
- ACAS Xu used on UAV intruder, when ownship is not equipped with any traffic awareness or collision avoidance system (8 selected scenarios from 2nd step)

**Workshop progress:**

The workshop with GA pilots was performed at Honeywell premises and lasted 2 hours. There were 8 participating GA pilots. First, HF experts from Honeywell presented the TSAA+ solution, explained the situations (scenarios) and handed out paper questionnaires. Then, each scenario was presented as a video and plots with trajectory and RA details (as above).

**Workshop outcome – ACAS Xu used on ownship:**

For the first part of workshop candidate scenarios No. 1 to No. 9 shown in Figures Figure 6-35 to Figure 6-35 in the 1st step description above were used. Although the suggested ACAS Xu RAs were mostly assessed as understandable (see Figure 6-47), some RA were not provided sufficiently in advance according to the pilots (Figure 6-48). Moreover, in several cases the manoeuvres were not compliant with the rules of the air, which was also recognized by the workshop participants (Figure 6-49). Thus, the main outcome of the exercise is that **ACAS Xu is not currently trustworthy and acceptable for the use on GA aircraft** (Figure 6-50).

The following figures show answers of workshop participants to the given questions for each scenario. The scenarios are denoted as A1 to A9 and correspond to the nine candidate scenarios in the same order.

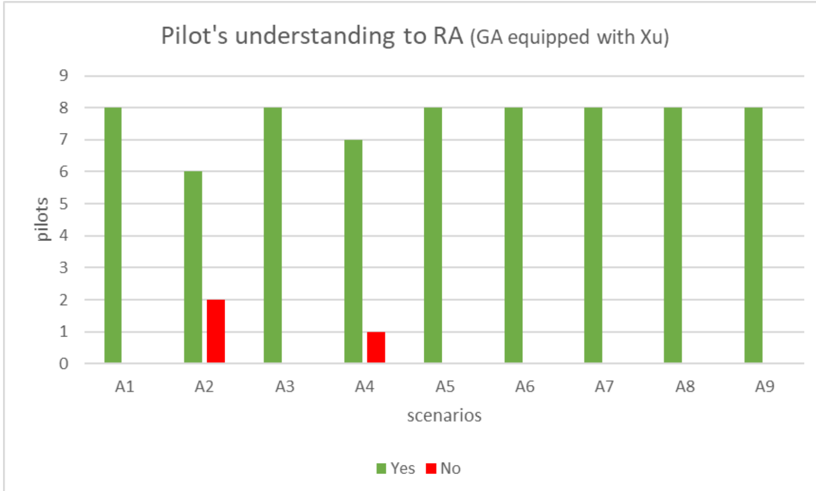



**Figure 6-47: Pilots' understanding to ACAS Xu RAs**

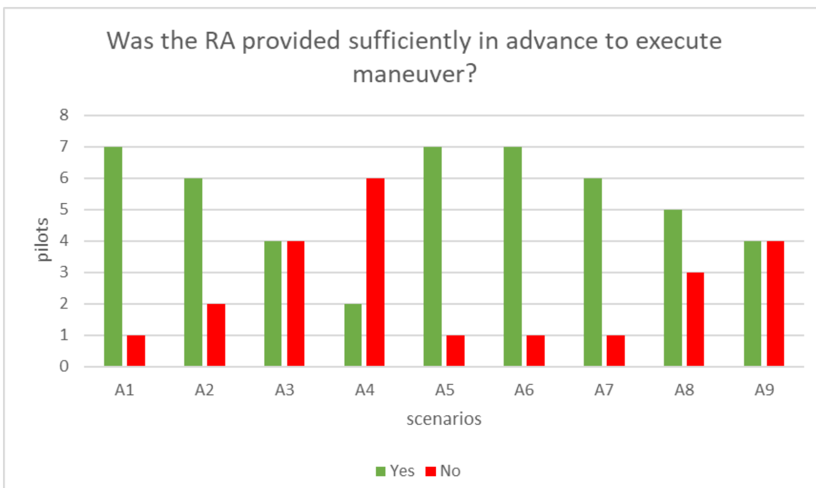



**Figure 6-48:ACAS Xu RAs timeliness**

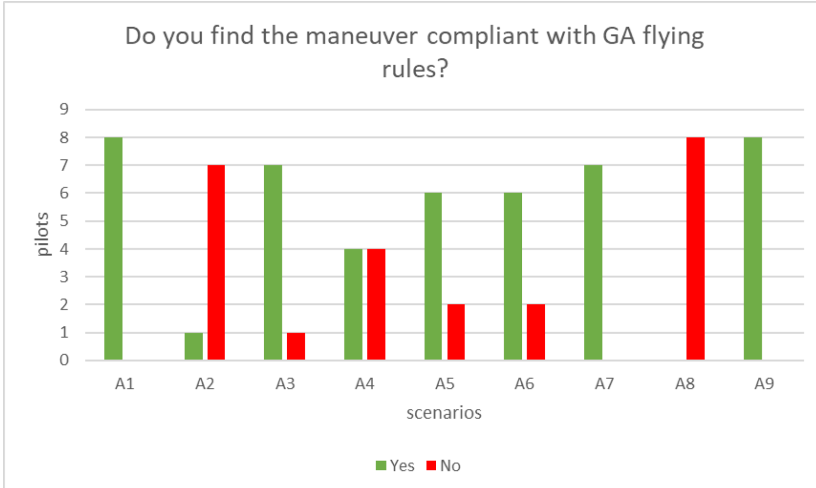



**Figure 6-49: Compliance of ACAS Xu RAs with rules of the air**

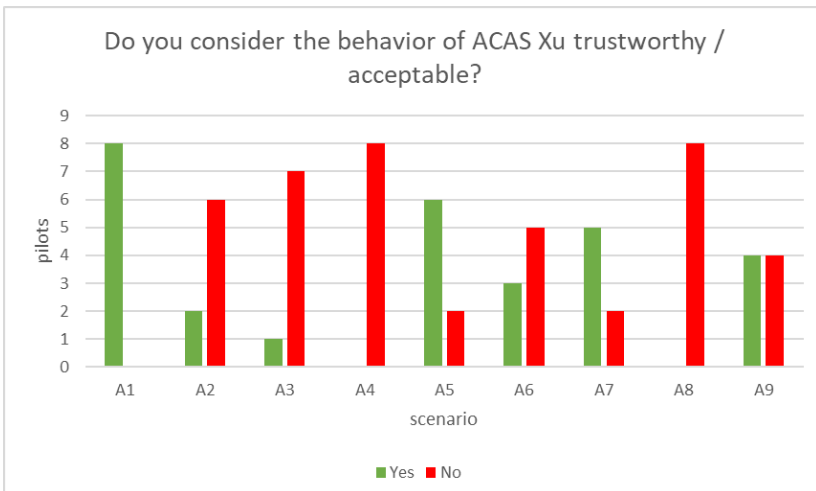



**Figure 6-50: ACAS Xu RAs overall acceptability**

**Workshop outcome – ACAS Xu used on intruder UAV:**

For the second part of the workshop artificial scenarios prepared in the 2nd step (candidate scenarios No. 10 to No. 17, Figures **Error! Reference source not found.** to **Error! Reference source not found.**) were used. They are denoted as B1 to B8 in the figures below.

The main questions to the participants were on predictability (Figure 6-51), acceptability (Figure 6-52) and compliance with the rules of the air (Figure 6-53).

The low results of acceptability and predictability of the intruder manoeuvring is again related to the non-compliance with rules of the air.

In scenario B2 (Figure 6-40), there was a vertical manoeuvre, but only one of eight pilots described it as unexpectable. However, when there was a horizontal manoeuvre in the opposite sense than required by the rules of the air, the participants gave rather negative feedback.

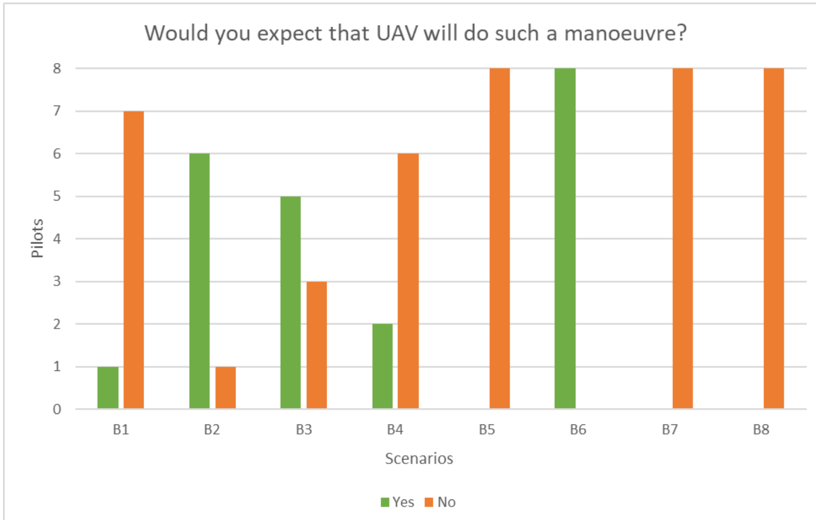



**Figure 6-51: Predictability of ACAS Xu RA on UAV**

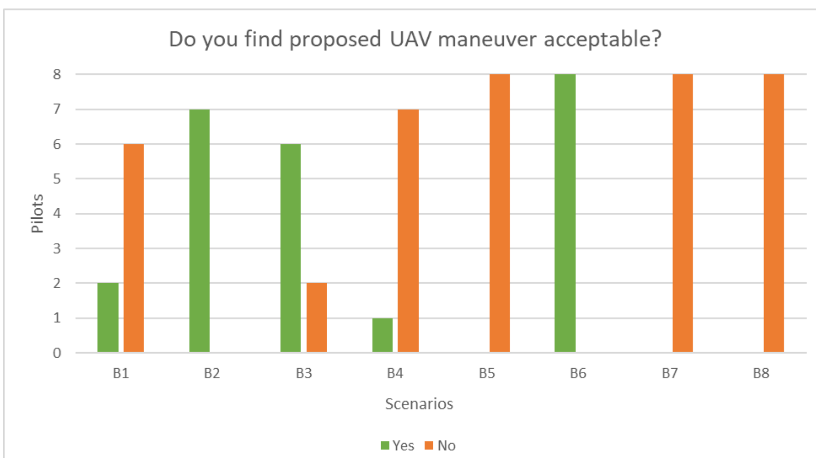



**Figure 6-52: Acceptability of ACAS Xu RA on UAV**

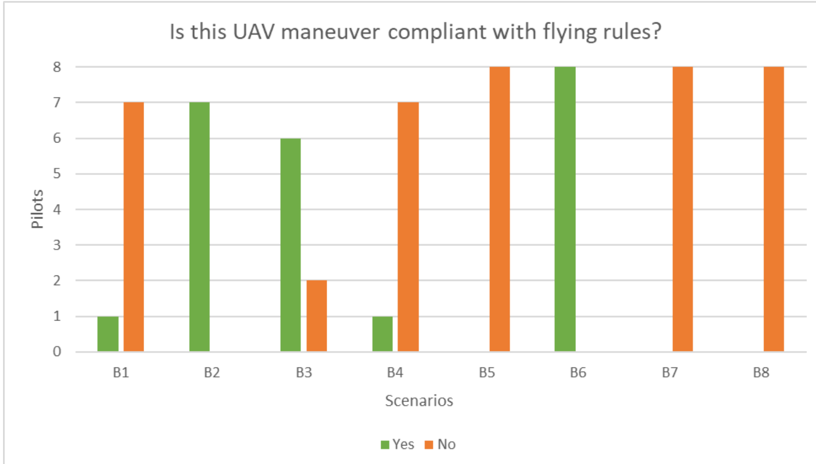



**Figure 6-53: ACAS Xu on UAV - compliance with the rules of the air**

## D.3.3 Unexpected Behaviours/Results

No unexpected behaviour.

## D.3.4 Confidence in Results of Validation Exercise 1

### 1. Level of significance/limitations of Validation Exercise Results

The limitations of the fast time simulations (1st and 2nd step) were as follows:

- ACAS Xu Run4.2 was used as it was the only available version at the time of the exercises.
- Scenarios were not dynamic. That means, trajectories of the encounters were not evolving in response to RA or a pilot action.
- Scenarios used for the 2nd step (ACAS Xu on UAV intruder) were artificial.

### 2. Quality of Validation Exercises Results

There was no negative impact on quality on top of the typical limitations of simulations and workshop sessions.

### 3. Significance of Validation Exercises Results

The results of the first two steps are significant as they are based on an encounter set that is both large and rich. The number workshop participants (3rd step) was large enough to provide a first feedback on acceptability. Thus, the results are considered significant.

## D.3.5 Conclusions

### 1. Conclusions on concept clarification

Compatibility rules of the air (right of way) is a key factor that should be incorporated.

## 2. Conclusions on technical feasibility

Technical feasibility of ACAS Xu was not assessed at this stage.

## 3. Conclusions on performance assessments

Performance assessment is left for higher level of matutiry of ACAS Xu. The initial limitations (regarding rules of the air) were identified.

### D.3.6 Recommendations

Compatibility rules of the air (right of way) is a key factor that should be incorporated.

# Appendix E Validation Exercise #08 Report

This appendix concludes validation report for EXE-PJ11.A4-V2-VALP-008, exercise performed by Thales.

## E.1 Summary of the Validation Exercise #08 Plan

As in the VALP PJ.11-A4_V2_VALP_SA+ (D6.1.010).

### E.1.1 Validation Exercise description, scope

This exercise for V2 maturity level was performed as FTS (Fast Time Simulation) on Thales simulation platform SIMPLY using TCAS II model according to [39] and ACAS Xu model according [41].

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

The objective was to assess quantitatively, the interoperability between TCAS II and ACAS Xu (ADS-B in Only) equipped aircraft, in terms of probability of near mid-air collision (NMAC).

Data received from EUROCONTROL (10^6 encounters) was generated by CAFÉ encounter model and were filtered to eliminate equipped-equipped or unequipped-unequipped encounters. Such filter eliminated 73% of the encounters, leaving a sample of 320000.

Encounter data from CAFÉ was sampled every second and interpolation has been done using MATLAB software to get data every 100 milliseconds.

CAFÉ Encounters included one unequipped aircraft (ownship) and one TCASII equipped aircraft (intruder).

One scenario has been used to analysis ACAS Xu performances:

1. TCAS II versus TSAA,
2. TCAS II versus ACAS Xu ADS-B in Only,

The ownship aircraft in scenario 1 is supposed to react to intruder as a TSAA equipped aircraft and its original trajectory has not been modified unlike in V1 exercise where the ownship trajectory has been modified according preliminary pilot reaction model that has been discarded for V2 exercise.

The ownship aircraft in scenario 2 is equipped with ACAS Xu (ADS-B in Only) and avoidance manoeuvres could be on horizontal or vertical plane.

Aircraft (ownship and intruder) performances used for manoeuvers are:

- Maximum vertical rate: 6000 fpm
- Maximum vertical acceleration: 500 fpm/s
- Banking angle: 25°
- Banking angle rate: 1 °/s

- Maximum turn rate: 3 °/s

Reaction delays used for ACAS Xu have been 3s and 5s.

Reaction delay for TCASII has been 5s.

### E.1.2 Summary of Validation Exercise #08 Validation Objectives and success criteria

| | |
|---|---|
| Identifier | **EX8-OBJ-PJ.11-A4-V2-VALP-001** |
| Objective | To evaluate the NMAC probability in the following encounter scenarios:<br>• ACAS Xu (ADS-B IN only) /TCAS II |
| Title | ACAS Xu NMAC probability assessment |
| Category | <safety> |
| EX8-CRT-PJ.11-A4-V2-VALP-001 | The NMAC probability is better in the ACAS Xu/TCAS II scenario than in the TSAA+/TCAS II scenario. |

### E.1.3 Summary of Validation Exercise #08 Validation scenarios

Following scenario has been applied in the validation:

- **TCAS II-equipped intruder vs. unequipped ownship**. The ownship has been supposed to react to intruder as a TSAA equipped aircraft because encounters provided have been generated according to controlled airspace features (cf. B.2) and its original trajectory has not been modified. The intruder has been equipped with *TCASII*, *Mode S transponder* and *ADS-B OUT*. The ownship has been equipped with *Mode C transponder*.

- **TCAS II-equipped intruder vs. ACAS Xu (ADS-B in Only) equipped ownship**. The intruder has been equipped with *TCASII*, *Mode S transponder* and *ADS-B OUT*. The ownship has been equipped with *ACAS Xu (ADS-B in Only)* and *Mode S transponder*.

### E.1.4 Summary of Validation Exercise #08 Validation Assumptions

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

| Identifier | Title | Type of Assumption | Description | Justification | Flight Phase | KPA Impacted | Source | Value(s) | Owner | Impact on Assessment |
|---|---|---|---|---|---|---|---|---|---|---|
| EX8-ASS-PJ.11-A4-001 | Pilot behaviour | Aircraft Equipage | Pilot behaviour is not repetitive for the same situation. | Pilot behaviour is based on time to react. Thus, the pilot behaviour depends on this factor, and it is not repetitive. | N/A | HP | Expert judgement | N/A | THALES | Low |
| EX8-ASS-PJ.11-A4-001 | Encounter Model | Environment constrains | Simulations will be limited to 2 aircraft: 1 ownship and 1 intruder. | Validation with more than 2 aircraft will be performed in V3. | N/A | Safety | Expert judgement | N/A | THALES | Low |
| EX8-ASS-PJ.11-A4-001 | ADS-B Only | Aircraft Technology | All sensors but ADS-B IN are deactivated in ACAS Xu | The objective is to compare TSAA/TSAA+ to ACAS Xu (ADS-B IN only) | N/A | Safety | Expert judgement | N/A | THALES | High |

**Table 32: Validation Assumptions overview**

## E.2 Deviation from the planned activities

No deviations from planned activities.

## E.3 Validation Exercise #08 Results

### E.3.1 Summary of Validation Exercise #08 Results

| Validation Exercise #08 Validation Objective ID | Validation Exercise #08 Validation Objective Title | Validation Exercise #08 Success Criterion ID | Validation Exercise #08 Success Criterion | Sub-operating environment | Exercise #08 Validation Results | Validation Exercise #08 Validation Objective Status |
|---|---|---|---|---|---|---|
| EX8-OBJ-PJ.11-A4-V2-VALP- | ACAS Xu ADS-B in Only NMAC | EX8-CRT-PJ.11-A4-V2-VALP- | The NMAC probability is better in | En-Route, TMA – various from | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 001 | probability assessment | 001 | the ACAS Xu/TCAS II scenario than in the TSAA+/TCAS II scenario | high to low complexity | | |

Table 33: Validation Results for Exercise 8

## E.3.2 Analysis of Exercise 8 Results per Validation objective

EUROCONTROL has provided 1 million safety encounters (i.e. with HMD<500ft) from CAFÉ Encounter Model. All encounters last 70 seconds.

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 is given every second. X and Y positions are distances respect to an unspecified origin whose location is not necessary for the successful outcome of the exercise.

Only Equipped-Unequipped encounters (approximately 23% of encounters) were filtered.

Such data has been post processed to MATLAB in order to have 100 milliseconds position, velocity and turn rate interpolation.

### 1. OBJ-PJ.11-A4-V-VALP-0004 Results

OBJ-PJ.11-A4-V-VALP-0004 for V2 validation phase refers to evaluation of safety of ACAS Xu (ADS-B in Only) system during mixed equipage encounters. 3s and 5s reaction delays for ACAS Xu have been used.

**EX8-OBJ-PJ.11-A4-V2-VALP-001:** *Evaluate the NMAC probability in the following encounter scenarios:*

- *TCAS II vs TSAA*
- *TCAS II vs ACAS Xu (ADS-B in Only)*

According to the TCAS MOPS [39], Near Mid Air Collision (NMAC) occurs when two aircraft come within 100ft vertically (VMD) and 500ft horizontally (HMD). The number of encounters used in simulations is too low for high level confident results.

Based on observations of European radar data, EUROCONTROL found that when HMD < 3000ft and VMD < 400ft there is a uniform distribution of observed encounters so NMAC conditions were extended to 400ft vertically (the maximum HMD is already less than 3000ft for all encounters) in order to have representative value of NMAC.

Results for TCAS II vs TSAA scenario are based on the assumption in B.2.

The computed PNMAC in TSAA scenarios is the reference for ACAS Xu scenarios. The value is 0.83%.

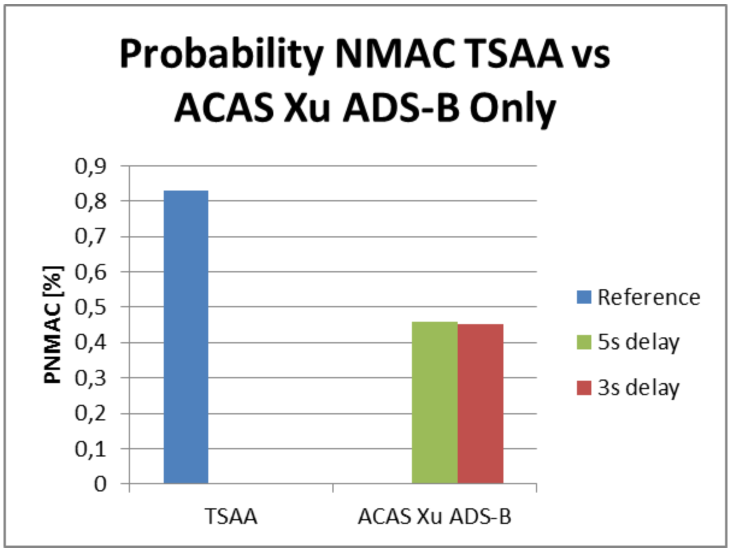



**Figure 6-54: Probability of NMAC – TSAA vs. ACAS Xu ADS-B Only**

In the figure on the top the reduction of NMAC probability is 45%. Differences between 5s and 3s pilot reaction delays are negligible.

### E.3.3 Unexpected Behaviours/Results

No unexpected behaviours/results found during V2 simulations.

### E.3.4 Confidence in Results of Validation Exercise 8

#### 1. Level of significance/limitations of Validation Exercise Results

All encounters are composed by only two aircraft and the impact of other neighbour aircraft on manoeuvers is not taken into account.

Equipped aircraft from CAFÉ model are supposed to have a TCAS II equipped aircraft behavior but sometimes this behavior doesn't comply TCASII MOPS [39].

ACAS Xu V4.1 algorithm is configured for UAV so proposed maneuvers during RA may be not adapted to GA performances.

#### 2. Quality of Validation Exercises Results

V2 simulations have been performed with SIMPLY simulator with an increased sampling rate based on an interpolating point factor of 10 (e.g. 100ms sampling rate).

All TCASII/ACAS Xu manoeuvers have been performed with constant parameters defined in E.1.1. The type of unequipped aircraft has not been taken into account.

ACAS Xu V4.1 is not yet the official version and RA logic is supposed to be improved in next releases.

### 3. Significance of Validation Exercises Results

CAFÉ encounters have been used only for safety purpose. The metric used in V2 exercise is probability of NMAC but the number of Equipped-Unequipped encounters available for simulations (320000 encounters) has been too low for high confidence probability results.

Based on observations of European radar data, EUROCONTROL found that when HMD < 3000ft and VMD < 400ft there is a uniform distribution of observed encounters so NMAC conditions were extended horizontally (3000ft) and vertically (400ft) in order to have representative value of NMAC.

## E.3.5 Conclusions

The obtained results for TSAA vs ACAS Xu ADS-B Only show that blended manoeuver reduces drastically NMAC probability by 45%.

### 1. Conclusions on concept clarification

The obtained results do not indicate needs for changes in the operational concept of collision avoidance or ACAS Xu at this stage. Differences between 5s and 3s pilot reaction delays are negligible.

### 2. Conclusions on technical feasibility

Technical feasibility was not assessed at this stage.

### 3. Conclusions on performance assessments

PNMAC assessment is described in E.3.5.

## E.3.6 Recommendations

All encounter data is not sorted by airspace classes (A, C, F and G) and aircraft environments (TMA, En-route) so results cannot give details about differences in airspace classes and environment. For next maturity phase more information in encounter data could show limits of ACAS Xu in specific scenarios.

Obtaining results with higher significance would require new real time simulations with human in loop. Scenarios shall be also extended to several intruders to have more realistic use cases.

# Appendix F SESAR Solution(s) Maturity Assessment

The maturity assessment was performed before completion of some deliverables. Therefore, some of the criteria were achieved only partially. This is expected to change before the final maturity assessment.

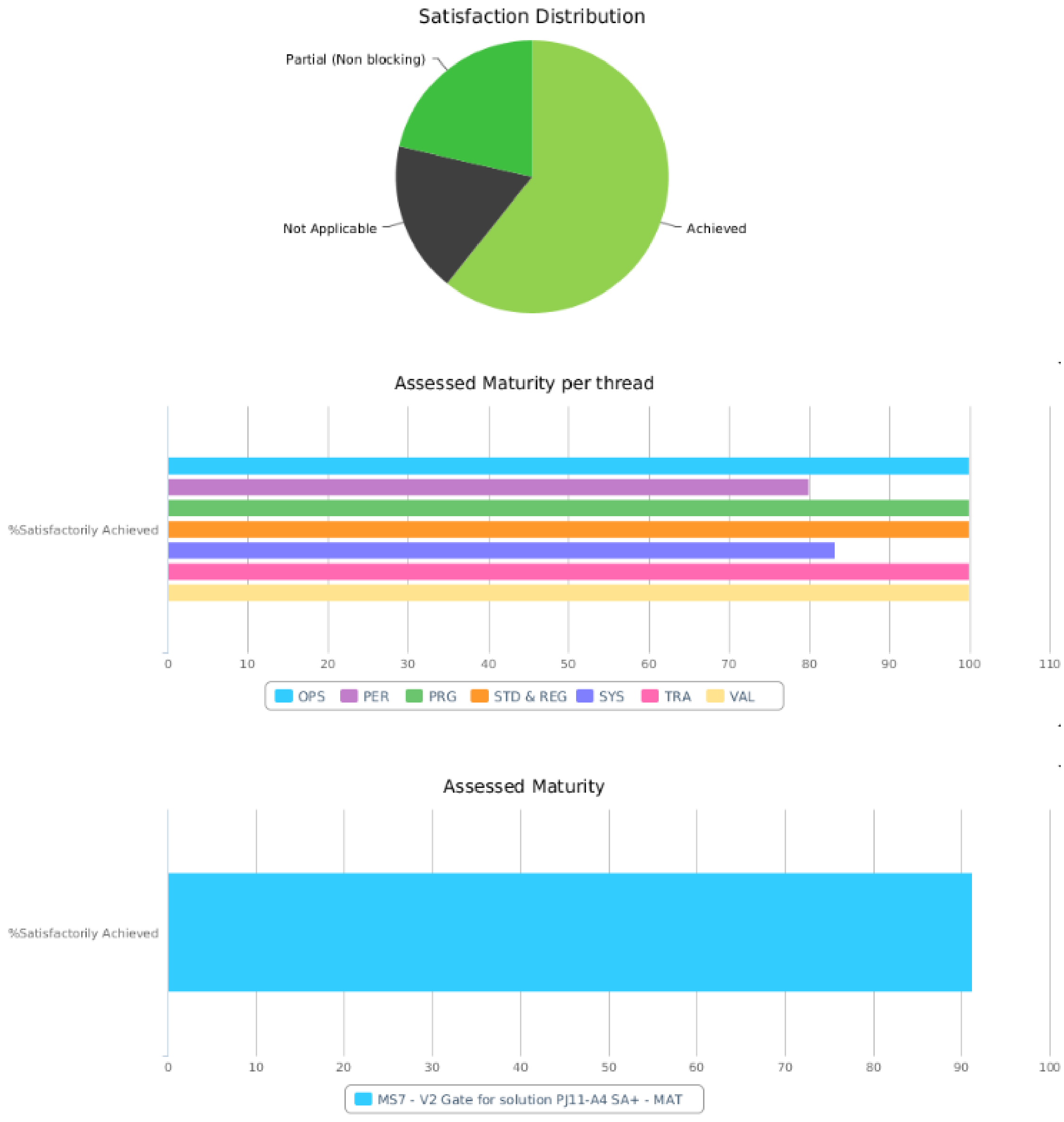



**Figure 6-55: V2 Maturity assessment overview.**

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