VALR from ACAS-Xa technical validation

Document information	
Project Title	TCAS Evolution
Project Number	09.47._
Project Manager	Honeywell
Deliverable Name	VALR from ACAS-Xa technical validation
Deliverable ID	D28
Edition	00.01.00
Template Version	03.00.00
Task contributors	
Honeywell	

Abstract

This document provides the Validation report for the second and last phase of ACAS Xa validation within SESAR 9.47 project (task T09.47-028). The validation was performed in real European environment, with ACAS Xa Run14 experimental platform tracking real traffic in the proximity of Toulouse airport via fixed roof-top antenna installation. In addition, roof-top recorded data were provided on the input to Run13 model to assess the difference in performance between the two Runs.

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Rational for rejection
None.

Document History

Edition	Date	Status	Author	Justification
00.00.01	31/07/2016	First draft	Jan Kubalčík	New Document
00.00.02	15/08/2016	Second draft	Jan Kubalčík	Added Appendix B, and comments from review incorporated.
00.01.00	16/08/2016	Final version	Jan Kubalčík	Version for submission to SJU extranet.

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Executive summary

This document provides the Validation report for the second and last phase of ACAS Xa validation within SESAR 9.47 project (task T09.47-028). The validation was performed in real European environment, with ACAS Xa Run14 experimental platform tracking real traffic in the proximity of Toulouse airport via fixed roof-top antenna installation. This validation report covers validation exercise EXE-09.47-VP-824 of V2 maturity level.

Three objectives are addressed in this document:

1. Evaluation of ACAS Xa Run14 performance in real environment,
2. Comparison with Run13 results by providing the roof-top recorded data on the input to Run13 model, and
3. Evaluation of suitability of ACAS Xa surveillance settings for current environment addressed by:
    a. Cross-validation failure ratio
    b. Active/passive data usage
    c. 1030/1090 MHz frequency usage

The conclusions of this exercise are rather straightforward reflecting the extent of changes between Run13 and Run14 STM. In general, results obtained during Run14V3 roof-top evaluation are consistent with (and thus confirms) Run13 conclusions.

- The outputs of trackers as well as the pre-STM report data are different for the estimated true trajectory (which is believed as real flown) and for the input (measured) trajectory. From the estimated true trajectory, the portion of the time when the true position is out of sigma sample area estimated by tracker is larger (higher than 5%) than the expected one (equal or lower than 5%). Consequently, we conclude, that **trackers are overconfident** in estimating confidence area (described by sigma sample) corresponding to 95% probability.

- The persisting trend of "**the more accurate ADS-B data (higher NACp), the lower confidence of declared accuracy**" also confirms the observations made for Run13.

- Implementation of hybrid surveillance significantly **increased the amount of passive data used for STM report generation**. While with Run13 it was only 11%, with Run14 it is 66%.

- Active **validation process** on the roof-top data was for the analyzed data sample **successful in 100%** for ACAS X qualified ADS-B traffic.

- With hybrid surveillance implemented in Run14V3, **1030/1090MHz frequency usage is comparable with TCAS II** with extended hybrid surveillance capability.

Core Run14V3 analysis were performed based on 2.5 hours data set. The data set was however considered as appropriate for the significance of the results also considering that additional 6 hours of real data set was modified, and evaluated via simulation confirming results from real-time data.

The general recommendation is that observations identified already in Run13, and confirmed by this Run14 validation should be taken into consideration in further development of ACAS Xa.

Validation activities presented in this document were performed by Honeywell, using prototype delivered under task 9.47-T027, with support of Airbus who hosted the roof-top data collection. The outcome of this validation aims to support the ongoing standardization activities (RTCA SC-147/EUROCAE WG 75), and will be used as input for ACAS Xa validation activities within the scope of SESAR2020.

1 Introduction

1.1 Purpose of the document

This document provides the Validation report for the second and last phase of ACAS Xa validation within SESAR 9.47 project (task T09.47-028). The validation was performed in real European environment, with ACAS Xa Run14 experimental platform tracking real traffic in the proximity of Toulouse airport via fixed roof-top antenna installation. It describes the results of validation exercises defined in Technical Validation Plan for 2016 validation of ACAS Xa (D26) and how they have been conducted.

This validation report covers validation exercise EXE-09.47-VP-824 of V2 maturity level.

Validation activities presented in this document were performed by Honeywell, using prototype delivered under task 9.47-T027, with support of Airbus who hosted the roof-top data collection.

1.2 Intended readership

The intended audience for this document are the members of P09.47 (Eurocontrol, Airbus, and DSNA) and those of the other projects involved in the Operational Focus Area (OFA) 03.04.02 “Enhanced ACAS”, in particular P04.08.01 (Enhanced safety net for en-route TMA operations) which is the operational mirror project to P09.47 and P10.04.03 “Safety Nets adaptation to new modes of operation”.

At a higher project level, the following projects may have an interest in this document:

- P09.49 Global Interoperability – Airborne Architecture and Avionics Interoperability Roadmap;

Stakeholders are to be found among:

- Flight crews;
- Executive Controllers (ATCOs) / Air Navigation Service Providers (ANSPs);
- Airborne equipment manufacturers;
- Airlines;
- Standardization bodies including RTCA SC-147/WG-75;
- FAA / EASA and other Airworthiness authorities, MIT/LL and JHU teams working on ACAS Xa in the US.

Details on stakeholders’ validation expectations are available in VALP [6].

1.3 Structure of the document

The document is organized as follows:

- Section 2 presents the overall concept of the validation, according to VALP [5].
- Section 3 provides the approach to conduction of validation exercise.
- Section 4 concludes the validation results.

- Section 5 summarizes conclusions and recommendations of the validation.
- Section 6 provides details on exercise and analysis of results.

1.4 Glossary of terms

Real measured data (or simply **measurements)** – are data on the input to the trackers. For the data designation "surveillance" is used as well and there are two types of them: Active surveillance, Passive surveillance.

Active surveillance – a type of surveillance including active tracking, where the tracking data about the target are obtained through interrogation of its transponder and subsequent analysis of transmission characteristics (delay, incoming direction) of its reply.

Passive surveillance – a type of surveillance including passive tracking, where the tracking data about the target are obtained through ADS-B reports.

True data / = ideal trajectory = most probable true trajectory / – are the estimation of the true flown aircraft position and velocity. For real measured data this information is not known and it is obtained through post-processing by combining both active and passive data in order to exclude jitter, bias and latency errors from recorded measurements. For the data designations "most probable true trajectory" and "ideal trajectory" are used as well.

Jitter – random deviation of measurements.

Bias – systematic offset between measurements and true values.

Latency – systematic time delay between real time of measurement and time of applicability.

1.5 Acronyms and Terminology

Term	Definition
ACAS	Airborne Collision Avoidance System
ACAS Xa	ACAS X – Active
ADD	Architecture Definition Document
ADS-B	Automatic Dependant Surveillance – Broadcast
ATM	Air Traffic Management
CAS	Collision Avoidance System
CPA	Closest Point of Approach
DOD	Detailed Operational Description
E-ATMS	European Air Traffic Management System
E-OCVM	European Operational Concept Validation Methodology

Term	Definition
EASA	European Aviation Safety Agency
EPU	Estimated Position Uncertainty
FAA	Federal Aviation Administration
IRS	Interface Requirements Specification
INTEROP	Interoperability Requirements
JHU	John Hopkins University
KPA	Key Performance Area
LL	MIT/Lincoln Laboratory
MIT	Massachusetts Institute of Technology
MOPS	Minimum Operational Performance Standards
NACp	Navigation Accuracy Category for Position
NACv	Navigation Accuracy Category for Velocity
NIC	Navigation Integrity Category
OFA	Operational Focus Areas
OSED	Operational Service and Environment Definition
PI	Performance Indicator
RA	Resolution Advisory
RTCA	Radio Technical Commission for Aeronautics
SC	Special Committee (RTCA)
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SIL	Source Integrity Level
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
STM	Surveillance & Tracking Module

Term	Definition
SUT	System Under Test
TA	Traffic Advisory
TAD	Technical Architecture Description
TCAS	Traffic Alert and Collision Avoidance System
TRM	Threat Resolution Module
TS	Technical Specification
VALP	Validation Plan
VALR	Validation Report
VALS	Validation Strategy
VP	Verification Plan
VR	Verification Report
VS	Verification Strategy

2 Context of the Validation

This validation report addresses the second and the last validation of ACAS Xa within the scope of SESAR 9.47 project. The validation was a roof-top validation performed in real European environment, with ACAS Xa Run14 experimental platform tracking real traffic in the proximity of Toulouse airport via fixed roof-top antenna installation. Experimental platform was implemented according Run14 Algorithm Design Description (ADD) V14R3 document produced by MIT Lincoln Laboratory prepared on behalf of FAA within RTCA SC-147.

Refer to Validation Plan (VALP) [6] for more details.

2.1 Concept Overview

ACAS X is an aircraft collision avoidance system being designed over past few years, with an intention to be proposed as the next generation of TCAS II system with general equipage beginning in the 2020-2023 timeframe. This system (having several variants), to be successful at a global level, promises to provide a response to different operational environments and priorities around the world, such as GA (ACAS Xp), unmanned aircraft (ACAS Xu), or specific operations (ACAS Xo).

From intended function perspective, there are two key modules in the ACAS X design:

- Surveillance and Tracking Module (STM), which detects aircraft in the vicinity and tracks their position, and
- Threat Resolution Module (TRM), which identifies threats and provides resolution guidance.

The following figure shows both TCAS II and ACAS X architectures:

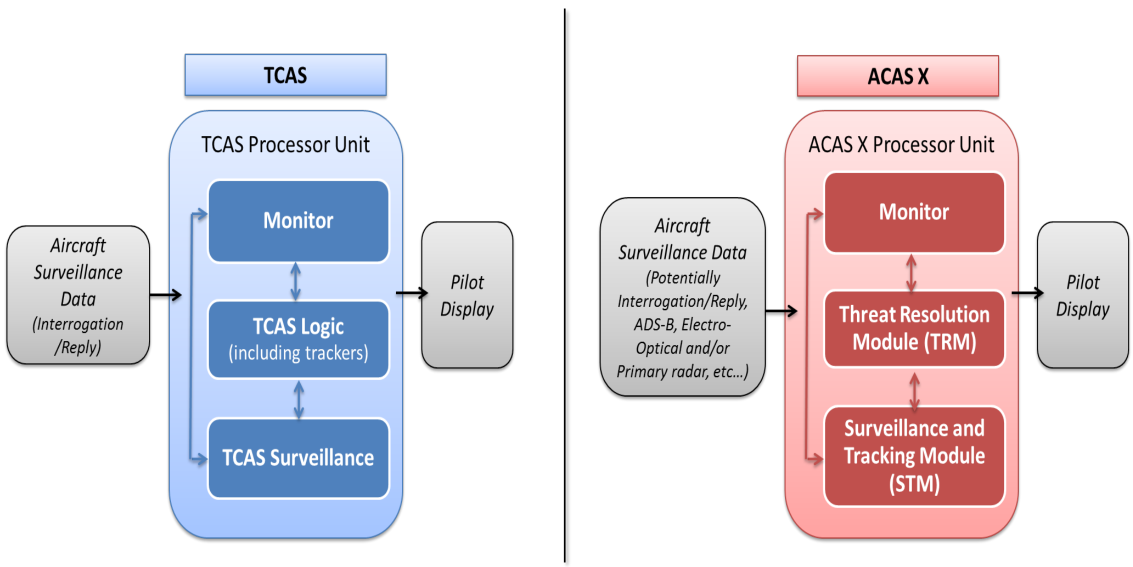


Figure 1: TCAS II and ACAS X architectures

It may seem like the TCAS (CAS) logic corresponds to ACAS Xa TRM and TCAS surveillance logic corresponds to ACAS Xa STM, but there are significant differences in the functional allocation between the two architectures (see for instance D19 [27]). One of them is related to tau computation/estimation. While in TCAS II, tau computation is not implemented inside CAS (although it is also defined in prescriptive manner through pseudo-code associated with CAS) and is defined as time-to-go to CPA[1]; in ACAS Xa logic tau already belongs to TRM - state estimation logic and is defined as time until the intruder comes within a lateral conflict distance of ownship. In more detail, "It is important to distinguish the tau in this logic from the tau that is used by the legacy TCAS logic. In the legacy logic, tau is interpreted to mean the time of closest approach and the logic uses simple models to provide a point estimate of tau."

ACAS Xa concept is still under definition (within RTCA SC-147/WG-75). It is developed, optimised and validated through the issuance of different versions of the collision avoidance logic called "Runs". The idea is that the validation of a given Run improves the design of the following until all operational, safety and performance requirements are met. New Runs are delivered approximately twice a year.

This validation report provides the results based on Run 14 version 3 of ACAS Xa.

So far, two flight tests of this system were performed by FAA:

1. Proof-of-concept flight test in 2013, using prototype of TRM software (Run11) with current TCAS surveillance and hardware.

2. Full system (STM+TRM) flight test in 2015 using Run13 experimental platform developed under SESAR 9.47 project, task 09.47-T027.

In parallel with this roof-top validation, a human performance aspects assessment within SESAR 04.08.01 project was performed using the same version of prototype. At the time of preparation of this document, 04.08.01 VALR is not yet available. These two validations, both held in Airbus, Toulouse are the last validation activities of ACAS Xa system within SESAR1. Continuation of validation activities is envisioned within the scope of SESAR2020, project PJ.11-A2 starting in Q4/2016.

Validation Exercise ID and Title	EXE-09.47-VP-824 : ACAS Xa validation in real environment (roof-top testing)
Leading organization	Honeywell
Validation exercise objectives	Evaluate the surveillance performance of ACAS Xa in real environment and compare it with Run13 performance OBJ-09.47-VALP-Xa-0001 OBJ-09.47-VALP-Xa-0002 OBJ-09.47-VALP-Xa-0003
Rationale	The aim of this validation is to evaluate surveillance functions of ACAS Xa in real environment for the first time (in Europe) and compare observed performance with Run13 using model STM developed during P.09.47-T021.
Supporting DOD / Operational Scenario / Use Case	The overall performance of ACAS Xa system
OFA addressed	**OFA 03.04.02** Enhanced ACAS operations
OI steps addressed	**CM-0808** Enhanced ACAS logic adapted to Trajectory Based Operations
Enablers addressed	**AC/54-A** Enhanced Airborne Collision Avoidance (ACAS)

[1] See glossary of terms for definition.

Applicable Operational Context	All airborne operations in En Route & TMA.
Expected results per KPA	Surveillance performance contributing to Increase in **Safety**
Validation Technique	Roof-top testing
Dependent Validation Exercises	N/A

Table 1: Concept Overview

2.2 Summary of Validation Exercise/s

2.2.1 Summary of Expected Exercise/s outcomes

Aim of this roof-top exercise is to validate the behaviour of ACAS Xa Run 14 experimental platform in real European environment focusing on its surveillance performance. Results of this validation will be compared with results of Run13 fast-time simulations in order to assess the progress in the system development. The outcome of this validation aims to support the ongoing standardization activities (RTCA SC-147/EUROCAE WG 75), and will be used as input for ACAS Xa validation activities within the scope of SESAR2020.

This validation is V2 validation of Enhanced ACAS (OI CM-0808) in the context of SESAR Trajectory Based Operations and OFA03.04.02 (Enhanced ACAS) for both En-Route and TMA airspace.

2.2.2 Benefit mechanisms investigated

The benefits investigated and presented in this document are those of ACAS X. Table below provides benefit mechanisms of ACAS Xa produced within operational project P04.08.02 (now P04.08.01).

Feature	Impact Area	Indicators		Benefit or negative impacts		Key Performance Area / Transversal Area
ACAS Xa	**Safety of ACAS**	Number of mid-air and near mid-air collisions	↓	Safety of ER / TMA operations	↑	Safety
	Alerting performance of ACAS	Number of not operationally relevant resolution advisories	↓	Compatibility of ACAS with ATM operations	↑	Safety
	Alerting performance of ACAS	Number of not operationally relevant resolution advisories	↓	Pilot acceptability of ACAS alerts	↑	Safety & Human Performance

Table 2: Benefit mechanisms overview

Validation activities described in this document address primarily the performance of the new surveillance functions and its impact on the overall system behaviour – and therefore also on the targeted benefits.

2.2.3 Summary of Validation Objectives and success criteria

Validation objectives and success criteria are as stated in VALP [6]..

Identifier	**OBJ-09.47-VALP-Xa14-0001**
Objective	Validate the overall performance of ACAS Xa surveillance in real environment
Title	ACAS Xa surveillance validation in real environment
Status	Covered by **EXE-09.47-VP-824**
Identifier	Success Criterion
CRT-09.47-VALP-0001-0001	The probability that true state of intruder lies outside of sigma sample area shall be lower than (or equal to) 5%.
CRT-09.47-VALP-0001-0002	The accuracy of tracked values shall be better than the accuracy of the input surveillance data.

Identifier	**OBJ-09.47-VALP-Xa14-0002**
Objective	Compare the performance of ACAS Xa in real environment (roof-top) with results obtained during Run13 STM fast-time evaluation.
Title	Surveillance performance comparison
Status	Covered by **EXE-09.47-VP-824**
Identifier	Success Criterion
CRT-09.47-VALP-0002-0001	The probability that true state of intruder (during roof-top validation) lies outside of sigma sample area shall be lower or equal to Run13 STM evaluation result (62%).
CRT-09.47-VALP-0002-0002	The accuracy of tracked values (during roof-top validation) shall be better than accuracy of the input surveillance data when compared with Run13 STM evaluation results.

Identifier	**OBJ-09.47-VALP-Xa14-0003**
Objective	Evaluate the suitability of ACAS Xa surveillance settings for current environment.
Title	Suitability of ACAS Xa surveillance settings
Status	Covered by **EXE-09.47-VP-824**
Identifier	Success Criterion
CRT-09.47-VALP-0003-0001	The probability of cross-validation failure for ADS-B data quality shall be less than 5%.
CRT-09.47-VALP-0003-0002	Evaluation of active/passive data usage rate completed.
CRT-09.47-VALP-0003-0003	The usage or 1030/1090 MHz frequency shall not be higher than with TCAS II with extended hybrid surveillance capability.

Table 3: Validation Objective layout

2.2.3.1 Choice of metrics and indicators

This validation report covers the last part (within SESAR1) of planned ACAS Xa validation activities at OFA level. As part of SPC03.04 (Air Safety Nets), OFA03.04.02 (Enhanced ACAS operations) only contributes to the Safety KPA. Metrics and indicators provided by 04.02 Validation strategy are not applicable to this validation, since VALS has not been updated to cover the ACAS Xa Solution as part of CM-0808.

To assess the objectives of this exercise, following metrics were used for evaluation:

- **Frequency of instances being out of tunnel**, where a “tunnel” is considered as sequence of two-dimensional areas (corresponding to 95% confidence) around each tracked point, as well as each input to the STM report (referred as pre-STM, see 2.2.6). Three additional metrics were assessed as supportive (Pseudo-radius of the “tunnel”, Pseudo-radius of the REAL “tunnel”, and Average 3D distance). [OBJ-09.47-VALP-Xa14-0001, OBJ-09.47-VALP-Xa-0002]

- **Standard deviation of Mode S range, bearing and ADS-B position** [OBJ-09.47-VALP-Xa14-0001, OBJ-09.47-VALP-Xa-0002]
- **Average of relative active validation success** [OBJ-09.47-VALP-Xa14-0003]
- **Ratio of active/passive measurements in STM report** [OBJ-09.47-VALP-Xa14-0003]

2.2.4 Summary of Validation Scenarios

[SCN]

Identifier	SCN-09.47-VALP-Xa14-0001
Scenario	ACAS Xa experimental platform tracking real traffic in the proximity of roof-top antenna installation
Status	<In Progress>

[SCN Trace]

Relationship	Linked Element Type	Identifier	Compliance
<JUSTIFIES>	<V&V Objective>	V&V Objective Identifier (VALP,VALS)	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change Reference	N/A

[SCN]

Identifier	SCN-09.47-VALP-Xa14-0002
Scenario	Use of surveillance data recorded during roof-top evaluation within Run 13 fast time simulations.
Status	<In Progress>

[SCN Trace]

Relationship	Linked Element Type	Identifier	Compliance
<JUSTIFIES>	<V&V Objective>	V&V Objective Identifier (VALP,VALS)	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change Reference	N/A

Table 4: Validation Scenario layout

2.2.5 Summary of Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Flight Phase	KPA Impacted	Source	Value(s)	Owner	Impact on Assessment
ASS-00.09.47-VALP-Xa.0001	Representativeness of traffic sample	Traffic Characteristics	Traffic sample recorded during roof-top testing will represent typical European fleet equipment.	The validation should assess ACAS X performance in European environment.	N/A	Environment	Expert judgement	N/A	N/A	Low

Identifier	Title	Type of Assumption	Description	Justification	Flight Phase	KPA Impacted	Source	Value(s)	Owner	Impact on Assessment
ASS-00.09.47-VALP-Xa.0002	Data sample	Airport Characteristics	Data collected during the validation will be sufficient for adequate data analysis and generating of representative results.	The validation will be performed using roof-top installation only, tracking aircraft near Toulouse airport.	N/A	Environment	Expert judgement	10-12 hours recorded	9.47	High
ASS-00.09.47-VALP-Xa.0003	ADS-B quality requirements decreased	Aircraft Equipage / Technology	ADS-B data with SIL=1 and SIL=2 will be allowed to pass to TRM	There is a requirement, that only ADS-B with SIL=3 can be qualified to pass to TRM. In current environment, this requirement would not be met.	N/A	Environment	Expert judgement	N/A	9.47	Medium
ASS-00.09.47-VALP-Xa.0004	ACAS X software version	Aircraft Equipage / Technology	The same software version that will be used for 04.08.01 human aspects validation will be used for this validation.	This will in the end enable to provide a full picture of Run14 ACAS X performance in European environment.	N/A	Safety	Overall validation goal	N/A	9.47	Medium

Table 5: Validation Assumptions

2.2.6 Choice of methods and techniques

Exercise EXE-09.47-VP-824 performed the technical validation of ACAS Xa surveillance in real European environment, when experimental platform was tracking real traffic in the proximity of Toulouse airport via fixed roof-top antenna installation.

The overall concept of ACAS Xa data processing is as follows: The STM module processes data to estimate the trajectory as precise as possible. It contains two filters – trackers for this purpose

- active trackers (for Mode S data: Cartesian tracker as well as range and vertical trackers), and
- passive trackers (for ADS-B data: both ADS-B tracker and vertical tracker).

The passive position measurement is combined with ownship position in order to obtain relative data used for ADS-B tracker. STM report is based on this passive tracker's result, or on the active one. So, three types of data are analyzed:

1. active trackers output data,

2. passive tracker output data, and
3. pre-STM report data.

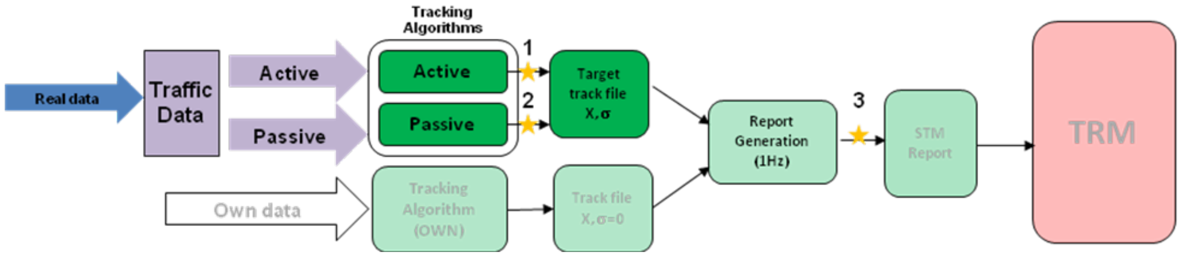


Figure 2: STM structure with marked data logging for the purposes of evaluation

Pre-STM report data are direct source for the STM report. The data contains the active tracker's result or the passive tracker's result (it could be switched in time). Moreover, the trackers' results can be extrapolated because the latest tracker's information can be older than the regular time when the STM report is generated.

Pre-STM report data are composed from the same mix (active and passive) data as STM report itself. The pre-STM report data are used because of their different structure. Whereas STM report consists of sigma samples, pre-STM report data contain the same information but expressed by Expected values and Standard deviations (what is more suitable for this analysis).
There are two main differences between the pre-STM data and the Passive data:

A) Pre-STM data are partially composed from active data too.
B) The timing of STM report generation is generally different from timings of trackers updates.

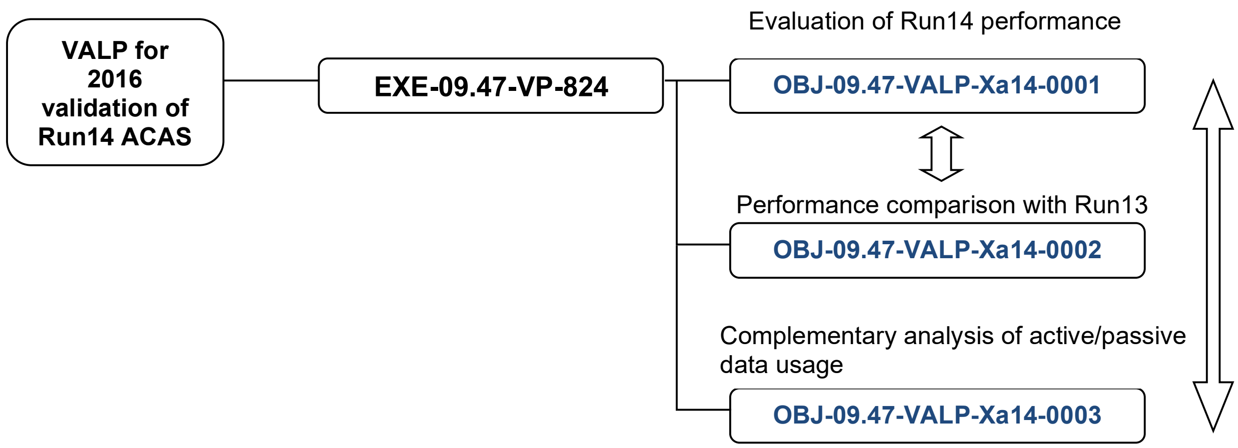
Each of these data are compared with both real measured and true trajectories what gives us six groups of results (see section 4.2).

Supported Metric / Indicator	Platform / Tool	Method or Technique
Overall surveillance performance of ACAS Xa Run14V3	Roof-top testing Airbus facility with integrated ACAS Xa Run14V3 prototype.	Real-time evaluation
Results comparison with Run13 surveillance performance	ACAS Xa Run13 model	Fast-time simulation

Table 6: Methods and Techniques

2.2.7 Validation Exercises List and dependencies

Following figure depicts exercise covered in this document, its objectives and dependencies between the results.


VALP for 2016 validation of Run14 ACAS
EXE-09.47-VP-824
Evaluation of Run14 performance
OBJ-09.47-VALP-Xa14-0001
Performance comparison with Run13
OBJ-09.47-VALP-Xa14-0002
Complementary analysis of active/passive data usage
OBJ-09.47-VALP-Xa14-0003

3 Conduct of Validation Exercises

3.1 Exercises Preparation

Run14 implementation activities on ACAS Xa prototype started in November 2015. The prototype was successfully implemented and tested at the beginning of April 2016 (with a slight delay due to the duration of preparing the prototype), shipped to Toulouse on 7th April. This experimental platform was intended to be used not only for this roof-top validation, but also for SESAR 04.08.01 human-in-the-loop validation performed by DSNA in cooperation with Airbus. To mitigate the risk of delay due to tight schedules of both validations, it was agreed to perform the two validations in parallel. Moreover, since roof-top validation required some validation specific platform modifications, not to endanger the HITL validation, a decision was taken to use second experimental platform for roof-top validation. This was delivered to Toulouse on 18th May 2016.

3.2 Exercises Execution

The aim of first objective was to evaluate the performance of ACAS Xa Run14V3 surveillance functions using experimental platform installed at roof-top testing facility at Airbus, Toulouse. It was the first technical validation of ACAS Xa surveillance functions in real European environment. Objectives of this validation were fulfilled by **detailed analysis of error characteristics observed on the output of surveillance functions.**

The approach to analysis was very similar to one taken during EXE-09.47-VP-807 (D21 - Initial STM evaluation of Run13 [1]) and FAA flight test data analysis of Run13 (D25 [3]). While previous evaluations (D21 and D25) were performed as fast-time-simulations, this time the experimental platform was tracking real-time traffic in Toulouse airport vicinity and processing it.

For the validation purposes, **real measured data ("measurements")** of tracked targets were post-processed using Honeywell developed surveillance error model to estimate the **most probable true trajectory ("ideal trajectory")** of the intruder. Ideal trajectory was then used as a reference for the data analysis.

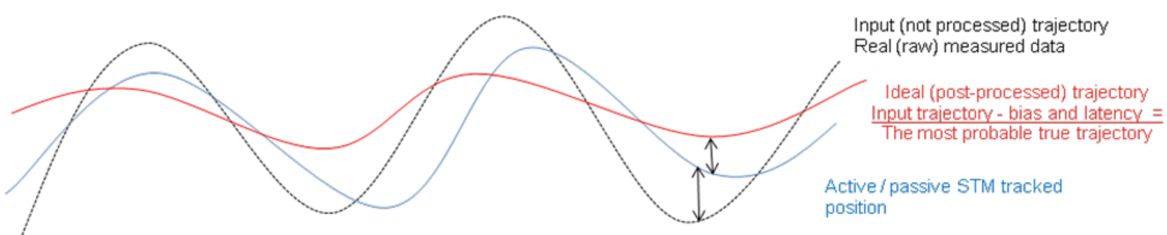


Figure 4: Exercise approach in graphics

To fulfil the second objective and compare the performance results with Run13, real measured data at the input to Run14 experimental platform were taken and provided as an input to Run13[2] fast-time simulation. The output of this simulation was then analysed into detail to assess the error characteristics differences.

[2] Run13 version was identical to one used for D21 and D25 evaluations, e.g. the one used during FAA flight testing in 2015.

Exercise ID	Exercise Title	Actuarcise execution start date	Actual Exercise execution end date	Actual Exercise start analysis date	Actual Exercise end date
EXE-09.47-VP-824	ACAS Xa validation in real environment (roof-top testing)	18/05/2016	03/06/2016	03/06/2016	29/07/2016

Table 7: Exercises execution/analysis dates

3.3 Deviations from the planned activities

3.3.1 Deviations with respect to the Validation Strategy

N/A

3.3.2 Deviations with respect to the Validation Plan

Deviations from the planned activities does not have an influence on the content of the analysis itself. Initial plan of the validation was tightly coupled with SESAR 04.08.01 HITL validation plan, since both should have been using the same HW platform. To mitigate potential risk of delay in HITL, which would cause delay in roof-top data recording and this report delivery, a decision was taken to perform both validations in parallel, using two independent HW platforms.

Due to several issues with prototype setting, and due to time and lab schedule constrains, the assumption ASS-00.09.47-VALP-2 was not fulfilled, and core Run14V3 analysis are performed based on 2.5 hours data set. The data set was however considered as appropriate for the significance of the results also considering that additional 6 hours real data set was modified, and evaluated via simulation (see Appendix B) confirming results from real-time data.

No changes with respect to content, objectives, scenarios, requirements or exercises.

4 Exercises Results

4.1 Summary of Exercises Results

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
EXE-09.47-VP-824	OBJ-09.47-VALP-Xa-0001	ACAS Xa surveillance validation in real environment	CRT-09.47-VALP-0001-0001	The probability that true state of intruder lies outside of sigma sample area shall be lower than (or equal to) 5%.	19%	NOK
			CRT-09.47-VALP-0001-0002	The accuracy of tracked values shall be better than the accuracy of the input surveillance data.	Active: Yes Passive: N/A	OK
	OBJ-09.47-VALP-Xa14-0002	Surveillance performance comparison	CRT-09.47-VALP-0002-0001	The probability that true state of intruder (during roof-top validation) lies outside of sigma sample area shall be lower or equal to Run13 STM evaluation result (62%).	Cannot be compared with Run13 (D21) fast time simulation due to different environment data set used, what significantly affects the results. However, performance of Run14 and Run13 is in general **is equal**.	OK

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
			CRT-09.47-VALP-0002-0002	The accuracy of tracked values (during roof-top validation) shall be better than accuracy of the input surveillance data when compared with Run13 STM evaluation results.	Equal	OK
	OBJ-09.47-VALP-Xa14-0003	Suitability of ACAS Xa surveillance settings	CRT-09.47-VALP-0003-0001	The probability of cross-validation failure for ADS-B data quality shall be less than 5%.	Negligible	OK
			CRT-09.47-VALP-0003-0002	Evaluation of active/passive data usage rate completed.	Completed. With this data sample, passive data are represented in STM report in 66%.	OK
			CRT-09.47-VALP-0003-0003	The usage or 1030/1090 MHz frequency shall not be higher than with TCAS II with extended hybrid surveillance capability.	Frequency usage comparable with TCAS II with extended hybrid surveillance	OK

Table 8: Summary of Validation Exercises Results

4.1.1 Results impacting regulation and standardisation initiatives

These exercise results are planned to be shared at RTCA/EUROCAE level in the context of ACAS Xa MOPS development.

4.2 Analysis of Exercises Results

4.2.1 ACAS Xa Run14 Validation in Real Environment

This section provides analysis of OBJ-09.47-VALP-Xa14-0001, e.g. roof-top validation of Run14 ACAS Xa surveillance performance.

4.2.1.1 STM Performance Using Real Measured Data

This subsection address the success criterion CRT-09.47-VALP-0001-0001.

With the approach described in 2.2.6, the main results are presented in the following table:

Comparison / Metrics	Average # of measured points	Average % of trajectory (based on points) out of "tunnel"	Pseudo-radius of "tunnel" [ft]	Pseudo-radius of REAL "tunnel" [ft]	Average 3D distance [ft]
Active – true tr.	100	20	507	1 635	1 385
Passive – true tr.	203	11	**5 658** (**408**)	291	235
Pre-STM – true tr.	122	19	615	1 719	1 427
Active – real measured tr.	100	2	507	363	739
Passive – real measured tr.	413	13	**5 077** (**392**)	190	100
Pre-STM – real measured tr.	378	13	1 459	317	369

Table 9: Run14 STM performance analysis

In the first part of the *Table 9* (the first triple of rows) the most probable true trajectory ("ideal trajectory") is the reference one. In the second part of the *Table 9* (the second triple of rows) the real measured trajectory ("measurements") is the reference one. By the first and the fourth rows output from the active tracker is analysed, by the second and the fifth rows output from the passive tracker is analyzed, and finally, by the third and the sixth rows the pre-STM data are analyzed.

High values of pseudo-radius of "tunnels" (see Appendix A) in passive cases are caused by distribution of analyzed intruders. Approximately 10% of the ADS-B OUT intruders reported a NACp = 0, indicating error estimate equal to 60 761 ft (see [4], Algorithm 43). The average is strongly influenced by these values. The distribution of intruders is described in *Figure 5*.

If the 3 intruders reporting a NACp = 0 were removed, the pseudo-radius for comparison between passive and true trajectory would be **408 ft** (instead of 5 658 ft) and the pseudo-radius for comparison between passive and real measured trajectory would be **392 ft** (instead of 5 077 ft).

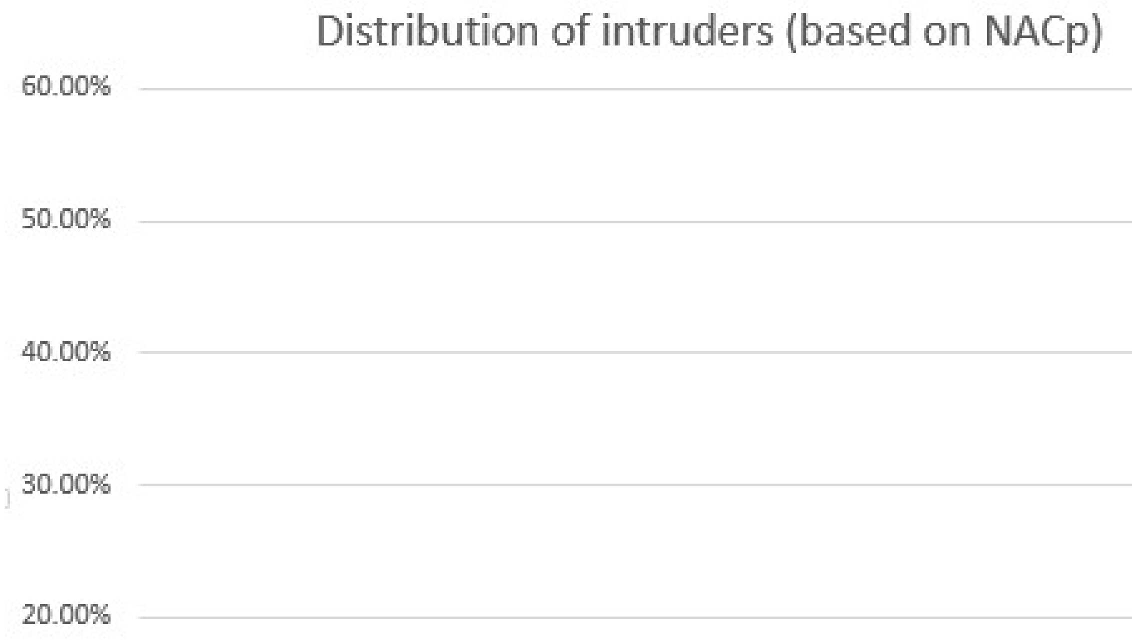


Figure 5: Roof-top intruders NACp distribution

4.2.1.1.1 Estimation of most probable position

3D distance – the precision of the most probable position estimate – is less accurate (the precision is lower) for the true trajectory than for the real measured one. This is caused by the fact, that the true trajectory is unknown for the tracker – in the meaning that the tracker cannot eliminate systematic errors (latency, bias of passive data, and bias of active bearing). 3D distances (the last column of *Table 9*) are absolutely higher for active data (the 1st and the 4th row of the table) than for the passive data (the 2nd and the 5th row of the table), because there are cases when the intruder is far away from the ownship, and even a small deviation in the active bearing implies the significant difference in the position estimate (in spite of the highest distances are eliminated).

4.2.1.1.2 Confidentiality of the declared accuracy

The probability that trajectory is outside of the tunnel is significantly lower for the real measured trajectory. To illustrate, *Figure 6* demonstrates the % of "out-of-tunnel" instances of pre-STM data for both real measured (blue) and true (red) trajectories. More than 75% of the STM outputs for real measured data are being "out-of-tunnel" only for 0-5% of the time. While in case of true trajectories, it is approximately 43% only. The reason is the same as for the 3D distance – the precision of the most probable position estimate.

For the assessment of success criterion the true trajectory was compared with pre-STM data, and as shown in the *Table 9*, **the probability that the true state of intruder lies outside the sigma sample area is 19%. Consequently, the declared accuracy is not sufficiently confident, however, it may be confident enough for TRM.** TRM is, in fact, specifically tuned based on STM output (implicitly: based on typical declared accuracy and confidentiality of the declaration…). This output can be "insufficient" based on criterions which are (naturally) constructed for STM itself – it means when the STM is considered as separated system. But, on the other hand, it is known it is not separated system. So, the TRM tuning can/may be successful despite of the STM itself is not confident enough.

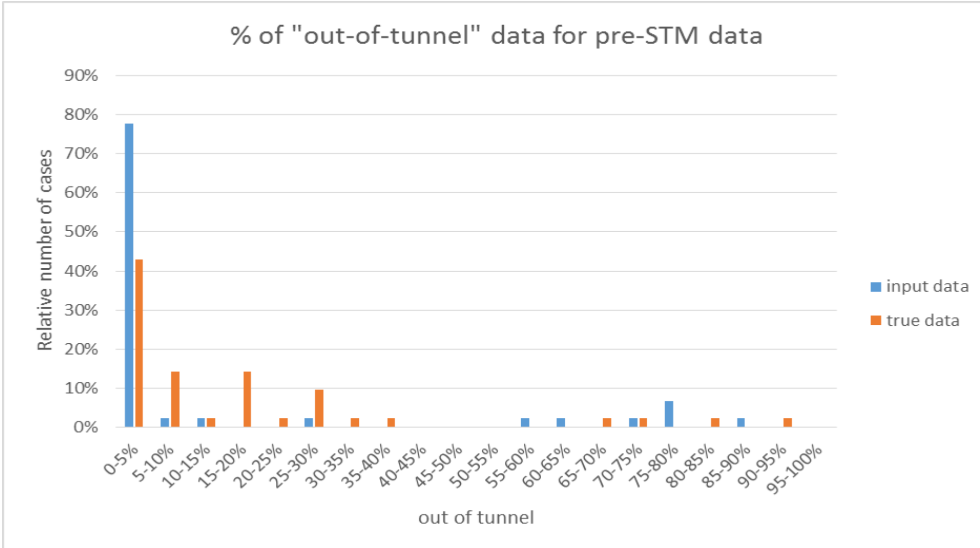


Figure 6: % of "out-of-tunnel" cases for pre-STM data

The 19% of data "out of tunnel" presented in the *Table 9* is the pondered sum of the orange bars of the *Figure 6*. Analogously, the 13% of data "out of tunnel" presented in the *Table 9* (the last row) is the pondered sum of the blue bars of the *Figure 6*.

4.2.1.1.3 NACp impact

Analyzed data for cases with NACp ≥ 7 are categorized per NACp (ADS-B position error parameter). It is necessary to highlight that there are 22 intruders with NACp = 8, but only 2 to 5 intruders for every other NACp.

As depicted in the following figures, the declared accuracy is higher (it means the estimated pseudo-radius is lower) for higher NACp. **The confidentiality of declared accuracy is worse for higher NACp, because the higher NACp the narrower estimated tunnel** (e.g. it is more challenging for the observation to be inside the tunnel).

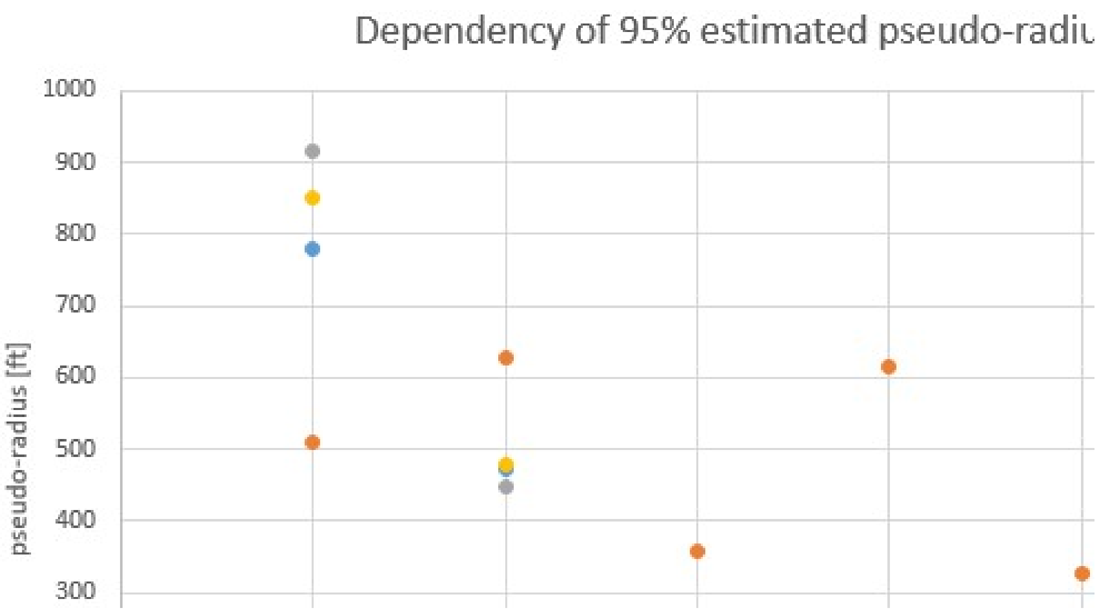


Figure 7: Estimated Pseudo-radius – NACp dependency

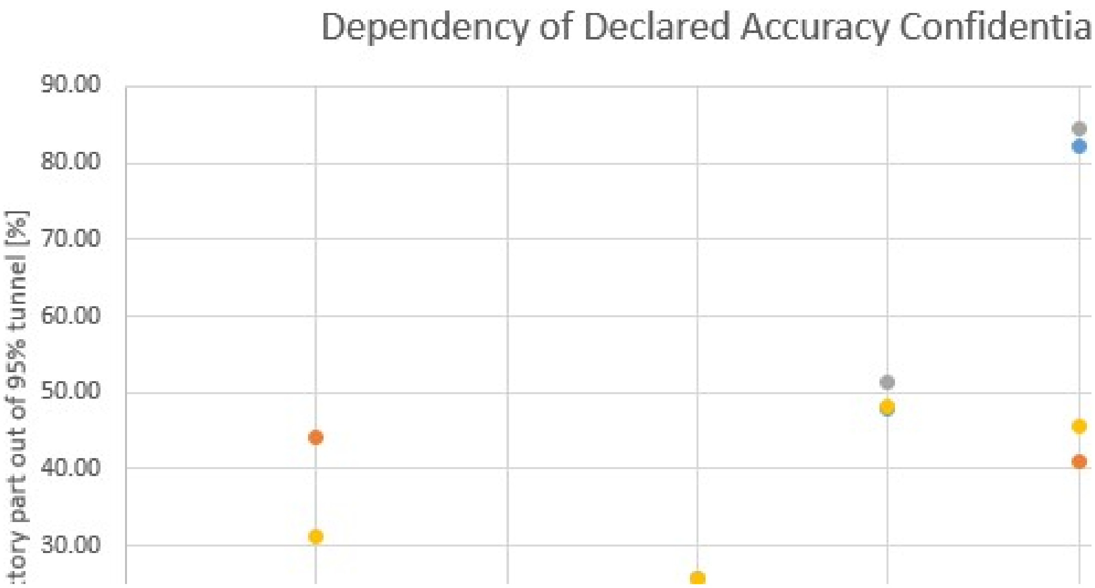


Figure 8: Confidentiality – NACp dependency

The blue points means pre-STM with regard to real measured data reference. The red points means pre-STM with regard to true data reference. The grey points represent results for comparison between the passive tracker results on the first side, and the input (real measured) trajectory (as reference one) on the second side. The yellow points represent results for comparison between the passive tracker results on the first side, and the true (ideal) trajectory (as reference one) on the second side.
Note, that the pseudo-radiuses presented in the *Figure 7* are calculated from associated standard deviations regarding the fact the situation is two-dimensional, what naturally brings larger tunnels (for instance, EPU for NACp = 7 is approx. 608 ft /see [4], Algorithm 43/ and there is standard deviation /sigma_hepu/ which is calculated based on the EPU value, for NACp = 7 it is approximately 310 ft). Moreover, the standard deviations after passive tracker (related to grey and yellow points…) depend not only on EPU, but on standard deviation of extrapolated observation as well.

4.2.1.2 Standard deviations of measurements (accuracy of tracked values)

This subsection address the success criterion CRT-09.47-VALP-0001-0002, and focusses on the performance evaluation of STM tracking algorithms, particularly standard deviation of the measurements.

Each tracker produces standard deviation (and covariance) for each result, what is a declaration of accuracy, or in other words, the indicator of confidentiality of the tracker's output. The effectiveness of the indicator is assessed by the probability that the reference trajectory is outside the 95 % tunnel. Results for standard deviations measured at different points (before the STM, at the tracker output, prior STM report) are provided in the *Table 10* .

Data / Measured at point	Before STM	After tracker	Pre-STM report
St. Dev. of the active range [ft]	27 (49)	43 (44)	65
St. Dev. of the active bearing [deg]	3.7 (4.6)	4.1 (4.3)	4.5 (5.4)
St. Dev. of the ADS-B position [ft]	23	2 315	138

Table 10: Results of standard deviation of measurements

The comparison of noise characteristics of the tracker inputs to the tracker outputs indicates the performance of tracking algorithms, as their general goal is improving the precision of trajectory. The aim of observation of these noises (before/after), and their comparison is detection whether the trackers reach their goal.

The standard deviations of pre-STM report output are influenced by the mentioned amplification caused by the time gap between the moment of data arrival and the moment of the STM report creation.

All these results are averages with upper estimates in the brackets which were used for conclusion. Based on these values we can see that **the accuracy of the tracked values** (for active surveillance) **is better than the accuracy of the real measured surveillance data** (44 ft < 49 ft for range, 4.3° < 4.6° for bearing)**.** Even though it may not seems so, but the sigma values in brackets shows much smaller deviations (and consequently smaller upper estimates).

The standard deviation of passive data before STM (23 ft) is only the noise obtained from the Error Model, what means that the latency and bias are not considered. On the other hand, for After tracker and Pre-STM report values both systematic errors are subsumed. Consequently we have not the appropriate value for the comparison but it is necessary to consider the limits mentioned just above. Based on this approach, it is not possible to conclude this kind of result for the passive tracker.

4.2.2 Performance comparison with Run13

This section provides analysis of OBJ-09.47-VALP-Xa14-0002. Approach to fulfil this objective is described in 3.2. Following results were obtained when roof-top gathered real data measurements were provided on the input to Run13 fast-time simulation. Consequently the same metrics as for OBJ-09.47-VALP-Xa14-0001 were applied and both results were compared.

Comparison / Metrics	Data source	Average # of measured points	Average % of trajectory (based on points) out of "tunnel"	Pseudo-radius of "tunnel" [ft]	Average 3D distance [ft]
Active – true tr.	**Run 14**	100	20	507	1 385
	Run 13	99	20	519	1 403
	Abs. dif.	1	0	12	18
Passive – true tr.	**Run 14**	203	11	5 658	235
	Run 13	240	12	5 571	235
	Abs. dif.	37	0[3]	87	0
Pre-STM – true tr.	**Run 14**	122	19	615	1 427
	Run 13	122	16	847	1 483
	Abs. dif.	0	3	232	56
Active – real	**Run 14**	100	2	507	739

[3] Rounding is the reason.

Comparison / Metrics	Data source	Average # of measured points	Average % of trajectory (based on points) out of "tunnel"	Pseudo-radius of "tunnel" [ft]	Average 3D distance [ft]
measured tr.	Run 13	109	1	615	722
	Abs. dif.	4	0	108	17
Passive – real measured tr.	Run 14	413 (126)	13 (4)	5 077 (4 976)	100 (37)
	Run 13	413	14	4732	99
	Abs. dif.	0	1	345	1
Pre-STM – real measured tr.	Run 14	378 (100)	13 (3)	1 459 (494)	369 (702)
	Run 13	107	4	988	862
	Abs. dif.	271	9	471	493

Table 11: STM performance Run 13 / 14 comparison

It is possible to say that the results based on **Run 14 data are very similar to results based on the Run 13 data.** The difference between numbers of involved passive points for true trajectory is caused by the fact that the passive tracker is updated more frequently for Run 13 fast-time simulation[4].

Worse % of trajectory out of "tunnel" for Pre-STM –real measured trajectory for Run 14 (13% compared to 4% for Run 13) is caused by significantly different portion of passive data in STM report: 66 % for Run 14, 11 % for Run 13. The difference is incurred by the fact[5] that there are active data in modes Hybrid, Reduced, and Normal for Run 14[6]. During time when the Run 14 active data are Hybrid (very low frequency of interrogations[7]) the STM report (when created) is composed from active data for Run 13 and from passive data for Run 14. The values in the brackets for Run14 refer to results when hybrid measurements are ignored (so as they are for Run 13). Exclusion of these data would bring results significantly closer to Run 13 results. The significantly better result for the passive tracker (4 % instead of 13 %) is implied by the fact that data with higher NACp (so, with lower confidentiality of declared precision) are removed[8]. Moreover, it should be reminded that the relationship between % of trajectory out of "tunnel" and Pseudo-radius out of "tunnel" is not linear (furthermore, both values are averages).

Out of "tunnel" trajectory % for true trajectory was computed based on Normal and Reduced data (not hybrid, See [1], chapter 3.2.1), and is more or less the same for both Run13 and Run14. To confirm this, an additional 2 sets of data from same environment were run through Run13 model. First a roof-

[4] The fact does not influence the number of involved passive points for real measured trajectory (413 for both Runs) because of slightly different interpolation approach (whilst the base for interpolation are tracked data for the true trajectory, the base for the real measured trajectory are input data).
[5] It would be incurred by the fact that there are no passive data with NACp = 7 in STM report for Run 13 as well, but for the roof-top test data there are no NACp = 7 data in the STM report for Run 14 because SIL < 3 for all of them.
[6] There are no such modes for the Run 13 active data.
[7] This is the reason why there is 107 points only in the Pre-STM real measured trajectory Run 13 situation.
[8] Even there are intruders with passive data which have two different NACp values (393D83, 393D84, 394C0E, 394C17, and 39B9F8) and active data in the Hybrid mode. When the measurements during the time when the active data are Hybrid are ignored, mainly the passive data with higher NACp are removed.

top data set recorded during 2014 extended hybrid surveillance validation – referred as data set A, and secondly a 6 hours data set recorded during Run14 prototype roof-top integration sessions requiring minor modifications to ownship setting – referred as data set B.

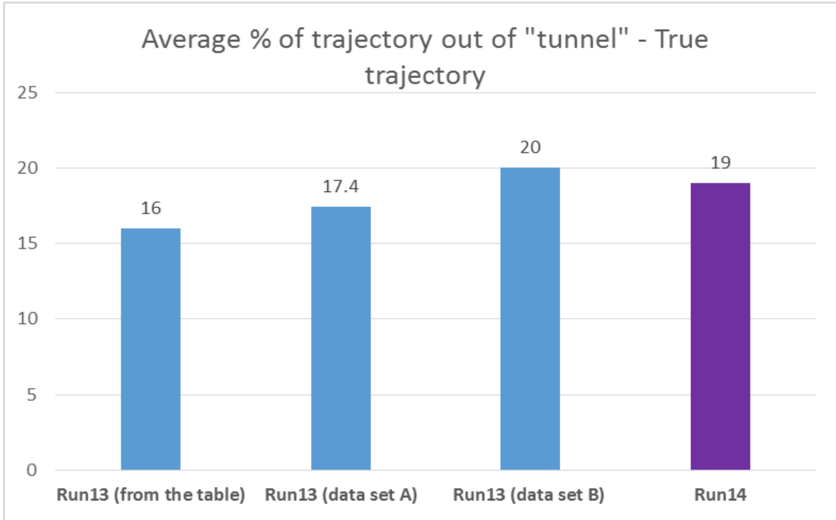


Figure 9: Different roof-top data sets run through Run13 model vs. Run14

It is necessary to remark the Pseudo-radius of "tunnel" is higher for the Run 13 (847 ft compare to 615 ft for the Run 14). Despite of the differences of the active as well as the passive tracker results are almost negligible, the difference of the results on the STM level is significant. The main reason is different timing of the STM report generation[9].

Data / Measured at point	Data source	Before STM	After tracker	Pre-STM report
St. Dev. of the active range [ft]	Run 14	27	43	65
	Run 13	27	45	109

[9] For instance, intruder 3985A8 recorded on 1st June, time (approximately) 668 – 820 s. In this interval the true trajectory estimation is available and the STM report is created purely based on the active data. The timing as well as results of the active trackers are almost the same (the difference is negligible) for the Run 13 and for the Run 14. But whilst the STM report is created 1.07 s (in average in this interval) after the track time for the Run 13, the delay is 0.5 s (in average in this interval) only for the Run 14. Consequently, the inflation of the standard deviations is significantly higher for the Run 13. The pseudo-radius of "tunnel" is 854 ft for the Run 13 and 665 ft for the Run 14 in this case and the same (for both Runs) true trajectory estimate is out of the "tunnel" in (less than) 27.0 % cases for the Run 13 and in 29.6 % cases for the Run 14.
Intruder 393D83 recorded on 1st June, time (approximately) 1 964 – 2 119 s. In this interval the true trajectory estimation is available and the STM report is created purely based on the active data for the Run 13 and based on the active as well as the passive data for the Run 14 (mostly from the active data – 5 reports based on the passive data and 151 reports based on the active data). The timing as well as results of the active trackers are almost the same (the difference is negligible) for the Run 13 and for the Run 14. But whilst the STM report is created 1.06 s (in average in this interval) after the track time for the Run 13, the delay is 0.47 s (in average in this interval) only for the Run 14. Consequently, the inflation of the standard deviations is significantly higher for the Run 13. The pseudo-radius of "tunnel" is 887 ft for the Run 13 and 649 ft for the Run 14 in this case and the same (for both Runs) true trajectory estimate is out of the "tunnel" in 14.2 % cases for the Run 13 and in 18.1 % cases for the Run 14.
There are opposite examples as well, but the behavior described above is typical.

Data / Measured at point	Data source	Before STM	After tracker	Pre-STM report
	Abs. dif.	N/A	2	44
St. Dev. of the active bearing [deg]	Run 14	3.7	4.06 (4.31)	4.5 (5.4)
	Run 13	3.7	4.06 (4.35)	4.6 (5.2)
	Abs. dif.	N/A	0.00 (0.04)	0.1 (0.2)
St. Dev. of the ADS-B position [ft]	Run 14	23	2 315	138
	Run 13	23	2 276	72
	Abs. dif.	N/A	38	66

Table 12: Standard deviation results – Run 13 / 14comparison

The behaviour of trackers is similar for all cases from trends point of view. The difference for standard deviation of ADS-B position in Pre-STM report situation is caused by the fact mentioned above: during time when the Run 14 active data are Hybrid the STM report is composed from passive data for Run 14. The most important is that in this situation the STM report is composed from passive data.[10]. On the other hand, during the same time the STM report is composed (when created) from active data only for Run 13.

4.2.2.1 Comparison of NACp dependencies

Dependencies on NACp were analyzed already in D21 resulting in interesting observation of dependency of the confidentiality on declared accuracy. Because of significant difference in STM report data composition, it is necessary to compare the data after the passive tracker (not on the STM level).

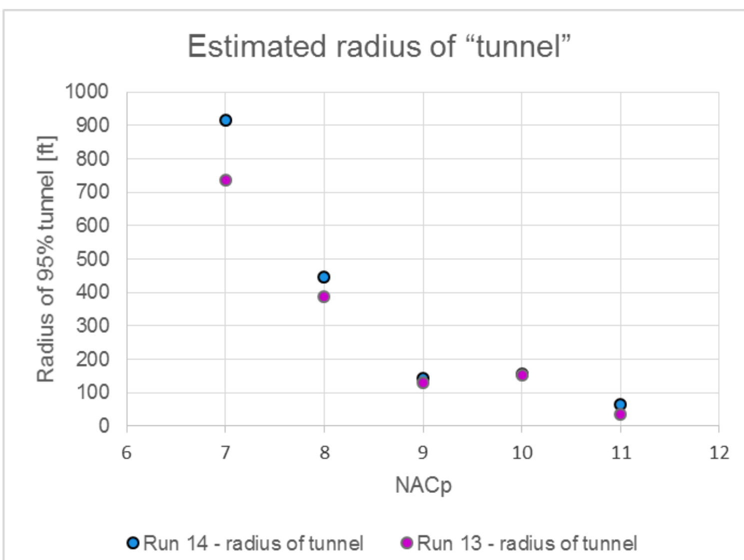


Figure 10: Dependency of declared accuracy confidentiality on NACp – Run 13 / 14 comparison (true trajectory)

[10] Regardless that the data does not satisfy the minimal condition (NACp ≥ 7, SIL = 3). For instance, intruder 393D81 recorded on 3rd June, time (approximately) 14 071 – 14 551 s.

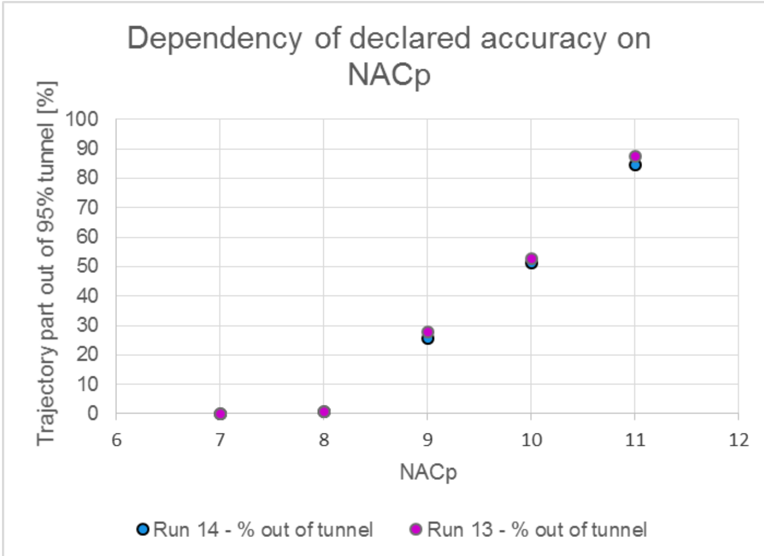


Figure 11: Dependency of declared accuracy confidentiality on NACp – Run 13 / 14 comparison (real measured trajectory – input)

A slightly higher radius of 95% tunnel for NACp = 7 and NACp = 8 with Run14 (Figure 10) is caused by Run14 passive tracker generating less amount of updates than passive tracker of Run13 does during fast-time simulation using same sample of the data. The root-cause of this behavior will be subject of more detailed analysis as part of complementary activities.

From the figures it is clear that results per NACp based on Run 14 are almost identical to those observed in Run13, having the same trend.

4.2.3 Suitability of ACAS Xa surveillance settings for current environment

This section provides analysis of OBJ-09.47-VALP-Xa14-0003. The suitability of surveillance settings was in this objective addressed by the:

- Evaluation of probability of cross-validation failure for ADS-B data quality;
- Evaluation of active/passive data usage;
- Evaluation of 1030/1090 MHz frequency usage;

4.2.3.1 Cross-validation data validation failure

This subsection address the success criterion CRT-09.47-VALP-0003-0001.

The STM report has a significant impact on the behavior of the whole system. The report is created either from active or passive tracker's results. However, the STM will provide TRM with estimated relative position and velocity of the target aircraft that has been derived from ADS-B surveillance data **only if the ADS-B track passes a number of checks**. This rule is valid when the active data are in Normal mode. For other modes (Hybrid, Reduced) the passive data are in the STM report despite of lower quality.

One such check is *active validation*, which compares ADS-B track with the Mode S track on the same target, and second check is *minimum data quality check*, which compares quality of received ADS-B data with minimum ADS-B data quality parameters defined in Parameter File.

Run 14 parameters file indicates minimal ADS-B data quality of following values:

- NIC = 6
- NACp = 7 (this is the important difference from Run 13 where the minimal value was 8)
- NACv = 1
- SIL = 3

Our analysis shows that active validation process is successful in 100% of the cases (for NACp ≥ 7 and SIL = 3). For complete picture, taking into account the full set of roof-top recorded data, it would be more than 95 %, and more than 99.9% even for data with NACp ≥ 7 only. There is 35 intruders with NACp higher than 7, however only 5 intruders with sufficient NACp and SIL = 3.

4.2.3.2 Active/Passive data usage for STM report

This subsection address the success criterion CRT-09.47-VALP-0003-0002.

Analysis of whole roof-top recorded data set showed that **STM report is generated from 66% of passive data**, while with Run13 it was just 11%.

For intruders (cases) with NACp ≥ 7 only (with SIL = 0, 1, 2 or 3, it means w/o SIL distinction) the STM report would be created from 69% of passive surveillance data. For intruders (cases) with NACp ≥ 7 and SIL = 3 (it means the passive data have the required minimal quality) the STM report would be created from 94% of passive surveillance data.

4.2.3.3 1030/1090MHz frequency usage

Hybrid and extended hybrid surveillance implementation was one of very few changes in STM since Run13.

To assess whether the benefits of hybrid surveillance remains with ACAS X, the estimated savings were calculated for the data set. The approach to this assessment is identical to one followed during TCAS II with Extended Hybrid Surveillance validation [7]. By comparison of sum of all interrogation really made (sum of all active interrogations, and interrogations made under hybrid surveillance), with estimated amount of active interrogations as expected without hybrid surveillance (aircraft that were under active would be interrogated in the same manner, and aircraft under hybrid and extended hybrid would be interrogated with a reduced surveillance rate, of which we assume 0.2 Hz), the assessment shows **37% of saved interrogations**, what corresponds to results for roof-top data collected in 2014 during TCAS II with extended hybrid surveillance validation (30,5%).

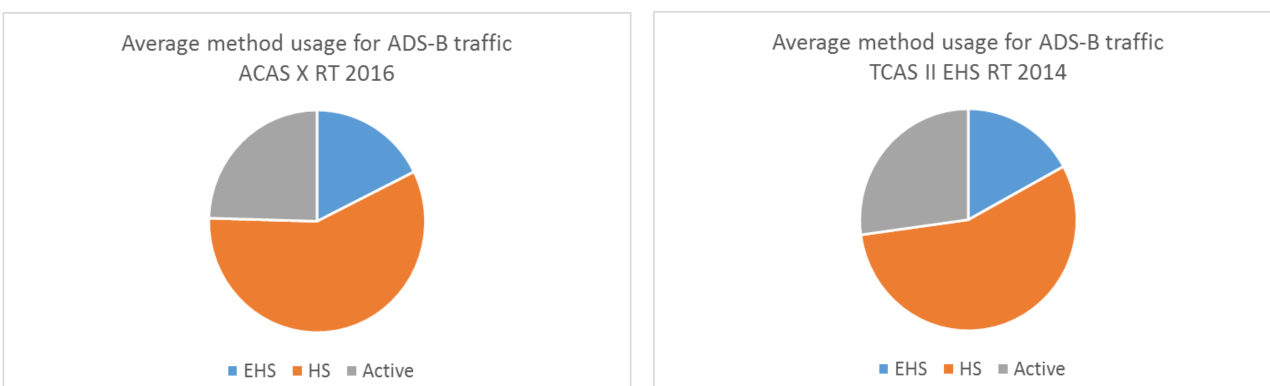


Figure 12: Average method usage for ADS-B traffic (ACAS X vs. TCAS II)

Please note that these results seems lower than those assessed in [7] which proved savings of up to 83%. The reason is that data analyzed herein are for a specific situation of a static ownship, located in airport area, with manually set “in the air” status. In this situation short ranges of intruders around airport does provide less opportunities for hybrid or extended hybrid method to be used.

4.2.4 Unexpected Behaviours/Results

N/A

4.3 Confidence in Results of Validation Exercises

4.3.1 Quality of Validation Exercises Results

It is important to note that validation main conclusion that overall performance of Run14 did not change in comparison with Run13 refers to the situation when we compare the data from similar conditions/operations as a roof-top data benefits from small ranges of intruders (typical for airport environment) and static ownship..There are significant differences in the results when comparing with overall Run13 STM fast-time evaluation. This is caused by difference in environment where the data sample was obtained, both D21 and D25 being based on a large set of flight data representing different conditions and phases of the flights.

4.3.2 Significance of Validation Exercises Results

A couple of recordings were performed between mid-May and early June. Unfortunately, the initial recording were affected by some incorrectly set ownship parameters, therefore they could not be considered as valid real-time data. Nevertheless they were subsequently corrected and evaluated at least via fast-time simulations (see Appendix B) to support the core results. After that, 2h25min48sec of valid data were successfully collected and used for analysis. Roof-top validation exercise was completed on 3rd June 2016. The core data set consists of 38 intruders, these were analysed in order to assess three objectives of validation.

5 Conclusions and recommendations

5.1 Conclusions

The conclusions of this exercise are rather straightforward reflecting the extent of changes between Run13 and Run14 STM. In general, results obtained during Run14V3 roof-top evaluation are consistent with (and thus confirms) Run13 conclusions.

- The outputs of trackers as well as the pre-STM report data are different for the estimated true trajectory (which is believed as real flown) and for the input (measured) trajectory. From the estimated true trajectory, the portion of the time when the true position is out of sigma sample area estimated by tracker is larger (higher than 5%) than the expected one (equal or lower than 5%). Consequently, we conclude, that **trackers are overconfident** in estimating confidence area (described by sigma sample) corresponding to 95% probability.

- The persisting trend of "**the more accurate ADS-B data (higher NACp), the lower confidence of declared accuracy**" also confirms the observations made for Run13.

- Implementation of hybrid surveillance significantly **increased the amount of passive data used for STM report generation**. While with Run13 it was only 11%, with Run14 it is 66%.

- Active **validation process** on the roof-top data was for the analyzed data sample **successful in 100%** for ACAS X qualified ADS-B traffic.

- With hybrid surveillance implemented in Run14V3, **1030/1090MHz frequency usage is comparable with TCAS II** with extended hybrid surveillance capability.

5.2 Recommendations

The general recommendation is that observations identified already in Run13, and confirmed by this Run14 validation should be taken into consideration in further development of ACAS Xa. It is also recommended to

- continue validation activities of consecutive runs, ideally during flight tests in more representative airspace,

- perform more detailed analysis using data set with higher number of intruders with NACp equal to 7 and 9-11,

- perform the validation of Run15 where more significant changes in STM are expected, expecting mitigation of findings reported already in D21 [1] and D25 [3] and confirmed in this VALR.

6 Validation Exercises reports

N/A

Since this validation report consists of one exercise only, its results are available in chapter 3 and 4.

7 References

[1] **SESAR 9.47, Validation Report from Initial STM Performance Evaluation**, D21, June 2015

[2] **Algorithm Design Description of the ACAS X** (ACAS X ADD), ACAS_X_ADD_RUN13(2014-12-10), Version 13, Revision 1, December 10, 2014

[3] **SESAR 9.47, Technical Lessons Learned (FAA 2015 Flight Tests)**, D25, February 2016

[4] **Algorithm Design Description of the Xa and Xo ACAS X**, ACAS_ADD_16_001_V14R3, V14R3, February 1, 2016

[5] **Surveillance Radar Range-Bearing Centroid Processing: Part II, Merged Measurements,** Benjamin J. Slocumb and Daniel L. Macumber, proc.of SPIE, Vol.6236

[6] **SESAR 9.47, Validation Plan (VALP) for 2016 validation of ACAS Xa**, D26, October 2015, v1.0

[7] **SESAR 9.47, Report on Improved Hybrid Surveillance Validation – issue2, D32**,February 2016, V2.0

7.1 Applicable Documents

[8] Template Toolbox 03.00.00
https://extranet.sesarju.eu/Programme%20Library/SESAR%20Template%20Toolbox.dot

[9] Requirements and V&V Guidelines 03.00.00
https://extranet.sesarju.eu/Programme%20Library/Requirements%20and%20VV%20Guidelines.doc

[10] Templates and Toolbox User Manual 03.00.00
https://extranet.sesarju.eu/Programme%20Library/Templates%20and%20Toolbox%20User%20Manual.doc

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

[12] EUROCONTROL ATM Lexicon
https://extranet.eurocontrol.int/http://atmlexicon.eurocontrol.int/en/index.php/SESAR

Appendix A Shape & size of the confidence areas

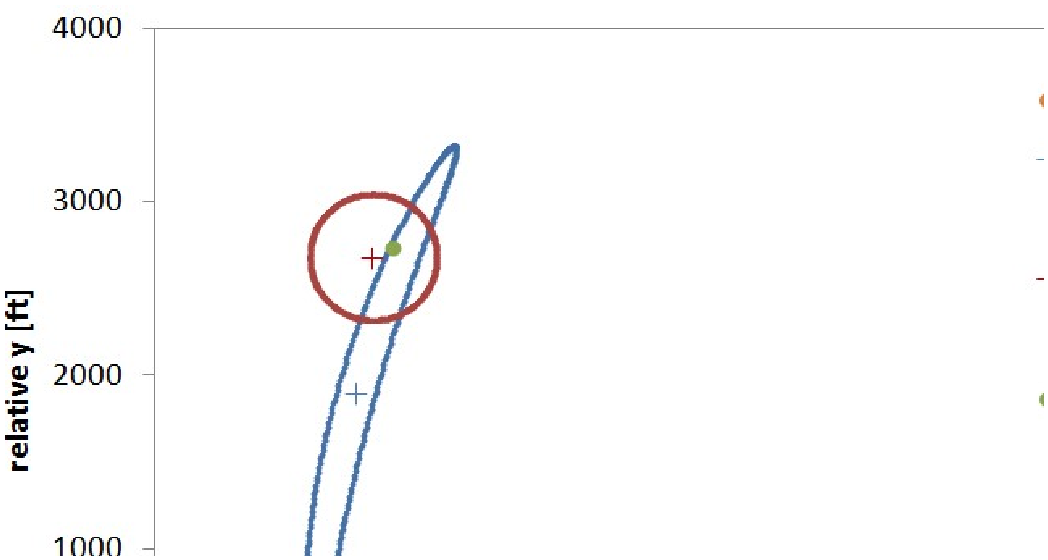
A "tunnel" is considered as a sequence of two-dimensional areas around each tracked point, each point – input to the STM report respectively, corresponding to 95 % confidence of 2D interval (area) based on the Gaussian distribution. STM provides a standard deviation for each point separately; consequently the extent of the areas mentioned above is different.

Error areas for the active data (results of active trackers) are generally elliptic. So, it is not possible to present them simply by radius – this is the reason why pseudo-radius was taken in place (see below). The pseudo-radius is "normal" radius for the passive data because error areas for the passive data are represented by circles. The error areas for the mixed data (just before the STM report) are inevitably considered as elliptic – with respect to the more general case.

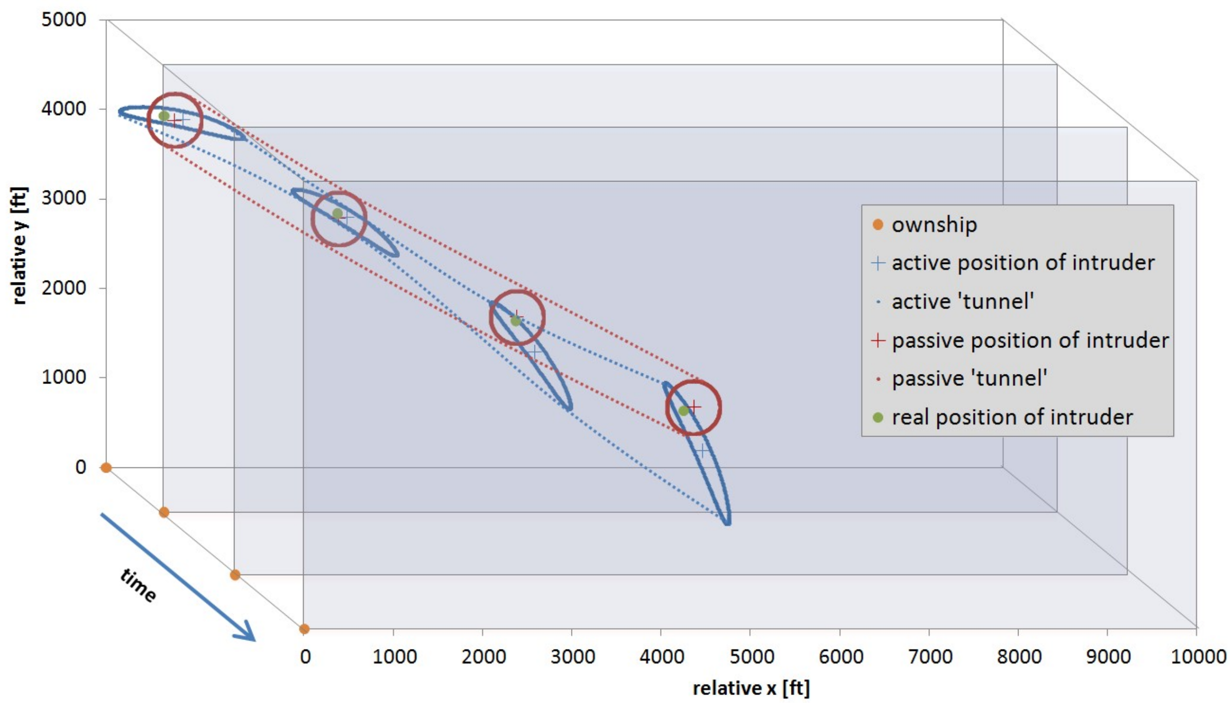
The pseudo-radius of tunnel in pre-STM case in the table above is moreover amplified by the fact that the report is generated more frequently than the source data (data based on which the STM report is created) are available, and the higher time gap – the larger standard deviation of the active data (range as well as bearing).

The large pseudo-radius of the passive data is caused by their low quality (see below).

The active tunnel, the passive tunnel (both of them constructed based on the 95% probability), and the true position of intruder are illustrated in the next figures. The ownship is in the origin position; the case corresponds to the artificial encounter composed (see the next Exercise) from the geometry D, the altitude profile „peak", the speed profile „acceleration – deceleration", and noise ID N8/L2 (see Table 17) – time 1075 s. In the Figure 16 the time evolution of the tunnels is schematically demonstrated.



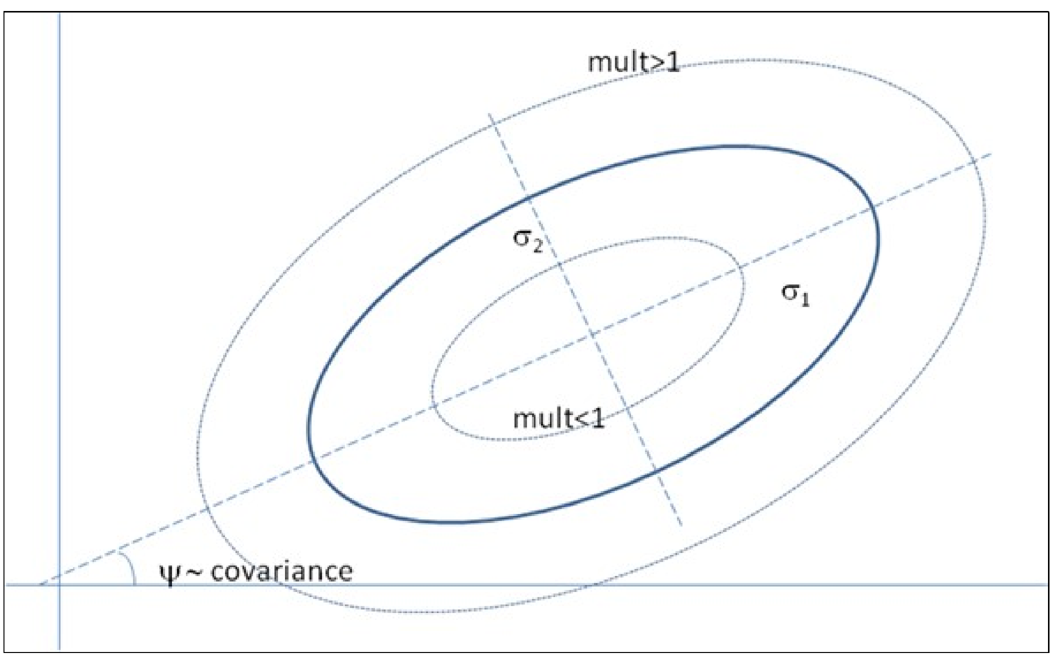
Active and passive tunnel



Time evolution of active and passive tunnel

A.1 What is pseudo-radius of the tunnel?

The horizontal tunnel is based on the two-dimensional (2D) Gaussian distribution (for passive, as well as active measurements – in active case the Gauss distribution is assumed in range and bearing, see [5]), more precisely based on error ellipses.



Error ellipse

The standard deviations of the 2D Gaussian distribution are represened by semi-axes of the error ellipse and the slope ψ corresponds to covariance. If the involded variables are independent of each other, the covariance is equal to 0 and consequently ψ = 0°. It is known that

$$tg(2\psi) = \frac{2}{\quad}$$

The width / size of the tunnel is controlled by the probability. It is required to set the width such that the observations are expected inside the tunnel with the input probability. In other words, it is necessary to find the appropriate multiplicator „mult“ of the semi-axis (standard deviations). By the multiplicator the „basic“ error ellipse (semi-axis are equal to the standard deviations exactly) is inflated (mult > 1) or deflated (mult < 1). The probability of 95% corresponds (app.) to mult = 2.44775, the probability of 99% corresponds (app.) to mult = 3.03485. The results are based on the solution of the following equation (where P is the probability, a, b are the standard deviations, and t = mult):

$$P = \iint_{\left(\frac{x}{a}\right)^2+\left(\frac{y}{b}\right)^2<t^2} \frac{1}{2\pi ab} \cdot e^{-\frac{1}{2}\left(\left(\frac{x}{a}\right)^2+\left(\frac{y}{b}\right)^2\right)}\, dx\, dy$$

The standard deviations of the observations – tracked points are changing, and consequently the error ellipses – tunnels are different. This is the reason why the average error ellipse is calculated – to present „typical tunnel“ for the intruder.

Average error ellipse is obtained in form of the area (the area of an ellipse is equal to multiplication of both semi-axes and π), because of the interpretation of semi-axis sizes is dificult (especially when covariance is not equal to zero...). But the area value (the connection between the area and the property of the tunnel) is not sufficiently explanatory. Therefore, the tunnel is finaly represented by the „pseudo-radius“ what is the average radius of the circles with the same areas as the associated error ellipses – precisely: the pseudo-radius of the tunnel is the average of multiplications of mult and square-root of the ellipses' semi-axis product.

It is necessary to note that the tunnel representation by the pseudo-radius is the more accurately the ratio $(\min\{\sigma_1, \sigma_2\})/(\max\{\sigma_1, \sigma_2\})$ closer to 1.

Finally, there is no fault in accuracy of passive observations, because both involved standard deviations are considered as equal (both involved components are considered as independent). Of course, covariance is zero in these cases.

Appendix B Fast time simulation results for subsequently corrected data

The aim of this appendix is to compare results obtained from data processed in real time by ACAS Xa Run14 experimental platform in a roof-top installation (and described in main sections of this document) with results obtained from additional data recorded during the integration sessions (more than 6 hours during 4 days: 18th, 19th, 20th, and 31st of May), but with incorrect simulation setup so requiring some extra post-processing. These additional recorded surveillance data were corrected and sent as an input to ACAS Xa STM Run 14 fast time simulation[11].

There are 72 intruders involved, STM report being created from passive data in 57% and cross-validation are successful in 96% of cases.

With the approach described in 2.2.6, the most important results are presented in the following table:

Comparison / Metrics	Average # of measured points	Average % of trajectory (based on points) out of "tunnel"	Pseudo-radius of "tunnel" [ft]	Pseudo-radius of REAL "tunnel" [ft]	Average 3D distance [ft]
Active – true tr.	95	20	587	2 824	2 842
Passive – true tr.	296	33	5 239	821	727
Pre-STM – true tr.	149	22	856	2 624	2 685
Active – real measured tr.	129	2	723	503	1 496
Passive – real measured tr.	583	29	4 948	272	138
Pre-STM – real measured tr.	433	26	2 570	538	874

Table 13: Run14 STM performance analysis – FT simulation for corr. data

Each tracker produces, in addition to mean value, also standard deviation (and covariance) for each state estimation, what is a declaration of accuracy, or in other words, the indicator of confidentiality of the tracker's output. The correctness of the indicator is assessed by the probability that the reference trajectory is outside the 95 % tunnel (with the expected value being 5%). Results for standard deviations measured at different points (before the STM, at the tracker output, prior STM report) are provided in the *Table 14*, the value in brackets representing upper estimates.

Data / Measured at point	Before STM	After tracker	Pre-STM report
St. Dev. of the active range [ft]	42 (72)	44 (45)	85
St. Dev. of the active bearing [deg]	3.9 (4.9)	4.3 (4.7)	5.1 (6.0)
St. Dev. of the ADS-B position [ft]	82	2 141	1 251

Table 14: Results of standard deviation of measurements – FT simulation for corr. data

[11] The fast time simulation platform was previously verified using the main roof-top recorded data set and comparing the recorded and simulated STM outputs.

The results presented in the validation report indicate that the STM output seems to be very sensitive to NACp values of the tracked intruders and also on the delay between the reception of the measured data and the STM report generation. The additional results presented in this appendix confirms fully this hypothesis as the observed differences in Table 13 seems to be caused by considerably different NACp distribution in this data set (see comparison in Figure 13) and also by a different STM report generation timing[9].

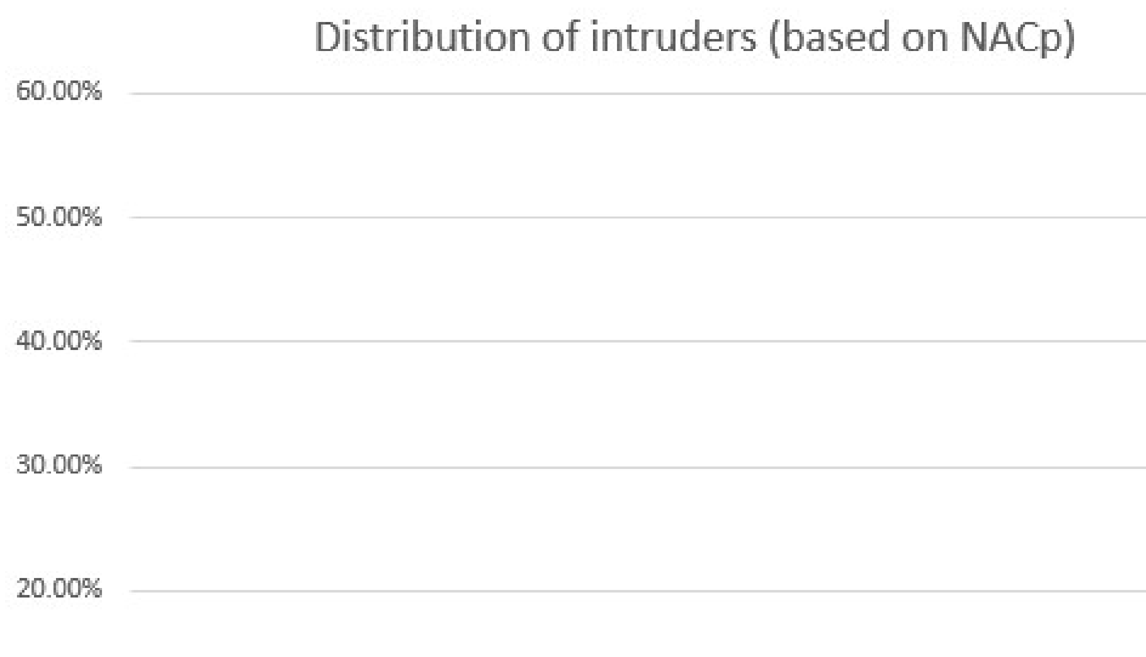


Figure 13: Roof-top intruders NACp distribution – corrected data and data from experimental platform

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