Report on Improved Hybrid Surveillance Validation - issue 2

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Abstract

The objective of extended hybrid surveillance is to considerably reduce the use of 1090 MHz frequency by TCAS interrogations. A key enabler is ADS-B Out technology. This document is a 2nd issue of report, and concludes all SESAR 9.47 validation activities of this new TCAS II capability, as well as provides feedback to the standardization activities on the extended hybrid surveillance MOPS.

The objective of this extended hybrid surveillance validation was to test the capability in real environment - via both roof-top test installation and flight testing. Focus was given on overall benefit analysis and behaviour in all conditions: on ground, in the air and during take-off and landing. One exercise was dedicated to evaluate overall impact of TCAS II extended hybrid surveillance on RF load of 1090 MHz in core European airspace.

Additional flight test data from more representative environment were collected, and their evaluation is available in Appendix B.

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Executive summary

Hybrid and extended hybrid surveillance (EXT) are TCAS II capabilities allowing tracking distant intruders using data from their ADS-B reports. The objective of these new surveillance techniques is to reduce TCAS utilization of the 1090 MHz channel via decrease of Mode S interrogations (about half of all today's communication on this channel in European airspace is associated with TCAS). The two techniques differ in the way how the quality of ADS-B data is assessed: while the hybrid surveillance uses active Mode S interrogations (with reduced frequency) and cross-check of obtained results, the extended hybrid surveillance relies on the quality parameters included in the ADS-B reports (only version 2 or higher of ADS-B Out capability is allowed for use of this technique) complemented by monitoring of the signal strength of the squitter messages. In both cases the TCAS switches to the active surveillance using only Mode S interrogations before the intruder could become a threat, i.e., before any alerting would be needed.

The hybrid surveillance was first standardized in 2009 in the US but the original definition was modified and extended hybrid surveillance was added in 2014 when the new Minimum Operational Performance Specifications (MOPS) were published. This report describes first worldwide validation of this capability with real industrial system in real environment including flight testing. The initial maturity level of this capability was V2, and by conducting this validation, V3 (and TRL6) were reached.

The main objectives of the performed validation are twofold:

- to validate the behaviour of the system implemented according the MOPS in real environment, provide feedback to standardization working groups on defined performance requirements and assumptions adopted during their development;
- and to evaluate the benefits achievable in European environment in terms of reduced 1090 MHz frequency load.

For these purposes three exercises were defined in the Validation Plan (D12):

- Within Exercise #820 the TCAS (developed by Honeywell) was integrated in Airbus lab with roof-top antenna installation in proximity of Toulouse airport and it tracked traffic in this area.
- Within Exercise #821 the TCAS was installed in Airbus experimental aircraft and used during a few flight tests during which the tracking of surrounding traffic was recorded.
- Within Exercise #822 the results obtained during Exercise #821 are extrapolated on the behaviour of aircraft in core European airspace and Eurocontrol simulation is used to evaluate the overall impact on RF load of 1090 MHz frequency in this area.

The main observation from the results obtained is that the system behaved according the expectations and fulfilled well the intended function. Only a few minor technical comments related to MOPS were communicated to the standardization working group. Although the TCAS implementation used during the validation deviated from MOPS in the way that legacy ADS-B reports (version 0 and 1) were allowed for use in extended hybrid surveillance – this change was necessary to achieve the validation objectives as there are very few aircraft equipped by ADS-B Out version 2 in Europe currently – the passive tracking worked according to expectations. Preliminary benefits evaluation delivered within 1st issue of validation report [8] showed reduction of Mode S interrogations by more than 70 %, which is a very promising result.

The main objective of 2nd issue of validation report was the evaluation of overall impact of TCAS II EXT on RF load of 1090 MHz in core European airspace. This exercise confirmed the expecting benefits of EXT capability, and showed that the reduction of DF 0 reply rate can be as high as 89% if TCAS II is replaced by TCAS II EXT for all TCAS II equipped aircraft, and all Mode S aircraft are emitting extended squitter (ADS-B level 2).

Additional flight test data collected in 2015 also confirmed the preliminary benefits and the refined analysis taking into account additional factors showed approximately 83% savings for 1090 MHz load.

In conclusion, extended hybrid surveillance implementation met the expectations and proved consistency with MOPS. Obtained results indicate that EXT is a very promising and important

tool for reduction of RF load, predestined to reduce pollution and prolong life of 1090 MHz. The implementation of extended hybrid surveillance capability is thus recommended to be taken into account by authorities when formulating the RF load reduction strategy.

1 Introduction

1.1 Purpose of the document

This document provides the Validation report for Extended Hybrid Surveillance capability. It describes the complete results of validation exercises defined in SESAR 9.470 D12 [7] and how they have been conducted. This validation report is an updated version SESAR 9.47 D13 [8].

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.

At the level of the federating projects and transversal areas, the following projects may have an interest in this document:

- P09.49 Global Interoperability – Airborne Architecture and Avionics Interoperability Roadmap
- P15.01.06 (Spectrum Management & Impact Assessment)
- P16.06.01 (Safety Support and Coordination Function)

Other stakeholders that should be interested in this document are to be found among:

- Airspace users;
- Standardization bodies including RTCA SC-147/ WG-75; and
- FAA and MIT/LL teams working on ACAS Xa in the US.

1.3 Structure of the document

The document is organized as follows:

- Section 2 presents overview of extended hybrid surveillance and validation exercises.
- Section 3 provides basic information on validation exercises conduct.
- Section 4 deals with validation exercises results and results analysis.
- Section 5 summarizes conclusions and recommendations.
- Section 6 provides detailed information on each of the validation exercises separately.
- Appendix A is reserved for KPA templates that were not applicable for this report.
- Appendix B provides an overview and results of additional flight tests that were performed since 1st issue of extended hybrid surveillance validation report [8].

1.4 Glossary of terms

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

Extended hybrid surveillance - a type of surveillance including passive tracking of target based on ADS-B and own position data when target's ADS-B data and own position data are of sufficient quality. This assessment is based on data quality indicators provided together with target's/own position information.

Hybrid surveillance – a type of surveillance including passive tracking of target based on ADS-B and own position data when the quality of tracking parameters is controlled through regular cross-check with data obtained via active surveillance method.

1.5 Acronyms and Terminology

Term	Definition
ACAS	Airborne Collision Avoidance System
ACT	Active surveillance (reference used in this document only)
ADD	Architecture Definition Document
ADS-B	Automatic Dependent Surveillance - Broadcast
AGL	Above Ground Level
ATM	Air Traffic Management
BIC	Best In Class
DOD	Detailed Operational Description
E-ATMS	European Air Traffic Management System
E-OCVM	European Operational Concept Validation Methodology
EU	European Union
EXT	Extended Hybrid Surveillance
HYB	Hybrid surveillance (reference used in this document only)
IRS	Interface Requirements Specification
INTEROP	Interoperability Requirements
MOPS	Minimum Operational Performance Standards
MTL	Minimum Trigger Level

Term	Definition
OFA	Operational Focus Areas
OSED	Operational Service and Environment Definition
PI	Performance Indicator
RA	Resolution Advisory
RF	Radio Frequency
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.
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
SUT	System Under Test
TA	Traffic Advisory
TAD	Technical Architecture Description
TCAS	Traffic alert and Collision Avoidance System
TMA	Terminal Manoeuvring Area
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 addresses the TCAS II system with hybrid surveillance capability implemented according the “Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II) Hybrid Surveillance” [9]. The scope of the validation is described in 09.47.D12 “Verification & Validation Plan for Improved Hybrid Surveillance” [7].

2.1 Concept Overview

The concept of extended hybrid surveillance is based on using one of three available surveillance methods: active surveillance (ACT), hybrid surveillance (HYB) and extended hybrid surveillance (EXT). Active surveillance consists in active interrogations of traffic, which enables the own ship to provide independent measurements of distance and bearing of the intruder. Only altitude is reported by the intruder (in its Mode S reply). Hybrid and extended hybrid surveillance relies on passive (ADS-B) position data when the intruder is not an imminent threat. The passive data are validated by interrogations on a regular basis and cross-check of obtained results (hybrid) or checking the data quality parameters included in the ADS-B reports (version 2 or higher) as well as signal strength of the intruder’s squitter messages (extended hybrid).

A track can be acquired actively or passively, and the surveillance methods can be changed during a life time of a track. There are conditions that govern the acquisition and surveillance methods and transition between them. These conditions include on-ground/airborne status of the own ship, availability of own data, EXT qualification criteria for own and intruder data, threat conditions, signal level and validation results and are discussed in detail in [10]. An overview of the acquisition and transition logic is given in Figure 1 or own ship taking-off or airborne and Figure 2 for own ship operating on ground.

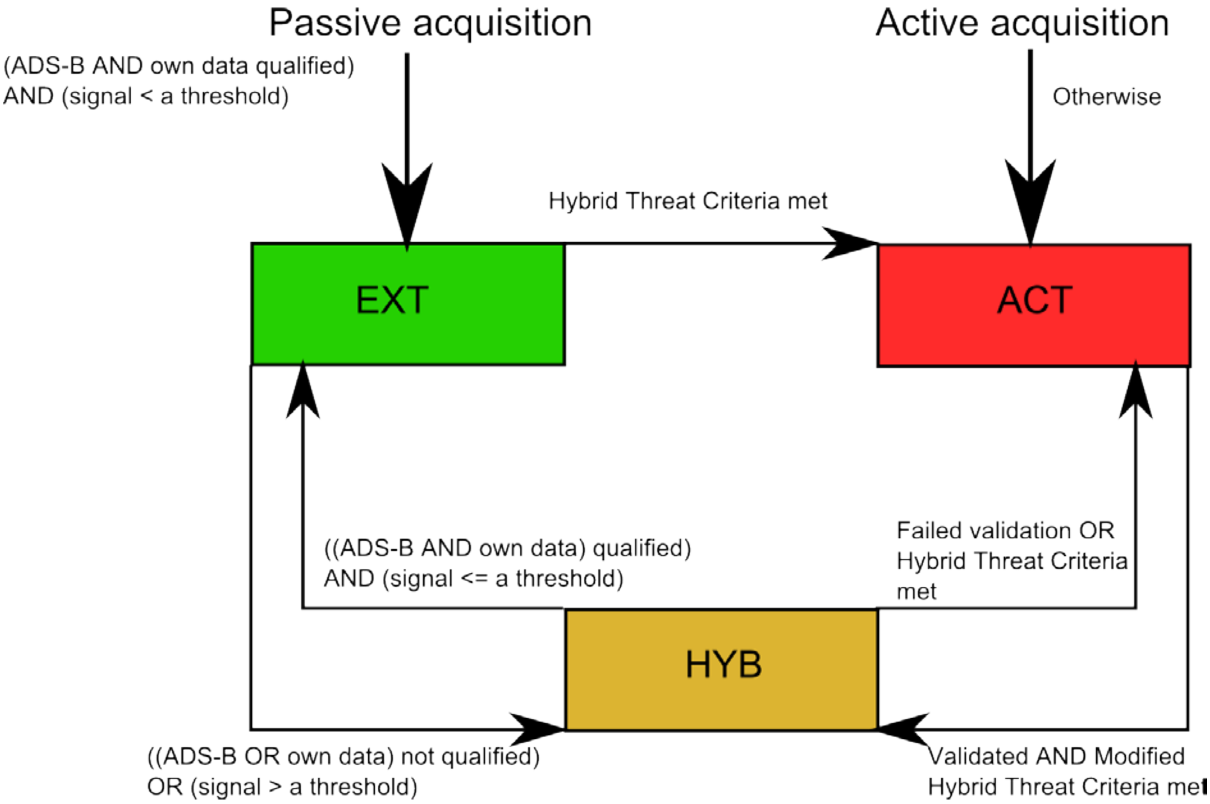

Figure 1: Transition diagram between surveillance modes when own is in the air or taking-off.

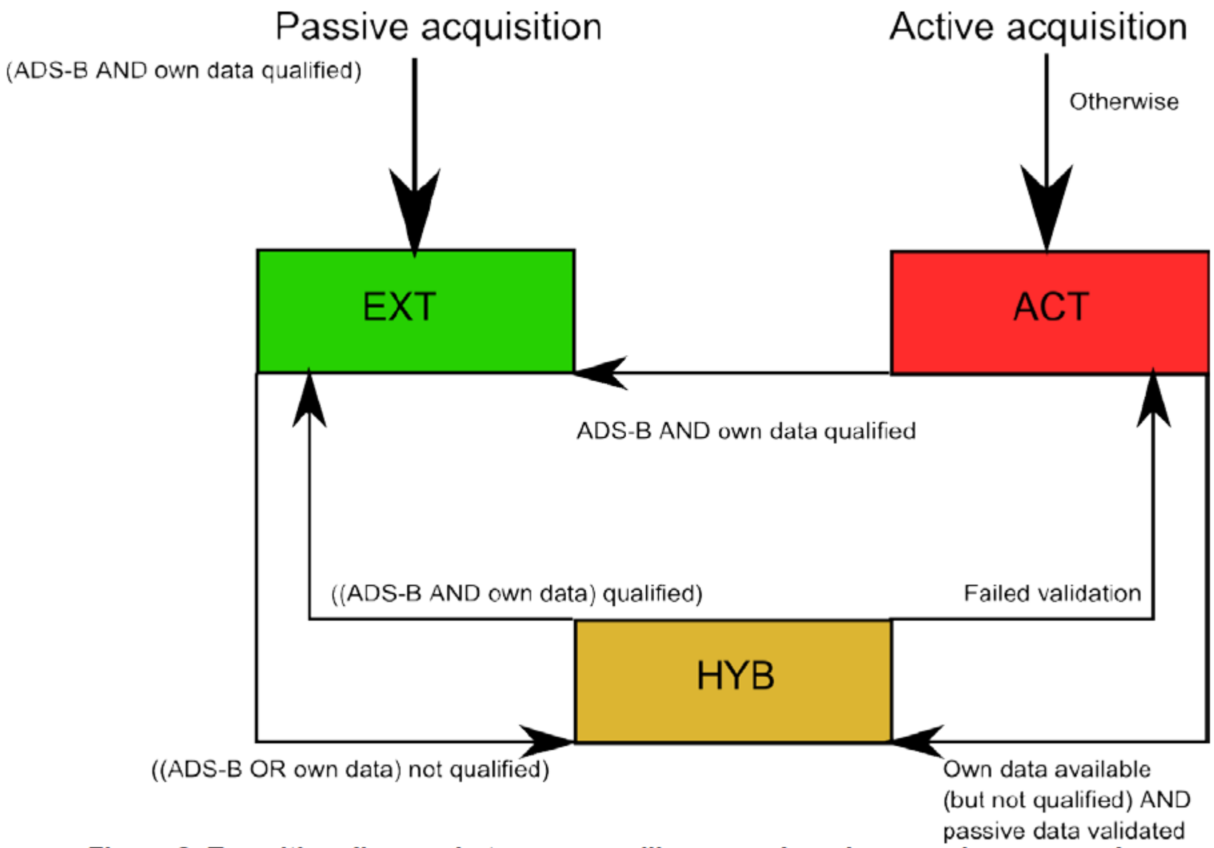

Figure 2: Transition diagram between surveillance modes when own is on ground.

The details of exercises required by the validation plan [7] are provided in Table 1, Table 2 and Table 3.

Validation Exercise ID and Title	EXE-09.47-VP-820
Leading organization	Honeywell / Airbus
Validation exercise objectives	Validate that the behaviour of the developed system in real environment is in accordance with assumptions adopted for the MOPS definition and system development.
Rationale	Feedback to the MOPS development team (SC147/WG75), system testing before the flight tests (EXE-09.47-VP-821)
Supporting DOD / Operational Scenario / Use Case	System behaviour in European airspace
OFA addressed	03.04.02: Enhanced ACAS Operations
OI steps addressed	CM-0808: Enhanced Airborne Collision Avoidance to Trajectory based operations
Enablers addressed	A/C-54a: Enhanced Collision Avoidance (ACAS)
Applicable Operational Context	Traffic in the proximity of Airbus roof top installation in Toulouse
Expected results per KPA	Increase in **Safety** – by reduced RF load and interference reduction

Validation Technique	Roof top test
Dependent Validation Exercises	EXE-09.47-VP-821

Table 1: EXE-09.47-VP-820 details

Validation Exercise ID and Title	**EXE-09.47-VP-821**
Leading organization	Honeywell / Airbus
Validation exercise objectives	Validate the behaviour of the system in real environment and evaluate the achieved benefits in terms of reduced number of interrogations needed to track surrounding traffic.
Rationale	Benefits assessment, feedback to the MOPS development team (SC147/WG75).
Supporting DOD / Operational Scenario / Use Case	System behaviour in European airspace
OFA addressed	03.04.02: Enhanced ACAS Operations
OI steps addressed	CM-0808: Enhanced Airborne Collision Avoidance to Trajectory based operations
Enablers addressed	A/C-54a: Enhanced Collision Avoidance (ACAS)
Applicable Operational Context	A typical flight through the core European airspace
Expected results per KPA	Increase in **Safety** – by reduced RF load and interference reduction
Validation Technique	Flight test
Dependent Validation Exercises	EXE-09.47-VP-822

Table 2: EXE-09.47-VP-821 details

Validation Exercise ID and Title	**EXE-09.47-VP-822**
Leading organization	EUROCONTROL
Validation exercise objectives	Quantification of the expected RF reduction for 1090MHz channel in European environment based on the results obtained in EXE-00.09.47-VALP.002
Rationale	Benefits assessment considering typical European traffic samples with different equipage levels.
Supporting DOD / Operational Scenario / Use Case	System behaviour in European airspace
OFA addressed	03.04.02: Enhanced ACAS Operations

OI steps addressed	CM-0808: Enhanced Airborne Collision Avoidance to Trajectory based operations
Enablers addressed	A/C-54a: Enhanced Collision Avoidance (ACAS)
Applicable Operational Context	A typical flight through the core European airspace
Expected results per KPA	Increase in **Safety** – by reduced RF load and interference reduction
Validation Technique	Simulations
Dependent Validation Exercises	N/A

Table 3: EXE-09.47-VP-822 details

The initial maturity level of this capability was V2, and by conducting this validation V3 maturity level (and TRL6) was reached.

2.2 Summary of Validation Exercises

2.2.1 Summary of Expected Exercises outcomes

The expected outcome of EXE-09.47-VP-820 is to validate that the behaviour of the developed system in real environment is in accordance with assumptions adopted for the MOPS definition [9] and system development.

The expected outcome of EXE-09.47-VP-821 is twofold: the first one is the same as of EXE-09.47-VP-820, but with higher representativeness due to the system use during the real flight. The second one is evaluation of the achievable benefits in terms of reduced number of interrogations needed to track surrounding traffic.

The expected outcome of EXE-09.47-VP-822 was to evaluate overall impact of TCAS II extended hybrid surveillance on RF load of 1090 MHz in core European airspace.

These outcomes should satisfy the following stakeholders' needs:

- To validate the new TCAS capability, as required by 9.47 air-framer and system integrator (Airbus);
- To assess the achievable benefits in EU environment;
- To provide feedback from the validation in real environment on the assumptions adopted in development of DO-300A/ED-221 and to support the performance and safety assessment, as required by SWG 147 /WG 75.

The initial maturity level of this capability was V2, and by conducting this validation V3 maturity level (and TRL6) was reached.

2.2.2 Benefit mechanisms investigated

TCAS with extended hybrid surveillance capability (RTCA DO-300A/EUROCAE ED-221) allows using of ADS-B position data for tracking a distant target (not representing a potential threat in terms of ACAS logic) provided that such passive tracking data are regularly validated against data obtained via active interrogation method or they meet a set of predefined performance criteria. Performed simulations (using the US data) suggest that the potential reduction of 1090 MHz usage with such approach can be up to 80% with respect to the 7.1 TCAS II system[1].

[1] FAA TCAS Surveillance update presentation to EUROCAE WG75 4/5 September 2012.

TCAS II with extended hybrid surveillance capability thus provides three different surveillance methods to track a target (contrary to the only one in a core TCAS II system), two of these methods allowing a considerable reduction of 1090 MHz load as shown in the table below.

	Tracking Mode	Interrogation Interval	Interrogation Use
Active Surveillance	Active	1 s or 5 s (reduced surveillance)	Tracking
Hybrid Surveillance	Passive	10 s – 60 s	ADS-B cross-check ((re)validation)
Extended Hybrid Surveillance	Passive	No interrogations	N/A

Table 4: Active interrogations across different surveillance methods

Substitution of active acquisition and surveillance by passive acquisition and surveillance in suitable situations is expected to bring considerable savings of interrogations (and, as a consequence, reduce the 1090 MHZ frequency burden) compared to the core TCAS II ver. 7.1 system.

2.2.3 Summary of Validation Objectives and success criteria

[OBJ]

Identifier	**OBJ-09.47-VALR-EHS1.0001**
Objective	Validate reduction of the own TCAS interrogation rate due to (extended) hybrid surveillance capability
Title	TCAS interrogation rate reduction
Status	<In Progress>

[OBJ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<V&V Objective>	OBJ-09.47-VALR-EHS1.0001	<Full>
<COVERS>	<ATMS Requirement>	Requirement Identifier(OSED, SPR)	N/A
<COVERS>	<V&V SUT Requirement>	V&V SUT Requirement Identifier	N/A
<COVERS>	<OI Step>	CM-0808	N/A
<ALLOCATED_TO>	<Operational Focus Area>	03.04.02	N/A
<ALLOCATED_TO>	<Project>	09.47	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change Reference	N/A

[OBJ Suc]

Identifier	Success Criterion
CRT-09.47-VALR-0001.0001	Interrogation rate of an aircraft with a DO-300A/ED-221 system is lower than with a core TCAS II ver. 7.1.

[OBJ]

Identifier	**OBJ-09.47-VALR-EHS1.0002**
Objective	Assessment of reduction of the 1090MHz RF load in European environment due to (extended) hybrid surveillance deployment.
Title	1090 MHz RF load reduction in European environment
Status	<In Progress>

[OBJ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<V&V Objective>	OBJ-09.47-VALR-EHS1.0002	<Full>
<COVERS>	<ATMS Requirement>	Requirement Identifier(OSED, SPR)	N/A
<COVERS>	<V&V SUT Requirement>	V&V SUT Requirement Identifier	N/A
<COVERS>	<OI Step>	CM-0808	N/A
<ALLOCATED_TO>	<Operational Focus Area>	03.04.02	N/A
<ALLOCATED_TO>	<Project>	09.47	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change Reference	N/A

[OBJ Suc]

Identifier	Success Criterion
CRT-09.47-VALR-0002.0001	Reduction of the 1090MHz RF load in European environment with respect to the current situation.

[OBJ]

Identifier	**OBJ-09.47-VALR-EHS1.0003**
Objective	Validate the MOPS assumptions concerning the expected system behaviour while airborne.
Title	System behaviour while airborne
Status	<In Progress>

[OBJ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<V&V Objective>	OBJ-09.47-VALR-EHS1.0003	<Full>
<COVERS>	<ATMS Requirement>	Requirement Identifier(OSED, SPR)	N/A
<COVERS>	<V&V SUT Requirement>	V&V SUT Requirement Identifier	N/A
<COVERS>	<OI Step>	CM-0808	N/A
<ALLOCATED_TO>	<Operational Focus Area>	03.04.02	N/A
<ALLOCATED TO>	<Project>	09.47	N/A
<CHANGED BECAUSE OF>	<Change Order>	Change Reference	N/A

[OBJ Suc]

Identifier	Success Criterions
CRT-09.47-VALR-0003.0001	Three surveillance methods are used effectively and without unnecessary interrogations of the targets.
CRT-09.47-VALR-0003.0002	There are not unnecessary transitions (e.g., oscillations) between surveillance methods.
CRT-09.47-VALR-0003.0003	The transition to active surveillance is performed sufficiently in advance before any potential TA/RA for the target.
CRT-09.47-VALR-0003.0004	Passive acquisition is used (and successful) in intended situations.
CRT-09.47-VALR-0003.0005	Value of the signal power threshold ensures a timely transition to the active surveillance.

[OBJ]

Identifier	**OBJ-09.47-VALR-EHS1.0004**
Objective	Validate the MOPS assumptions concerning surface/take off phase of flight.
Title	System behaviour in airport environment
Status	<In Progress>

[OBJ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<V&V Objective>	OBJ-09.47-VALR-EHS1.0004	<Full>
<COVERS>	<ATMS Requirement>	Requirement Identifier(OSED, SPR)	N/A
<COVERS>	<V&V SUT Requirement>	V&V SUT Requirement Identifier	N/A
<COVERS>	<OI Step>	CM-0808	N/A
<ALLOCATED TO>	<Operational Focus Area>	03.04.02	N/A
<ALLOCATED TO>	<Project>	09.47	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change Reference	N/A

[OBJ Suc]

Identifier	Success Criterion
CRT-09.47-VALR-0004.0001	Passive surveillance used correctly during ownship surface operations
CRT-09.47-VALR-0004.0002	Timely and correct transitions of surveillance methods during take-off/landing.

2.2.3.1 Choice of metrics and indicators

The main expected benefit of EXT is reduction of the 1090 MHz RF load with respect to the current situation. The new technology itself does not lead to improvement of KPI (as defined in SESAR Performance Framework) on its own, but is one of key contributors to increased KPA - Safety due to interference reduction and RF load reduction.

The metric used for evaluating the reduction of 1090 MHz RF load was the **number of active interrogations to intruders**, directly recorded during the experiments using TCAS with EXT, compared to the number of interrogations that would have been needed if a core TCAS II ver. 7.1 had been used.

Other indicators include internal **TCAS variables** (such as surveillance methods information, traffic and own ship data etc.)

2.2.4 Summary of Validation Scenarios

There were three validation scenarios, namely:

[SCN]

Identifier	**SCN-09.47-VALR-EHS1.0001**
Scenario	Real traffic in the proximity of roof top antenna installation
Status	<In Progress>

In this scenario, TCAS II unit with improved hybrid surveillance capability was exposure on CNS bench with real top antenna located at the roof of Airbus Lab building in Toulouse.

[SCN]

Identifier	**SCN-09.47-VALR-EHS1.0002**
Scenario	Real traffic in the core European airspace (within surveillance range from the used Airbus ferry or test aircraft non-specific flight(s)).
Status	<In Progress>

In this scenario, the system was used on board of Airbus test aircraft and several flights, including take-offs, landings and surface movements were conducted. The departure and destination was Toulouse airport.

[SCN]

Identifier	**SCN-09.47-VALR-EHS1.0003**
Scenario	Sample(s) of a typical traffic in the core European airspace based on real SSR data recordings (recorded outside of SESAR 9.47).
Status	<In Progress>

In this scenario, the simulations have been performed using EUROCONTROL RF Model.

2.2.5 Summary of Assumptions

The validation assumptions are listed in the Table 5. For EXE-09.47-VP-820, only assumption ASM-00.09.47-VALP-0001 is relevant. For EXE-09.47-VP-821 and EXE-09.47-VP-822 both assumptions are applicable.

Identifier	Title	Type of Assumption	Description	Justification	Flight Phase	KPA Impacted	Source	Value(s)	Owner	Impact on Assessment
ASM-00.09.47-VALP-0001	ADS-B legacy versions	Traffic Characteristics / Environment Constraints	The performance results obtained using ADS-B version 0 and 1 will not strongly deviate from results obtainable with version 2.	Only few a/c are currently equipped with ADS-B version 2 (covered by IR 1207/2011).	Any	Efficiency	Expert opinion	N/A	9.47	Medium
ASM-00.09.47-VALP-0002	Benefits generalization	Environment Constraints	The TCAS behaviour observed during the flight tests will be sufficiently representative of a typical behaviour of the TCAS with extended hybrid surveillance within future European airspace.	The flight will be performed through core European airspace during conventional operation.	Any	Efficiency	Expert opinion	N/A	9.47	Low

Table 5: Validation Assumptions

2.2.6 Choice of methods and techniques

The main indicators – number of active interrogations and internal state variables of the TCAS unit – are recorded during experiments and subsequently analysed offline (post-processing). The analysis methods are objective-specific and are described in detail in later Section 6.

Supported Metric / Indicator	Platform / Tool	Method or Technique
Active interrogations	TCAS unit with EXT capability, Honeywell recording tool	Roof-top test and flight test recording and analysis
Internal TCAS variables	TCAS unit with EXT capability, Honeywell recording tool	Roof-top test and flight test recording and analysis

Table 6: Methods and Techniques

2.2.7 Validation Exercises List and dependencies

Improved hybrid surveillance validation is defined by three exercises in total:

Exercise #820 is a prerequisite for Exercise #821. The aim is to detect and correct as many potential system behaviour deviations during roof-top testing as possible (before flight testing).

Exercise #821 is a prerequisite for Exercise #822. The RF model used in Exercise #822 was calibrated by parameters estimated based on Exercise #821 measurements of real communication.

3 Conduct of Validation Exercises

3.1 Exercises Preparation

A standard Honeywell TCAS unit was modified according to the MOPS [9]. A deviation from the standard was made according to requirement REQ-00.09.47-VALP-0001 to accept also ADS-B ver. 0 and 1 data. Requirements REQ-00.09.47-VALP-0002 and REQ-00.09.47-VALP-0003 specify changes of system requirements that are necessary to process legacy versions of ADS-B.

Moreover, Honeywell recording tool was adapted to satisfy requirement REQ-00.09.47-VALP-0004 on logging important parameters.

Subsequent preparation steps are exercise-specific and are listed in Sections 6.1.2.1 and 6.2.2.1.

3.2 Exercises Execution

Exercise ID	Exercise Title	Actual Exercise execution start date	Actual Exercise execution end date	Actual Exercise start analysis date	Actual Exercise end date
EXE-09.47-VP-820	Roof-top Testing	20/02/2014	10/04/2014	20/02/2014	25/04/2014
EXE-09.47-VP-821	Flight Tests	26/08/2014	03/10/2014	24/08/2014	14/10/2014
EXE-09.47-VP-822	RF Load Simulations	07/07/2015	17/09/2015	07/07/2015	14/10/2015

Table 7: Exercises execution/analysis dates

Details on individual flight test dates in EXE-09.47-VP-821 are listed in Section 6.2 and Appendix B.

3.3 Deviations from the planned activities

3.3.1 Deviations with respect to the Validation Strategy

N/A (No Validation Strategy available).

3.3.2 Deviations with respect to the Validation Plan

There were following deviations with respect to the Validation Plan [7]:

- Validation scenario SCN.00.09.47.VALP.0002: The aim was to fly through core European airspace. However, due to lack of opportunities for such a flight, a set of shorter flights in the vicinity of Toulouse airport was used instead. A longer flight through more congested areas provided more representative data in October 2015, at the time when this report was under finalization. Collected data were evaluated, and their analysis is available in Appendix B.

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-820	OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	CRT-09.47-VALR-0003.0001	Three surveillance methods are used effectively and without unnecessary interrogations of the targets.	Confirmed	OK
EXE-09.47-VP-820	OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	CRT-09.47-VALR-0003.0002	There are not unnecessary transitions (e.g., oscillations) between surveillance methods.	There are some transitions between methods, but there is no impact on efficiency and observable behaviour.	OK
EXE-09.47-VP-820	OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	CRT-09.47-VALR-0003.0003	The transition to active surveillance is performed sufficiently in advance before any potential TA/RA for the target.	Confirmed	OK
EXE-09.47-VP-820	OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	CRT-09.47-VALR-0003.0004	Passive acquisition is used (and successful) in intended situations.	Validated	OK
EXE-09.47-VP-820	OBJ-09.47-VALR-EHS1.0003	System behaviour while	CRT-09.47-VALR-	Value of the signal power	Confirmed	OK

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
		airborne	0003.0005	threshold ensures a timely transition to the active surveillance.		
EXE-09.47-VP-821	OBJ-09.47-VALR-EHS1.0001	TCAS interrogation rate reduction	CRT-09.47-VALR-0001.0001	Interrogation rate of an aircraft with a DO-300A/ED-221 system is lower than with a core TCAS II ver. 7.1.	Validated (savings of approx. 71 %)	OK
EXE-09.47-VP-821	OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	CRT-09.47-VALR-0003.0001	Three surveillance methods are used effectively and without unnecessary interrogations of the targets.	Confirmed	OK
EXE-09.47-VP-821	OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	CRT-09.47-VALR-0003.0002	There are not unnecessary transitions (e.g., oscillations) between surveillance methods.	There are some transitions between methods, but there is no impact on efficiency and observable behaviour.	OK
EXE-09.47-VP-821	OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	CRT-09.47-VALR-0003.0003	The transition to active surveillance is performed sufficiently in advance before any potential TA/RA for	Confirmed	OK

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
				the target.		
EXE-09.47-VP-821	OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	CRT-09.47-VALR-0003.0004	Passive acquisition is used (and successful) in intended situations.	Validated for 90 % of the cases. The remaining 10 % understood and considered as a potential room for improvement, however the achievable benefits increase is very small.	OK
EXE-09.47-VP-821	OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	CRT-09.47-VALR-0003.0005	Value of the signal power threshold ensures a timely transition to the active surveillance.	Confirmed	OK
EXE-09.47-VP-822	OBJ-09.47-VALR-EHS1.0002	1090 MHz RF load reduction in European environment	CRT-09.47-VALR-0002.0001	Reduction of the 1090MHz RF load in European environment with respect to the current situation.	Confirmed	OK

Table 8: Summary of Validation Exercises Results

4.1.1 Results on concept clarification

N/A[2]

[2] The reason why feedback to the concept is "N/A" is due to fact that this validation was a technical validation rather than operational validation.

4.1.2 Results per KPA

Results of this validation indirectly support the **Safety KPA**[3].

The main results already presented in 1st issue of validation report [8] were twofold:

1. Preliminary quantitative analysis of benefits in terms of saved interrogations. This analysis was performed in Exercise #821 on data recorded in vicinity of Toulouse airport. The measured interrogations were compared with assumed interrogations that would be necessary using a core TCAS II ver. 7.1 in the same situation. The estimated savings are 71 %, however these results were refined in this issue of validation report, based on Exercise #822 and additional flight test data.
2. Validation of requirements/assumptions from MOPS [10]. The aim of the validation was to focus on system behaviour while airborne, while on ground and during landing and take-off. The transitions of the surveillance modes both on ground and in the air were according to the expectations and without any unwanted observable oscillations. Performance during acquisition is also acceptable, although it can be even improved (approximately 10 % of track acquisitions that could be performed passively are performed actively however the impact on interrogation rate is very small). The EXT MTL of -68 dBM was tested on a large sample (more than 100 000 data points) and it can be concluded that this value seems to be a good balance between safety and efficiency: there is enough time to switch from passive to active tracking before an intruder can become a threat. Moreover, landing and take-off of the own ship is also handled timely and correctly.

Exercise #822 confirmed the expecting benefits of EXT capability, and showed that the reduction of DF 0 reply rate can be as high as 89% if TCAS II is replaced by TCAS II EXT for all TCAS II equipped aircraft, and all Mode S aircraft are emitting extended squitter (ADS-B level 2).

Additional flight test data collected in 2015 also confirmed the preliminary benefits and the refined analysis taking into account additional factors showed approximately 83% savings for 1090 MHz load.

4.1.3 Results impacting regulation and standardisation initiatives

Validation results performed in Exercise #821 confirmed that implementation of DO-300A/ED-221 leads to expected behaviour of the system. The suggested value of EXT MTL of -68 dBm seems to be both safe and efficient. Some minor errors in the MOPS tests were identified and reported to standardization working group.

4.2 Analysis of Exercises Results

4.2.1 Unexpected Behaviours/Results

N/A

4.3 Confidence in Results of Validation Exercises

4.3.1 Quality of Validation Exercises Results

The experiments were conducted in real environment and using real systems so the results are accurate from this point of view.

[3] As this validation was a technical one rather than operational; the readers should not expect a typical results per KPA.

4.3.2 Significance of Validation Exercises Results

All the flights in Exercise #821 were conducted in vicinity of Toulouse airport while more congested area and flights in higher altitude are evaluated in Appendix B.

On the other hand, the results of Exercise #820 and #821 are based on large data set (more than 16 hours of operation) so the results are considered reliable.

5 Conclusions and recommendations

5.1 Conclusions

The aim of Exercise #820 was to perform first verification and validation of the system using real traffic inputs. Although the antenna was mounted on a roof of the building in the proximity of the airport, the communication with surrounding traffic was real and thus the system's behaviour in response to received ADS-B messages and Mode S interrogations provided realistic results. The conclusion from this exercise was that the system is functional, meets the requirements and could be used for Exercise #821 (flight testing).

Conclusions from the Exercise #821 are multifold and can be summarized as follows:

- Preliminary benefits constitute approximately 70 % of saved interrogations. Although the result is sensitive to environment related factors (such as type and density of surrounding traffic, characteristics of own flight, time spent on ground and in the air etc.), it can be concluded that the results are very promising and that the new technology provides important benefits for the spectrum usage.
- The usage of the three surveillance methods (ACT, HYB and EXT) is according to expectations including safety and efficiency demands. The system correctly uses active interrogation whenever situation and requirements requires so.
- Acquisition methods are applied according to the standard in 90 % of the cases in the current implementation and the impact of the remaining cases (the behaviour is well understood) to the benefits is very limited.
- The value of the signal strength threshold designed as an additional safety barrier for timely switching between EXT and HYB or ACT seems to be a reasonable balance between safety and efficiency.
- Landing and taking-off operations of the own ship are handled correctly in terms of surveillance methods transition logic.

The main objective of 2nd issue of validation report was the evaluation of overall impact of TCAS II EXT on RF load of 1090 MHz in core European airspace. This exercise confirmed the expecting benefits of EXT capability, and showed that the reduction of DF 0 reply rate can be as high as 89% if TCAS II is replaced by TCAS II EXT for all TCAS II equipped aircraft, and all Mode S aircraft are emitting extended squitter (ADS-B level 2).

Additional flight test data collected in 2015 also confirmed the preliminary benefits and the refined analysis taking into account additional factors showed approximately 83% savings for 1090 MHz load.

In conclusion, extended hybrid surveillance implementation met the expectations and proved consistency with MOPS. During this validation, extended hybrid surveillance capability reached V3 maturity level (and TRL6). Obtained results indicate that EXT is a very promising and important tool for reduction of RF load, predestined to reduce pollution and prolong life of 1090 MHz. The implementation of extended hybrid surveillance capability is thus recommended to be taken into account by authorities when formulating the RF load reduction strategy.

5.2 Recommendations

The recommendations adopted from Exercise #820 and the work performed so far within Exercise #821 (within 1st issue of VALR [8]) for MOPS are as follows:

- EHS MTL value of -68 dBm seems to be adequate;
- There are not any major comments to the MOPS based on the obtained results

The recommendations after completed Exercise #822 regarding future work are to

- Perform more flight test(s) through a core European airspace;
- Perform more testing session on the surface of a busy airport
- The implementation of extended hybrid surveillance capability is recommended to be taken into account by authorities when formulating the RF load reduction strategy.

6 Validation Exercises reports

6.1 Validation Exercise #820 Report

This section remains unchanged with regard to 1st issue of validation report [8].

6.1.1 Exercise Scope

The objective of the exercise is to validate the capability of extended hybrid surveillance in real environment using a roof-top antenna installation.

In addition to objective OBJ-00.09.47-VALP-0003, titled "System behaviour while airborne", the aim is also to validate assumption ASM-00.09.47-VALP-0001 related to the use of legacy ADS-B Out reports.

6.1.2 Conduct of Validation Exercise

6.1.2.1 Exercise Preparation

An antenna connected to experimental TCAS unit with EXT (developed by Honeywell) was mounted on top of Airbus facility close to Toulouse airport in France.

Modification of TCAS software was required for this exercise due to the fact that only one antenna was used in this experiment while normally two antennas are used, one on top and one on the bottom of the aircraft.

Three testing sessions for software verification were performed in February and March, 2014, each of approximately 2 hours of recording.

6.1.2.2 Exercise execution

There were multiple preparatory sessions in order to verify the system installation and basic behaviour. The roof-top testing for validation purposes was performed on the 10th April, 2014, in total duration of approx. 2 hours and 40 minutes. The total recording time was split between the "in the air" conditions (1 hour and 19 minutes) and "on ground" conditions (1 hour and 23 minutes). The on-ground status switch was performed manually, resulting in unavoidable interruptions of the recording. The recording overview is depicted in Figure 3.

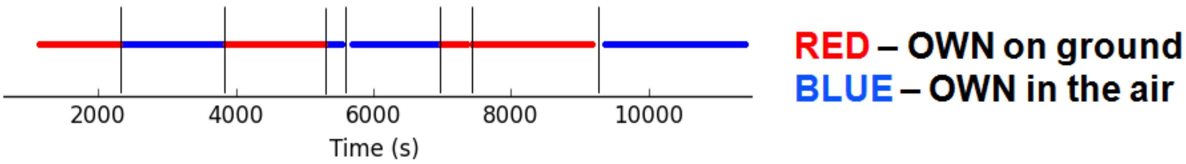

Figure 3: Roof-top recording overview

6.1.2.3 Deviation from the planned activities

Although Exercise #820 requires only validation of the system behaviour for the "in the air" status of the own ship, it was decided to take the opportunity to verify also behaviour during the "on ground" status and on-ground status change.

6.1.3 Exercise Results

Exercise ID	Objective ID	Scenario ID	Scenario Title	PI ID	Measure Value
EXE-09.47-VP-820	OBJ-09.47-VALR-EHS1.0003	SCN-09.47-VALR-EHS1.0001	System behaviour while airborne	N/A	According to standard

Table 9: Exercise #820 results table

6.1.3.1 Summary of Exercise Results

6.1.3.1.1 Results on concept clarification

N/A. Refer to section 4.1.1.

6.1.3.1.2 Results per KPA

Refer to section 4.1.2 for results per KPA.

6.1.3.1.3 Results impacting regulation and standardisation initiatives

N/A for this exercise.

6.1.3.2 Analysis of Exercise Results

6.1.3.2.1 System Behaviour While Airborne

This exercise has only one validation objective, OBJ-00.09.47-VALP-0003, titled “System behaviour while airborne”. The objective consists of five success criteria. The results are provided with respect to each of them below:

1. **Criterion: Three surveillance methods are used effectively and without unnecessary interrogations of the targets.**

   In this paragraph we focus on a few items that are tightly related to effectiveness of the usage of surveillance methods. Since the discussions of other criteria for this objective (such as absence of oscillations between surveillance methods, correct acquisitions etc.) partially address also this topic, here we discuss only the aspects that are not covered elsewhere.

   First, we investigate usage of surveillance method in order to see how much time (for all suitable targets, i.e. those that were ADS-B equipped and tracked) was spent with each of the surveillance method. In Figure 4 we see that all the three methods were used in a substantial part of the overall time (for all aircraft). Almost half of the time was spent in HYB. This is due to the fact that there were many landing and taking-off intruders the signal level of which was over the EXT MTL. Taking-off intruders were usually leaving the surveillance volume by passing through the altitude boundary (which is 10 000 ft above the roof-top based antenna) while they were still in HYB. This also corresponds to the relatively high portion of active surveillance, which was not only due to unqualified intruders, but mainly due to Hybrid Threat Criteria of the near traffic.

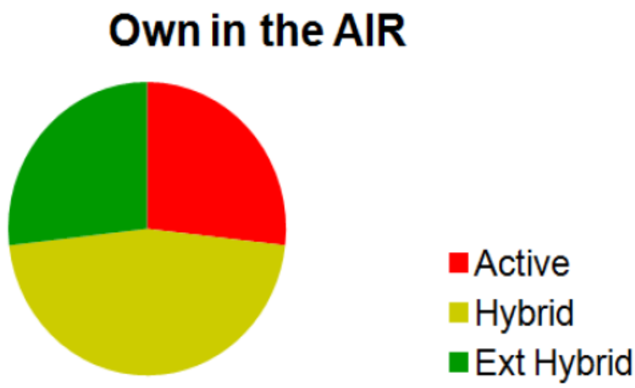

Figure 4: Use of surveillance methods during roof-top testing (own ship set "in air")

Different insight into efficiency of surveillance mode usage can be obtained by delimiting spatial areas according to applied surveillance methods (see *Figure 5*). Although transitions ACT/HYB and HYB/EXT depend on multiple factors, a rough estimation of ranges at which these transitions occur in nominal cases (i.e. signal power level and Hybrid Threat criteria) can be made. It should be emphasized that the results are also influenced by the environment (i.e. type of sector and traffic).

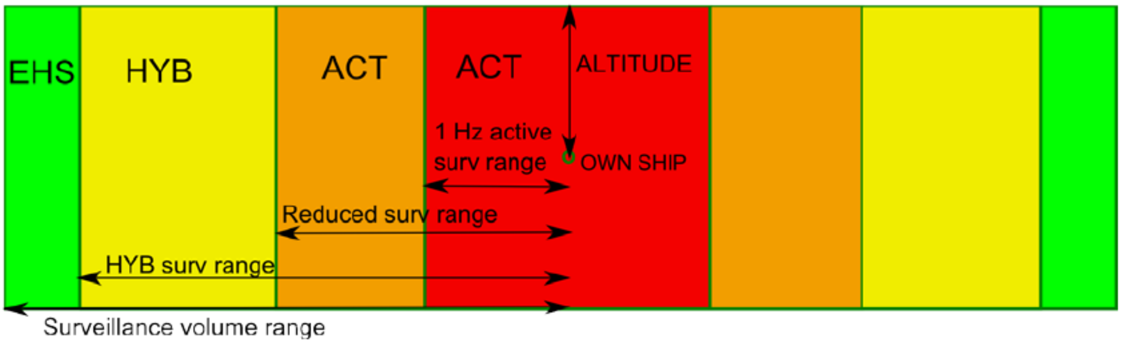

Figure 5: Surveillance zones overview (not in scale)

Transition	Sample size	Mean (NM)	Max (NM)	Min (NM)
ACT to HYB	12	3.54	3.63	3.36
HYB to ACT	9	5.38	5.77	4.15
HYB to EXT	7	15.23	31.98	10.23
EXT to HYB	6	17.79	23.49	14.13

Table 10: Estimation of ranges of surveillance mode transitions (roof-top testing)

The success of revalidations under HYB is also a crucial sign of validity of assumptions used within the definition of the new concept. If the failures were often, it would be a sign of unreliability of the passive data. However, the first results (see *Table 10*) suggest that validation failures are quite exceptional. There is only one altitude error higher than the predefined threshold of 100 ft and only one bearing error higher than the predefined threshold of 45 degrees. Both are triggered by different aircraft. The slant range threshold of 290 m was not reached.

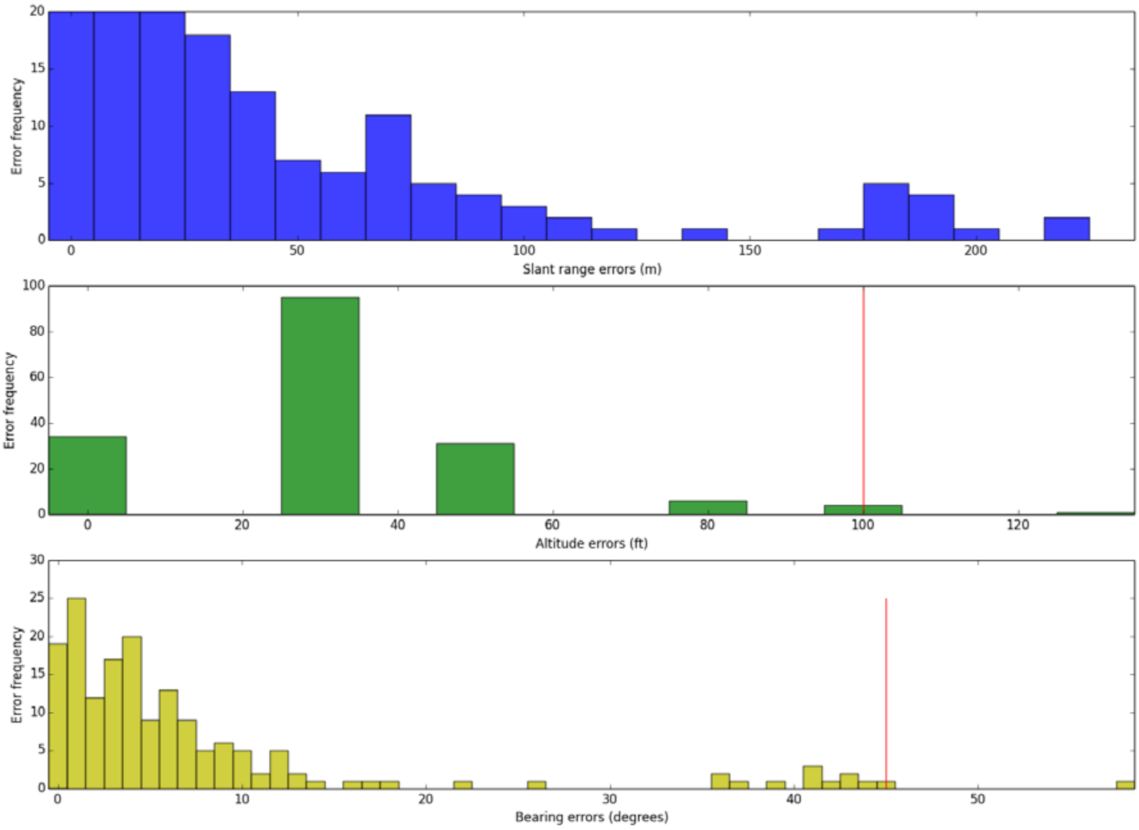

Figure 6: (Re) validation results of HYB of the roof top testing

A look at a histogram of revalidation intervals (Figure 7) and a histogram of revalidation ranges Figure 8) provides more details on the usage of active interrogations during HYB. It follows that the whole range of revalidation intervals, i.e. from 10 to 60 seconds, has its use. Most often cases, however, are 60 s intervals. This is very positive finding from the effectiveness point of view since in these situations interrogations are sparse under HYB. The histogram of ranges (in NM), at which revalidations are performed, roughly shows the distribution of ranges at which HYB is used. It follows that most of the revalidations are performed at around 5 NM. The decreasing amount of interrogations with the increasing range is not surprising – it is expected that the closer the intruder, the shorter the validation interval and the higher the interrogation rate.

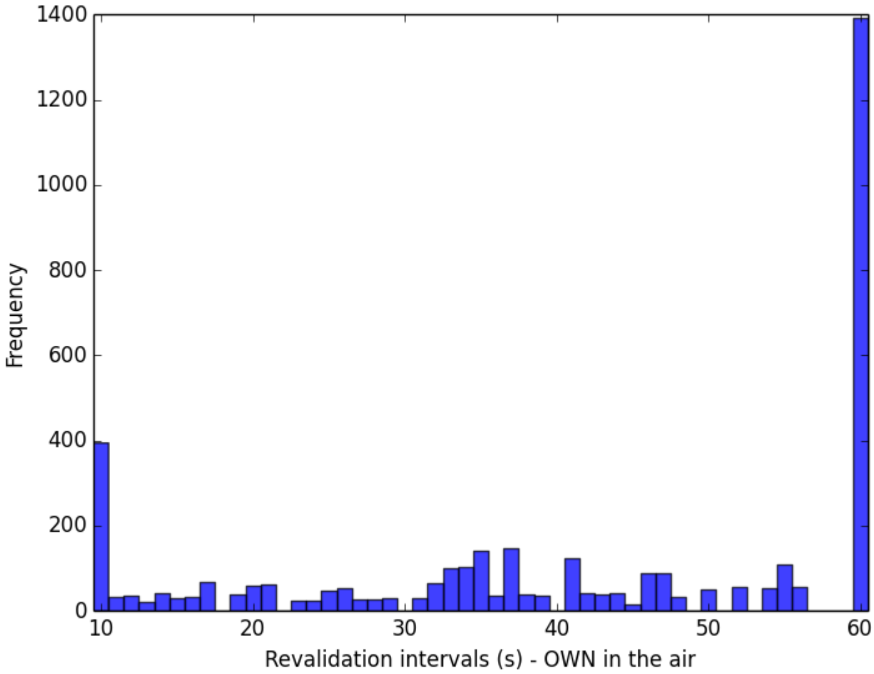

Figure 7: Roof-top testing: a histogram of (re)validation intervals

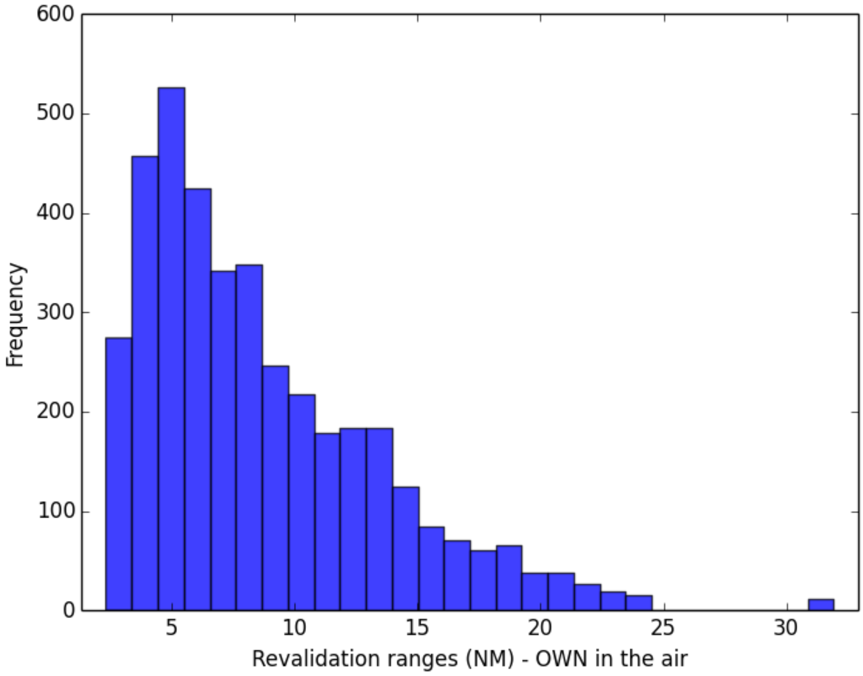

Figure 8: Roof top testing: A histogram of (re)validation ranges

The relation between revalidation ranges and revalidation intervals is also shown in *Figure 9*. A few interesting facts can be discovered: first, revalidation intervals of 60 s are used for the whole set of applicable ranges (data points labelled by A). Second, there is a positive correlation between range and interval length (data points labelled by B), which is an expected result. However, we also see that for certain short ranges (around 5 NM) there is another cluster of data points (labelled by C). These significant sets of data points correspond to different set of trajectories: data points A correspond to intruders, which are at various ranges, but do not pose a potential threat, i.e. those flying in high altitudes. B and C correspond to landing and taking-off aircraft. Trajectories of taking-off aircraft are steep, they get to higher altitudes while still staying ad a close range. Trajectories of landing aircraft are not that steep, of course.

To conclude, the behaviour of the system when own ship was set “in the air” is according to expectations from the conceptual point of view. This conclusion, however, needs to be complemented by other success criteria, which are listed below.

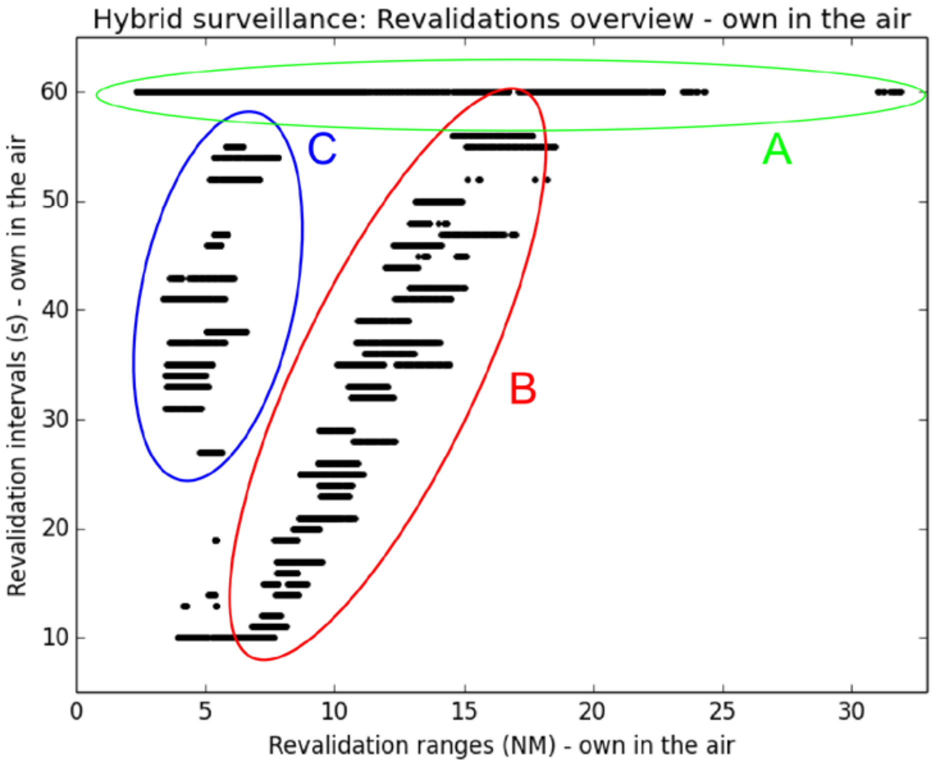

Figure 9: Relation between revalidation intervals and ranges (roof top testing, own in the air).

2. **Criterion: There are not unnecessary transitions (e.g., oscillations) between surveillance methods.**

   A few cases of oscillations were detected when transitioning between HYB and EXT[4]. However, this situation is well addressed in the MOPS and therefore revalidation interval countdown is not affected by these oscillations. Thus the number of interrogations is not increased by the oscillations.

   An illustrative example of such oscillations due to signal strength is provided in *Figure 10*.

[4] In the experiment there were in total 136 surveillance methods transitions. Out of these, 102 transitions were due to signal level, either from HYB to EXT (48 transitions) or from EXT to HYB (54 transitions). 98 of them appear in 7 tracks only. The longest oscillation string detected contains 43 consecutive transitions.

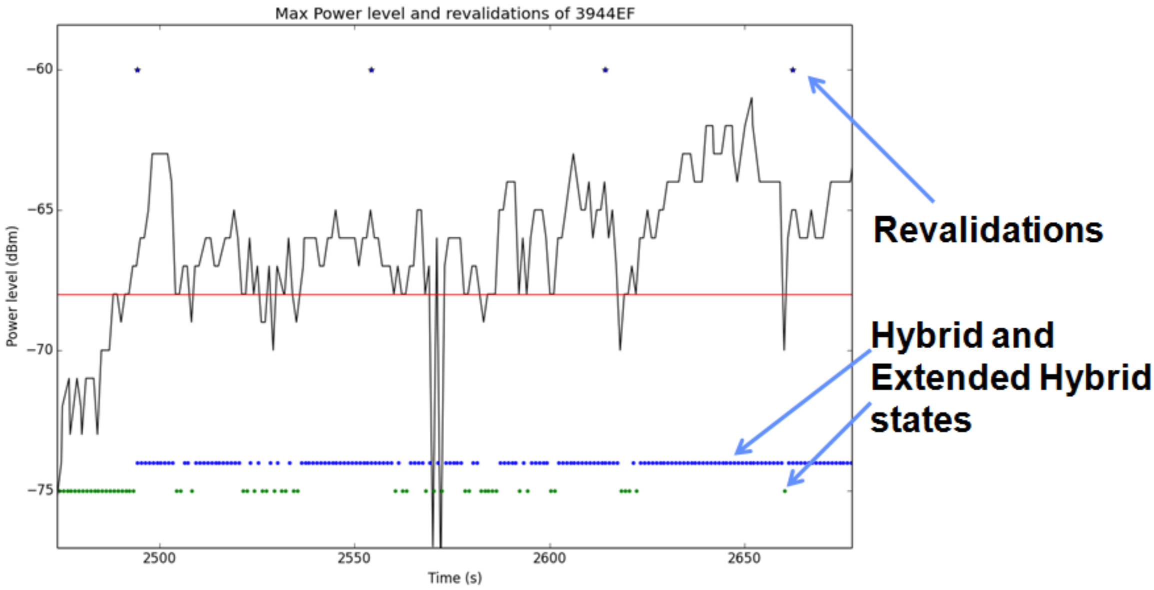

Figure 10: Oscillations between EXT and HYB surveillance as a result of signal level variation do not lead to excessive interrogations (an illustrative example).

The blue and green intervals depict times in which HYB or EXT is applied. Revalidations over time are depicted by dots. The red line shows the EXT MTL.

3. **Criterion: The transition to active surveillance is performed sufficiently in advance before any potential TA/RA for the target.**

   Approach Taken: TCAS issues TA no later than 20 to 48 seconds before closest point of approach (depending on the selected sensitivity level). Hybrid surveillance definition aims to ensure that the transition to active surveillance (through hybrid threat criteria) happens at similar conditions as the transition from reduced to normal active surveillance. Transition to 1 Hz surveillance rate is performed 60 seconds before closest point of approach. It is thus sufficient to verify if transition to ACT takes place earlier than transition to 1 Hz surveillance (see *Figure 11*).

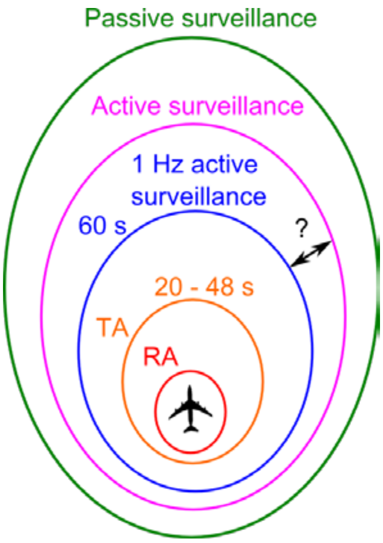

Figure 11: Alert and surveillance zones around the own ship.

Data used:

There are several natural requirements to the data samples used for this criterion:

- The track contains transition to active surveillance as a result of Hybrid Threat Criteria (other trigger conditions for active surveillance, such as validation failure, data quality deterioration or change of own ship ground status from “on ground” to “in the air”, etc. can occur any time and are thus unrelated to the suitability of Hybrid Threat Criteria, which are the subject of analysis in this experiment).
- The same track consequently transitions to 1 Hz active surveillance, so that the time difference between the two transitions can be obtained.

Out of 9 transitions from Hybrid surveillance to Active surveillance with own ship in the air, 8 cases fulfil both the abovementioned requirements (in one case the transition to 1 Hz active surveillance was missing due to change of the own ship ground status and the target transitioned to Extended Hybrid surveillance instead).

Results:

The time and range differences between the two transitions for the 8 cases were as follows:

Value	Time difference (s)	Range difference (NM)
Minimum	1.99	0.14
Median	31.00	1.20

Table 11: Exercise #821 - time and range differences between the two transitions

It can be seen that in all cases including the most extreme ones[5] there was a positive time margin between switching to active surveillance and increasing the interrogation frequency to 1 Hz. Moreover, for the case of roof top test and the airport environment, sensitivity level 2 is applied. This brings additional 40 seconds before traffic advisory is issued.

4. **Criterion: Passive acquisition is used (and successful) in intended situations.**

   Results: All acquisitions made when the own ship was set “in the air” were analysed. Out of 23 acquisitions, 13 were acquired passively and 13 actively. The reasons for active acquisitions were as follows: in 11 cases the aircraft was not qualified for passive acquisition. One case was active due to high signal power level, and in the last case active acquisition happened since a DF11 message was also available at the time when the target first entered the surveillance volume by passing the altitude boundary. The DF11 message was processed before processing the DF17 message, which led to active acquisition. However, after three seconds, the track transitioned under EXT.

   To sum up, all the cases were acquired according to the requirements. It seems that there is still some potential room for additional interrogations saving, however the associated benefit is already small.

5. **Value of the signal power threshold ensures a timely transition to the active surveillance.**

[5] In these cases the predicted time to closest point of approach temporarily dropped below 60 s soon after transition to ACT for a few seconds, but then reduced surveillance range was applied again for some time.

The purpose of EXT MTL is to provide a safety barrier for potential cases when the position reported by an intruder in its ADS-B reports is not correct. There was not any single case of such situation during the validation so the following description is provided only for theoretical context of the following discussion.

The passive track can be wrong in generally two ways:

a. Intruder is not a threat but the passive data indicate that it is.

This is a potential false alert situation. However, in this case the system switches to the active surveillance well before the intruder becomes a threat, active surveillance will provide the correct information and alert will not be issued.

b. Intruder is becoming a threat but the passive data indicate that it is not.

The signal strength check is specifically designed to address this situation and it is thus necessary to make sure that the threshold is low enough to enable validation of the passive track well before the intruder becomes a threat. On the other hand, the threshold should not be too low due to efficiency reasons.

A comparison of Hybrid Threat Criteria parameters (namely, Altitude Tau and Range Tau) to the corresponding estimated signal strength[6] (2.2.5.2.4 of RTCA-DO300-A) was performed for a sample containing 7 691 values of 19 tracked aircraft. It was observed that all the cases that fulfil Hybrid threat criteria have estimated signal strength above EXT MTL (depicted as red crosses in *Figure 12*). That means that for all cases, the intruder first switches to HYB due to power level criterion and only after that it may become a threat.

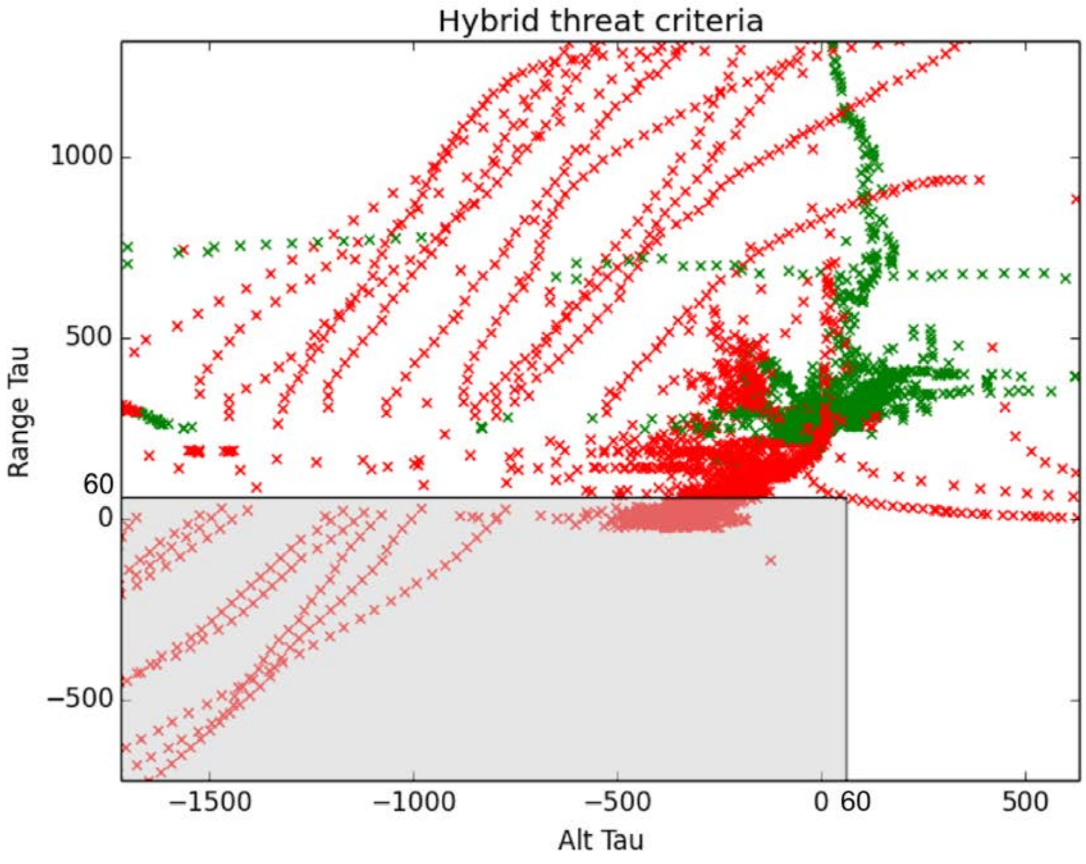

Figure 12: A comparison of hybrid threat criteria to signal power (red crosses depict signal power higher than EXT MTL.

[6] The signal strength is determined as maximum signal strength from DF11 and DF17 squitters received since the last computation, which is (at least) once per every surveillance processing cycle.

Green crosses depict lower or equal values). – Data from the roof test. Only a cut-out of the plot is shown.

To conclude, the first results suggest that the EXT MTL of -68 dBm is safe. A room for improvement in terms of efficiency (e.g. selecting a higher threshold value) could potentially exist but bigger and more representative data sample would be needed for such a discussion.

6.1.3.2.2 ADS-B Legacy Versions

Assumption ASM-00.09.47-VALP-0001 states that only a few aircraft are equipped with ADS-B version 2, which is the requirement for EXT. This concern was justified: out of all ADS-B traffic detected by the ADS-B In function of the installed system (including aircraft outside the TCAS surveillance volume) there were only four ADS-B version 2 aircraft recorded (approx. 1 %) and only 21 ADS-B version 1 aircraft (approx. 5 %). However, none ver. 2 intruder was tracked and only one intruder ver. 1 was tracked. The experiment therefore relies on ver. 0 traffic and the results are positive. As the reliability and consistency of ADS-B information is expected to be higher for version 2, it is expected that the results will be the same or better.

6.1.3.2.3 Unexpected Behaviours/Results

N/A

6.1.3.3 Confidence in Results of Validation Exercise

6.1.3.3.1 Quality of Validation Exercise Results

The results of Exercise #820 were obtained using real traffic recorded by a real antenna and processed by the real TCAS II unit. Accuracy and confidence of the result is not deteriorated. All specificities resulting from using a fixed installation of the antenna (instead of a flying aircraft) are covered in the next section.

6.1.3.3.2 Significance of Validation Exercise Results

Roof-top installation of an antenna brings a few points in which Exercise #820 results may differ from real application. These include:

- Limited range of range rate of an intruder: Since own ship is not moving the closure speeds in this experiment can be only as high as speed of one aircraft.
- Limited type of trajectories of intruders: Since the antenna is mounted in proximity of an airport, majority of the intruders are taking off or landing (i.e. the trajectories are quite steep, especially for taking off).

The abovementioned limitations only restrict the set of typical encounters. The obtained results are all realistic and are thus valuable and useful. Note that only “own in the air” situations (without taking-off and landing of the own ship) are evaluated.

Traffic recorded during the experiment contained 29 ADS-B equipped aircraft, which were inside the surveillance volume and thus tracked. Three of them were tracked only passively without any interrogations, the others were interrogated (either in HYB for the purpose of passive data validation, or in ACT). These 29 targets formed the core sample for our validation. There were, of course, other tracked targets without ADS-B (46 aircraft).

6.1.4 Conclusions and recommendations

6.1.4.1 Conclusions

The validation objectives of Exercise #820 were all fulfilled. The system works as expected and according the designers’ intention.

6.1.4.2 Recommendations

Based on Exercise #820 results it was recommended to continue in Exercise #821 (real flight tests), which should be the key activity to assess EXT.

6.2 Validation Exercise #821 Report

This section remains unchanged with regard to 1st issue of validation report [8].

6.2.1 Exercise Scope

The objective of the exercise is to perform first worldwide flight test of extended hybrid surveillance. There are there validation objectives: OBJ-00.09.47-VALP-0001 entitled "TCAS interrogation rate reduction", OBJ-00.09.47-VALP-0003, entitled "System behaviour while airborne", and OBJ-00.09.47-VALP-0004 entitled "System behaviour in airport environment".

6.2.2 Conduct of Validation Exercise

6.2.2.1 Exercise Preparation

For this exercise several non-specific Airbus test flights on opportunity basis were performed.

The TCAS unit with DO-300A/ED-221 capability (developed by Honeywell) with a directly wired GPS unit was used on-board of Airbus test aircraft.

A recording tool of Honeywell was involved so that all data required in REQ-00.09.47-VALP-0004 of the Validation plan *Table 12* could be recorded. A test engineer was trained to operate the recording tool.

6.2.2.2 Exercise execution

Eight individual flight tests were conducted. The dates, duration, time spent on ground and in the air, and the number of take-offs and landings are listed in Table 12.

No.	Date	Duration on ground	Duration in the air	Duration total	Ownship Take-offs	Ownship Landings
FT1	26. 8. 2014	2015 s --- 00:33:35	3922 s --- 01:05:22	5937 s --- 01:38:57	1	1
FT2	28. 8. 2014	2131 s --- 00:35:31	4722 s --- 01:18:42	6853 s --- 01:54:13	1	1
FT3	2. 9. 2014	2631 s --- 00:43:51	6497 s --- 01:48:17	9128 s --- 02:32:08	1	1
FT4	3. 9. 2014	1894 s --- 00:31:34	6613 s --- 01:50:13	8507 s --- 02:21:47	2	2
FT5	3. 9. 2014	1942 s --- 00:32:22	7634 s --- 02:07:14	9576 s --- 02:39:36	1	1
FT6	4. 9. 2014	1636 s --- 00:27:16	2696 s --- 00:44:56	4332 s --- 01:12:12	2	1
FT7	5. 9. 2014	1911 s --- 00:31:51	2969 s --- 00:49:29	4880 s --- 01:21:20	2	2
FT8	3. 10. 2014	2694 s --- 00:44:54	7635 s --- 02:07:15	10329 s --- 02:52:09	2	2

Table 12: Exercise #821: Flight tests overview.

6.2.2.3 Deviation from the planned activities

The original plan was to use data from a high density traffic environment and also from high altitudes. There was lack of opportunity for such a flight and thus only the above mentioned flights were conducted so far.

6.2.3 Exercise Results

6.2.3.1 Summary of Exercise Results

Objective ID	Objective title	Success Criterion	Result	Details
OBJ-09.47-VALR-EHS1.0001	TCAS interrogation rate reduction	Interrogation rate of an aircraft with a DO-300A/ED-221 system is lower than with a core TCAS II ver. 7.1.	Validated (Preliminary validation)	Validated (savings of approx. 71 % of interrogations)
OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	Three surveillance methods are used effectively and without unnecessary interrogations of the targets.	Validated	Usage of surveillance methods and revalidation intervals is balanced. The system behaves according expectations.
OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	There are not unnecessary transitions (e.g., oscillations) between surveillance methods.	Validated	In fact, there are some (internal) oscillations between Hybrid and Extended Hybrid surveillance, but this situation is already well reflected in the MOPS requirements. External behaviour of the system is not negatively influenced.
OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	The transition to active surveillance is performed sufficiently in advance before any potential TA/RA for the target.	Validated	Validated, all observed transitions happened according the requirements.
OBJ-09.47-VALR-EHS1.0003	System behaviour while airborne	Passive acquisition is used (and successful) in intended situations.	Validated for 90 % of cases	10 % of acquisitions are performed actively (even if passive acquisition could be used in principle) due to concurrency of DF11 and DF17 messages availability. However, the resulting impact on the number of interrogations is very limited.
OBJ-09.47-VALR-	System behaviour while	Value of the signal power	Validated	In extremely rare and isolated cases, the value of signal

Objective ID	Objective title	Success Criterion	Result	Details
EHS1.0003	airborne	threshold ensures a timely transition to the active surveillance.		power can be lower than the threshold even if active surveillance (based on Hybrid threat criteria) is applied. However, these isolated cases never influenced the transition to ACT and therefore the threshold value seems to be adequate.
OBJ-09.47-VALR-EHS1.0004	System behaviour in airport environment	Passive surveillance used correctly during own ship surface operations.	Validated	15 % of acquisitions are performed actively due to DF concurrency of DF11 and DF17 messages availability (as in the case of airborne environment).
OBJ-09.47-VALR-EHS1.0004	System behaviour in airport environment	Timely and correct transitions of surveillance methods during take-off/landing.	Validated	All take-offs and landings handled correctly.

Table 13: Summary of Exercise #821 results.

All these flights were performed in the vicinity of Toulouse airport. The maximum altitude was approximately 15 000 ft.

6.2.3.1.1 Results on concept clarification

N/A. Refer to section 4.1.1.

6.2.3.1.2 Results per KPA

Refer to section 4.1.2 for concluded results per KPA.

6.2.3.1.2.1 Validation objective OBJ-09.47-VALR-EHS1.0001 “TCAS interrogation rate reduction”

This validation objective was analysed by comparing the number of interrogations (denoted as *A*) measured in real flights of an aircraft with a DO-300A/ED-221 system to the number of interrogations (denoted as *B*) that a core TCAS II ver. 7.1 would have generated in the same situations. See Figure 13 or an overview.

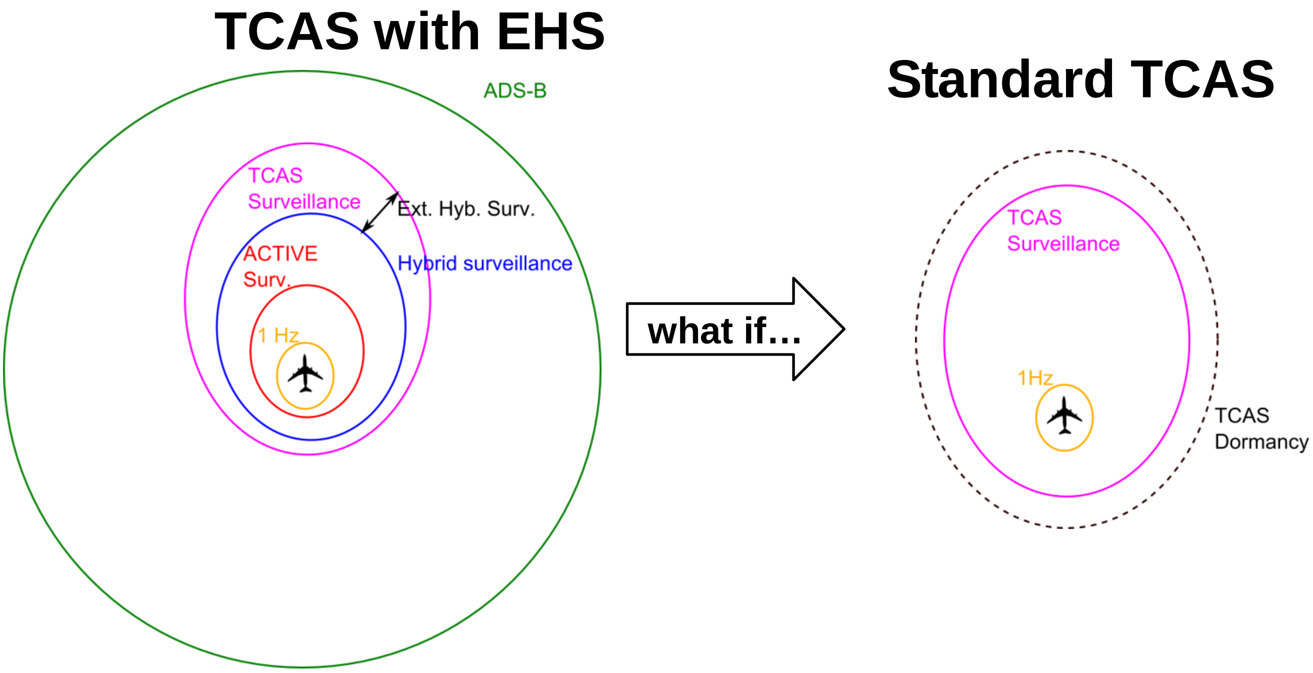

Figure 13: The number of interrogations of standard TCAS can be estimated based on traffic processed by TCAS with EXT.

Only traffic equipped with ADS-B Out (version 0-2) equipped[7] was included in this analysis. All other intruders were ignored.

Value *A* was simply computed as a sum of all real interrogations to all intruders with ADS-B Out. It can be expressed as *A1* + *A2*, where *A1* is the sum of all interrogations under ACT and *A2* is the sum of all interrogations under HYB. There are no interrogations under EXT.

For computing *B* we can analyse each surveillance mode separately as follows:

All aircraft that were under Active surveillance when a DO-300A/ED-221 system was used would be interrogated in the same manner also if a core TCAS II ver. 7.1 had been used.

All aircraft that were under Hybrid and Extended Hybrid surveillance would be interrogated with a reduced surveillance rate, for which we assume 0.2 Hz rate.

B can be thus computed as $B_1 + B_2$ where:

B_1 is the number of all interrogations that were issued to intruders with EXT capability under Active surveillance mode. Note that *B1* = *A1*.

B_2 is the time spent by all EXT capable intruders in Hybrid and Extended Hybrid surveillance modes (in seconds) divided by 5, which results in the expected number of interrogations for these targets in the same configuration had the own ship been equipped with a core TCAS II ver. 7.1.

[7] Traffic with ADS-B Out data of low quality (i.e. not qualified for EXT) was included as well. Rare cases of aircraft transmitted ADS-B Out messages with missing position information. These were totally excluded from validation analysis.

The number of saved interrogations (by having EXT capable system instead of core TCAS II ver. 7.1) can be computed as the difference between *B* and *A*, i.e. *B2 – A2*. Relative savings with respect to made interrogations can be obtained by comparison of A and B2 – A2. Table 14 provides details of this analysis. Only the key values are listed.

Value	Own on ground	Own in the air	Total
A (made interrogations)	435	11175	11610
A2 (Interrogations in HYB)	53	2484	2537
B2 (Interrogations we would have instead of HYB or EXT)	780	30281	31062
B2 – A2 (saved interrogations)	780 – 53 = 727	30281 – 2484 = 27797	31062 – 2537 = 28525
Made interrogations (yellow) vs. saved interrogations (green)	37 % vs. 63 % 	28 % vs. 72 % 	29 % vs. 71 % 

Table 14: Interrogation rate comparison for Exercise #821.

Remark: In these computations the following simplifications have been made:

- For a core TCAS II ver. 7.1 we do not consider dormancy and acquisition interrogations. If considered, the observed benefits would be even higher.
- In the computations only successfully received interrogation replies were considered. It is assumed that the ratio of successful and unsuccessful interrogations is the same for a core TCAS II ver. 7.1 and DO-300A/ED-221 system and thus the ratio of saved vs. made interrogations would remain the same.

6.2.3.1.2.2 Validation objective OBJ-09.47-VALR-EHS1.0003 "System behaviour while airborne"

As in Exercise #820, five success criteria are analysed.

1. **Three surveillance methods are used effectively and without unnecessary interrogations of the targets.**

   For this criterion the same approach as in Exercise #820 is taken.

   Usage of surveillance methods (Figure 14) is different than for the roof-top test results in Exercise #820. The biggest portion of the time per all aircraft belongs to EXT. On the other hand, ACT forms only about 10 %.

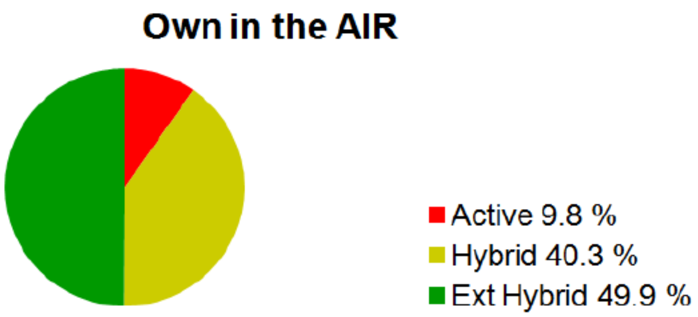

Figure 14: Use of surveillance methods during flight testing.

Surveillance mode transition ranges (Table 15) are also different: transitions between ACT and HYB were observed at higher ranges than in the roof test cases. This is due to the fact that flight tests provide less steep trajectories of the intruders than taking-off and landing aircraft during the roof-top sessions.

Transitions between HYB and EXT will be computed when more representative data (i.e. not only data recorded in vicinity of Toulouse airport) are available. The results will be presented in an update of this validation report.

EXTTransition	Sample size	Mean (NM)	Max (NM)	Min (NM)
ACT to HYB	41	5.14	11.62	3.32
HYB to ACT	39	6.99	10.88	3.38
HYB to EXT	TBD	TBD	TBD	TBD
EXT to HYB	TBD	TBD	TBD	TBD

Table 15: Estimation of ranges of surveillance mode transitions (flight testing).

Focusing on revalidations under HYB (Figure 15), a few more revalidation errors can be observed than in Exercise #820: There were 29 altitude errors and six range errors. No bearing errors were detected. Considering the total number of revalidations (1 936), we see that the percentage of failed validations is very low.

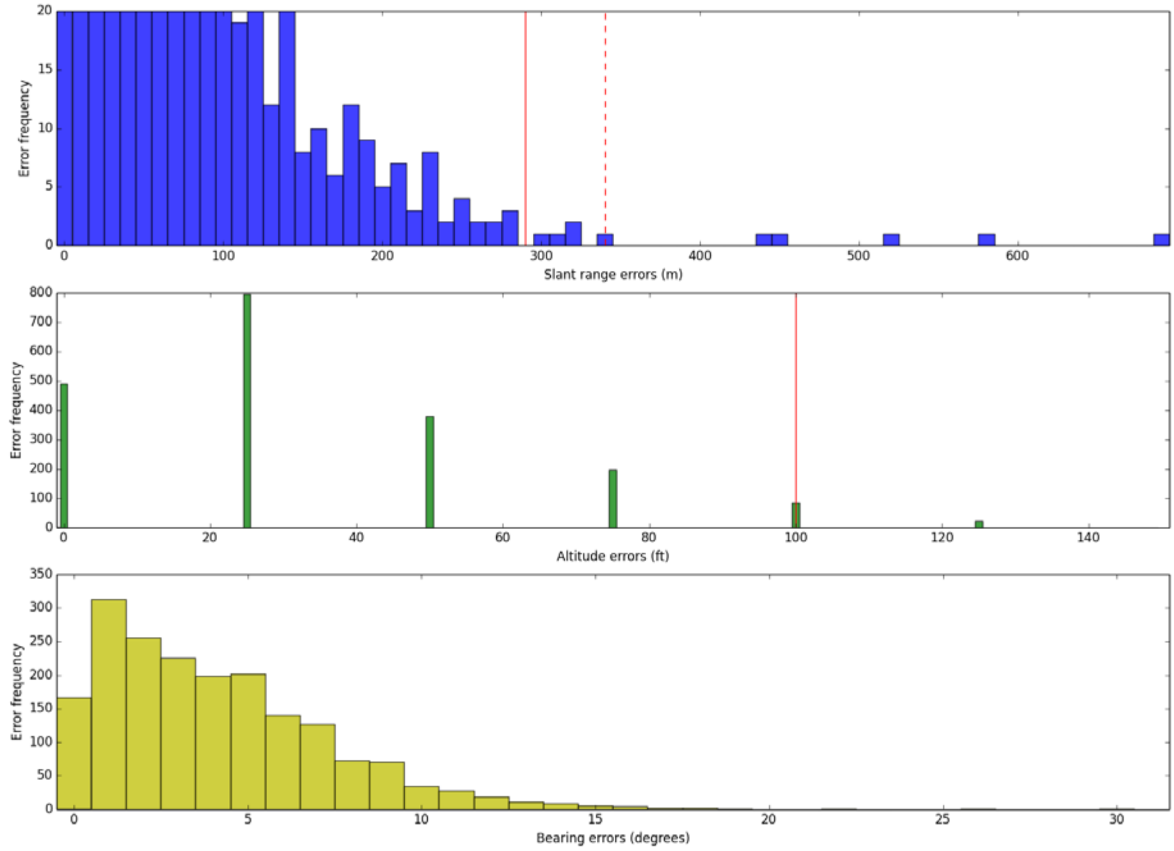

Figure 15: (Re) validation tests summary for Exercise #821.

Plots of revalidation intervals and ranges are similar to those from Exercise #820 and bring no surprising information – they simply confirm the same outcome: the whole range of revalidation intervals is used, but the majority of cases are 60 s. For this reason they are not listed here.

On the other hand, relation between revalidation ranges and intervals (Figure 16) shows that the sample contained richer set of intruder trajectories. The result is a more homogeneous set of data points. What is again clear is the decreasing usage of small revalidation intervals with increasing range. The 60 s revalidation interval was again used in all ranges.

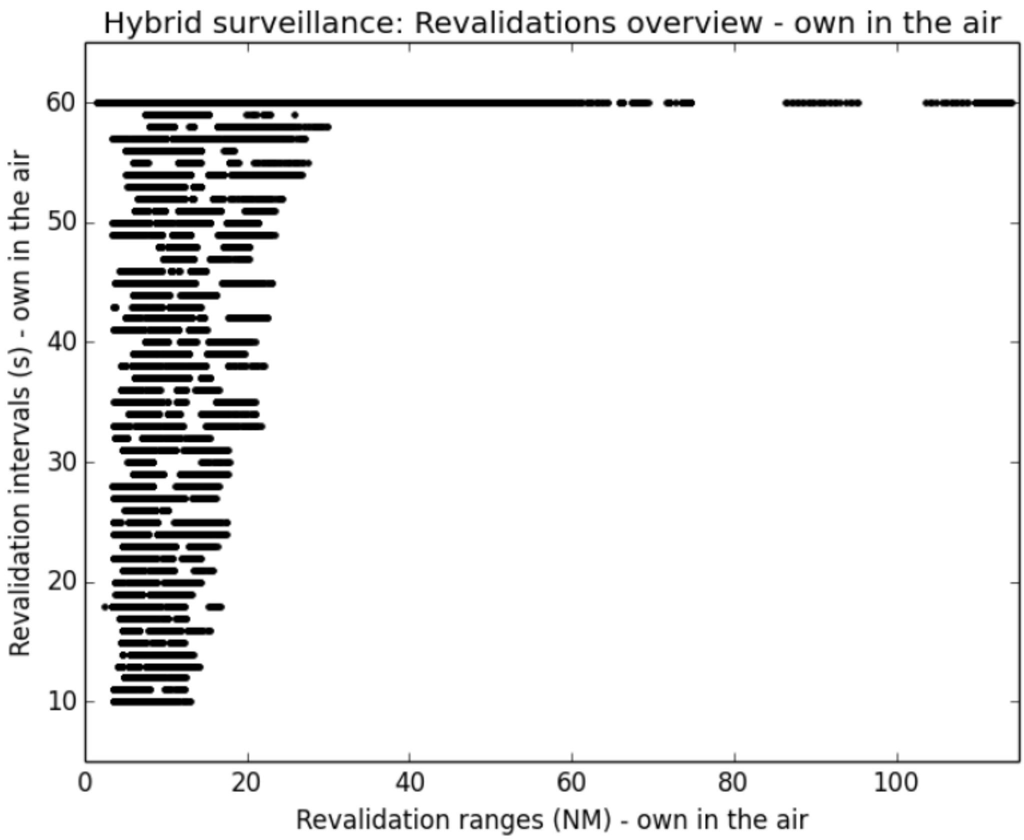

Figure 16: Relation of validation intervals and ranges.

Exercise #821, flight test results, own in the air. Similarly to Exercise #820, the presented experiments support the observation that the system behaves according to expectations.

2. **There are not unnecessary transitions (e.g., oscillations) between surveillance methods.**

   The observations and discussion are the same as in Exercise #820.

3. **The transition to active surveillance is performed sufficiently in advance before any potential TA/RA for the target.**

   Two situations can occur in which it is necessary to analyse this requirement.

   When the own ship is in the air and the intruder transitions from passive surveillance to active surveillance, the approach is the same as in Exercise #820. The results specifically obtained in real flight tests are as follows:

Value	Time difference (s)	Range difference (NM)
Minimum	2.00	0.13
Median	9.00	0.31

Table 16: Exercise #821 time and range differences

The results are based on 17 samples. The minimum values are positive and thus the time buffer for ACT with reduced surveillance rate is guaranteed. The median values are smaller than those from Exercise #820. The difference is due to the fact that closing speeds were lower in the case of a fixed antenna in Exercise #820 than in real flight tests of Exercise #821.

To conclude, there is a positive margin between transition from HYB to ACT and transition to 1 HZ surveillance update rate, which guarantees that ACT is employed sufficiently in advance before TA/RA when the own ship is airborne.

When the own ship takes off (i.e. its on-ground status is changing from on-ground to airborne), theoretically there may be intruders that transition from passive surveillance to active at the same moment (since different requirements apply based on the air/ground status change of the own ship). This happens on physical take-off of at the latest, but usually even earlier due to speed threshold condition. In this specific case the intruder could potentially switch to Active surveillance mode even with normal surveillance update rate (1 Hz). This situation was not observed and therefore this discussion is based only on theoretical analysis of the requirements.

It should be also reminded that in this very specific situation no potential RA would be issued (since at sensitivity level 2, which applies below 1000 ft above ground level, RAs are not issued) and below 400 ft AGL the aural annunciations for TAs are inhibited as well.

An example of a transition to Active surveillance mode with a normal surveillance rate can be seen in Figure 17.

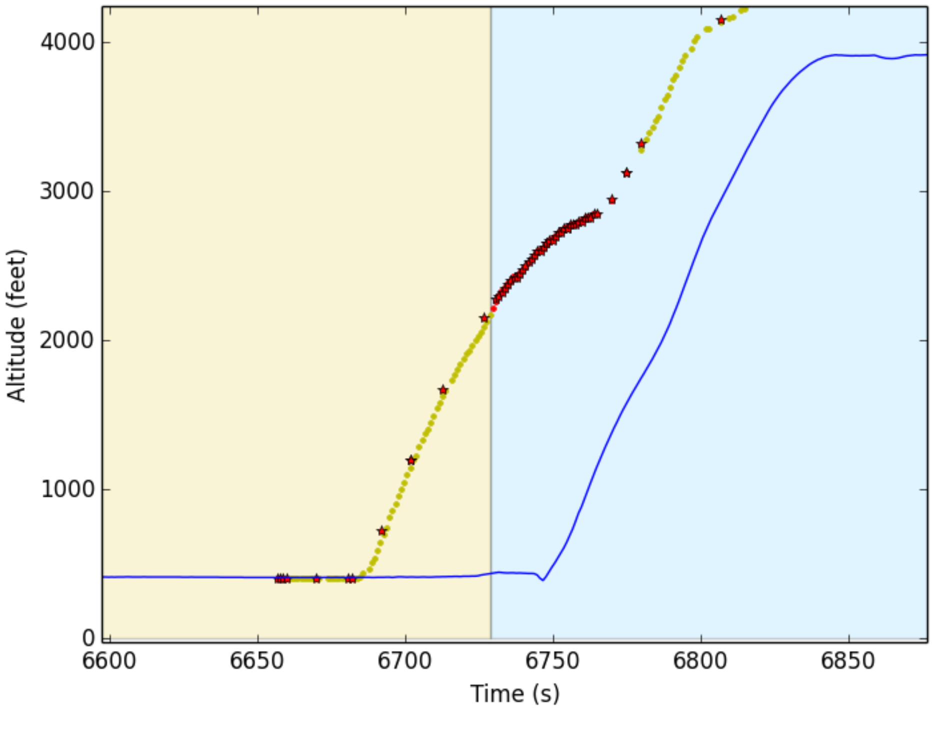

Figure 17: Altitude profile of own ship (blue line) and an intruder (two-coloured line).

When the own ship changes the status from on ground to in the air (depicted by background colour change), the intruder switches from HYB (yellow colour) to ACT (red colour). Red stars denote active interrogations.

4. Passive acquisition is used (and successful) in intended situations.

Figure 18 provides an overview of all acquisitions performed when own ship was in the air. The sample contained 1161 cases (i.e. acquired tracks) coming from 8 flight tests. The results are similar to the outcome of the roof-top testing: Vast majority is acquired passively (approx. 70 %) or actively in line with the standard (high signal power – 7 %, qualification conditions not fulfilled – 13 %). About 10 % could be acquired passively, but are acquired actively due to concurrent availability of DF 17 and DF 11, messages, as discussed in 6.1.3.2.1. Also in this case all these tracks transitioned to passive surveillance after a few cycles. To conclude, there is room for potential improvement, however, the resulting impact on the interrogation rate would be very limited.

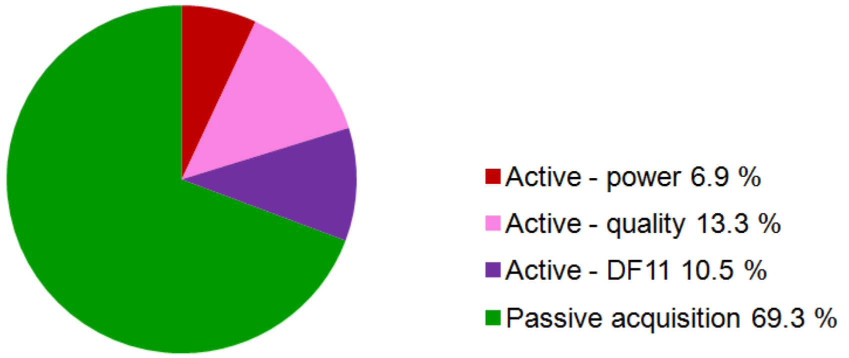

Figure 18: Acquisition methods overview - Exercise #821.

5. **Value of the signal power threshold ensures a timely transition to the active surveillance.**

The analysis is performed in the same way as in Exercise #820.

In Exercise #821, the sample of 14 1871 values from 502 intruders was used. For 5 aircraft 12 values (i.e. 0.008 % of all the analysed cases) were detected for which the signal level was lower or equal to EXT MTL, while both Range Tau and Altitude Tau were below 60 s.

These cases are due to a combination of generally weak signal of an aircraft and signal oscillations. However, in no case the signal is low for a substantial period of time. On the contrary, these cases are isolated in time and thus have no impact on the required transition to ACT.

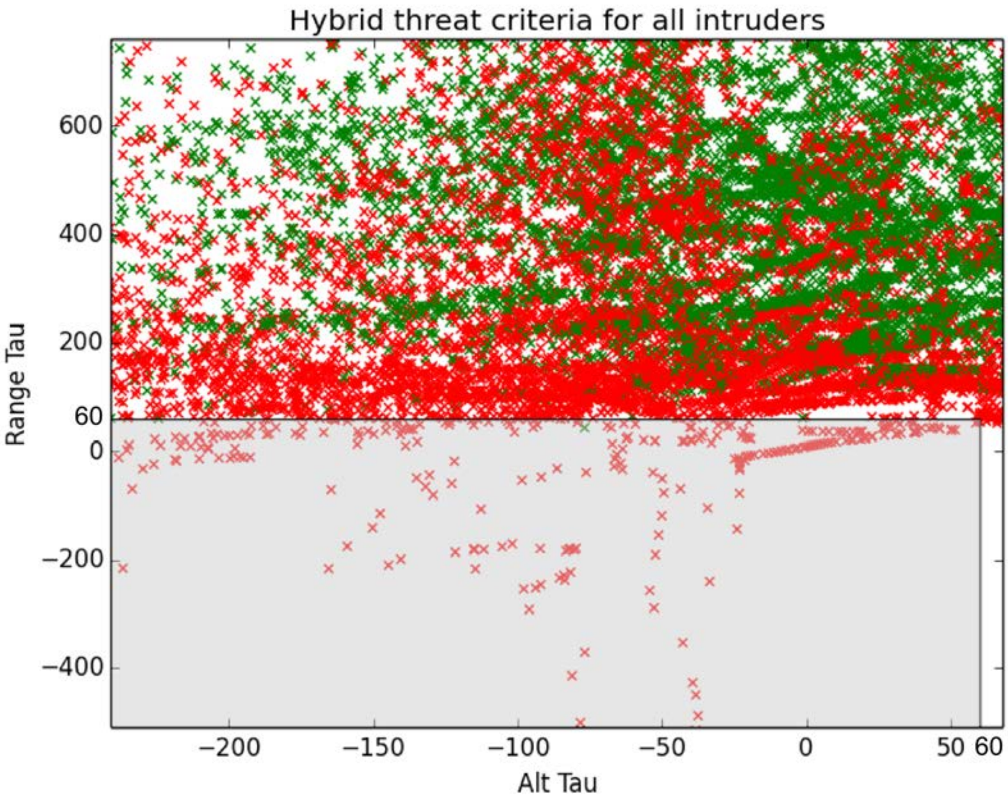

Figure 19: Hybrid threat criteria for all intruders - Exercise # 821

6.2.3.1.2.3 Validation objective OBJ-09.47-VALR-EHS1.0004 "System behaviour in airport environment"

This validation objective consists of two success criteria.

1. **Passive surveillance is used correctly during own ship surface operations**

   For the sake of analysis of this criterion, we focus on correct acquisitions and transitions between surveillance modes.

   Figure 20 shows an overview of track acquisition. Similarly to the airborne environment, approximately 70 % of all tracks are acquired passively. Active acquisition is attributed to the DF11 message presence (15 %) and to cases that are not qualified for EXT (15 %). Signal power level condition is not applied when the own ship is on a surface.

   Sample: 45 acquisitions (in 8 flight tests).

Figure 20: Acquisition method overview - own on ground. - Exercise #2.

Transitions between surveillance modes were also according to DO-300A/ED-221. Since neither power level nor hybrid threat criteria play role in airport environment, transitions were rare. They were of two types:

- Transitions from Active to Passive surveillance (after active acquisition due to DF11 message availability)
- Transitions due to change of EXT qualification status

To conclude, behaviour of the system when the own ship was on ground was according to the expectations.

2. Timely and correct transitions of surveillance methods during take-off/landing.

There are three types of transitions that can happen during take-off or landing of the own ship: Nominal transitions (i.e. transitions between states that are due to hybrid threat criteria and power level only), acceptable transitions (in which some surveillance modes are due to validation failures or lack of qualification for EXT), and suspicious transitions (all remaining possibilities, which are not impossible, but highly improbable). The classification of transitions is given in Table 17.

Transition	Take-off	Landing
A→A	Acceptable	Acceptable
A→H	Suspicious	Acceptable
A→E	Suspicious	Nominal
H→A	Acceptable	Suspicious
H→H	Acceptable	Acceptable
H→E	Suspicious	Nominal
E→A	Nominal	Suspicious
E→H	Nominal	Suspicious
E→E	Nominal	Nominal

Table 17: Classification of transitions for own ship on-ground status change.

In the sample containing 9 transitions during own ship take-off and 8 transitions during own ship landing, no suspicious transition was detected. Based on the received results, this criterion is fulfilled.

6.2.3.1.3 Results impacting regulation and standardisation initiatives

System behaviour observed during validation was according the intended function described in the MOPS.

6.2.3.2 Analysis of Exercise Results

6.2.3.2.1 Unexpected Behaviours/Results

N/A

6.2.3.3 Confidence in Results of Validation Exercise

6.2.3.3.1 Quality of Validation Exercise Results

The results of Exercise #821 were obtained by flight testing in a real environment and are thus considered accurate and confident.

6.2.3.3.2 Significance of Validation Exercise Results

Overview of relevant traffic sample recorded during all the flight tests contained aircraft ADS-B equipped aircraft, which was used for analyses, is provided here:

Flight test	Tracked ADS-B equipped aircraft	Aircraft in HYB	Aircraft in EXT	ADS-B ver. 1 tracked / HYB / EXT	ADS-B ver. 2 tracked / HYB / EXT
1	53	19	47	1 / 0 / 0	1 / 0 / 1
2	71	21	61	3 / 2 / 1	1 / 0 / 1
3	91	32	78	4 / 4 / 0	3 / 2 / 2
4	53	26	44	0 / 0 / 0	3 / 1 / 2
5	132	30	123	4 / 3 / 1	3 / 2 / 2
6	32	16	23	2 / 2 / 1	3 / 1 / 3
7	28	14	24	1 / 1 / 0	1 / 0 / 0
8	72	27	63	6 / 3 / 1	2 / 0 / 1
Sum	532	185	463	21 / 15 / 4	17 / 6 / 12

Table 18: Exercise #821 traffic sample overview

Note that the recorded traffic sample was much richer and included also ADS-B unequipped aircraft and ADS-B equipped aircraft out of TCAS surveillance volume. This traffic is not relevant for the purpose of this document.

The number of tracks under analysis (45 acquisitions when own is on ground, 1 161 acquisitions when own is in the air, 1 206 acquisitions in total) is even higher than the number of ADS-B equipped aircraft inside the surveillance volume: the same intruder can be tracked by multiple consecutive tracks (e.g. due to landing and consequent take-off, or due to temporal loss of data).

6.2.4 Conclusions and recommendations

6.2.4.1 Conclusions

The validation objectives of Exercise #821 were all fulfilled with the following observations:

- The system works as expected both in the air and on surface.
- The proposed value of EXT MTL -68 dBm seems to be both safe and efficient.
- Passive acquisition is used in majority of the intended situations. Room for potential improvement is understood and the achievable benefits are very limited.
- Air/ground transition of own ship status is handled correctly.
- There were no unwanted oscillations between surveillance methods.
- Transitions to active surveillance are made sufficiently in advance before TA and RA.

6.2.4.2 Recommendations

The additional flight tests in higher altitudes and in dense traffic are be needed to provide more representative data for benefits evaluation (Exercise #822). Also data recording on the surface of some busy airport would allow further increase in the representativeness of the results.

6.3 Validation Exercise #822 Report

6.3.1 Exercise Scope

The objective of the exercise is to evaluate the overall impact of TCAS II Extended Hybrid Surveillance on RF load of 1090 MHz in core European airspace. Simulations have been performed with the EUROCONTROL RF Model.

6.3.2 Conduct of Validation Exercise

6.3.2.1 Exercise Preparation

The EUROCONTROL RF Model supports TCAS II interrogations, as specified in the “Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II)” (ED-143, September 2008). ED-143 without Change 1 and Change 2 is considered in this study.

For this exercise the RF Model has been updated to simulate the TCAS II Extended Hybrid Surveillance (EXT), as specified in the “Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II) Hybrid Surveillance” (DO-300A).

The RF Model has then been validated using data recording of real TCAS communication. The results of the RF Model simulations have been compared to the number of TCAS messages contained in 1030MHz and 1090MHz video data recordings[8] analysed with the RF Analyser Tool (RFAT).

Finally Aircraft Scenarios has been created using a typical traffic sample and run on the RF Model to evaluate the impact of TCAS II Extended Hybrid Surveillance on TCAS interrogations.

6.3.2.2 Exercise Execution

6.3.2.2.1 RF Model TCAS Algorithm

[8] Detection of the intermediate frequency (60 MHz in our case)

TCAS II (ED-143, Sept 2008) and TCAS II EXT (DO-300A)

If own TCAS II or TCAS II EXT Interrogator is above 2000 feet and the aircraft is on the ground, then

- the aircraft is not interrogated for acquisition and tracking

TCAS II Interrogator (ED-143, Sept 2008)

If own TCAS II Interrogator is on the ground, then

- it monitors all aircraft within ±10,000ft of own aircraft in an approximate surveillance range of 3 NM (highest density terminal areas to support reliable ground TCAS surveillance) to 14 NM (very low density airspace) every 5 seconds

If own TCAS II Interrogator is at or below 2000ft, then

- it monitors all aircraft on the ground in the surveillance range (up to 55NM) every 5 seconds
- it interrogates all airborne aircraft within ±10,000ft of own aircraft in the surveillance range (55NM) with active interrogations (the interrogation rate depends on the range, see *Active Interrogation (ACT)* paragraph for more information about active interrogations)

Note: the line of sight of an aircraft flying at 2000 ft is theoretically at 55 NM, i.e. that the aircraft can see another aircraft which is on the ground (at 0 ft) up to a distance of 55 NM.

If own TCAS II Interrogator is above 2000ft, then

- it does NOT interrogate aircraft on the ground
- it interrogates all airborne aircraft within ±10,000 ft of own aircraft in the surveillance range (55NM) with active interrogations (the interrogation rate depends on the range, see *Active Interrogation (ACT)* paragraph for more information about active interrogations)

Acquisition Message:

- In addition to tracking interrogations (active interrogations and monitoring[9] interrogations), the own TCAS II may also send dormancy interrogations (every 10 seconds) to get additional information (altitude, position).
- In the RF Model we consider that own TCAS II Interrogator sends a dormancy message to half of aircraft which are not tracked but which are in line of sight, in the power budget and not on the ground. This value has been chosen after analysis with the RFAT tool.

Re-interrogation:

- The own TCAS II Interrogator sends tracking interrogations or dormancy interrogations to Mode S aircraft which are in the vicinity. But the own TCAS II Interrogator may not receive any response from some Mode S aircraft:
  - o The interrogated aircraft do not “receive” the interrogation and do not reply.
  - o The interrogated aircraft “receive” the interrogation and reply, but the own TCAS II Interrogator does not “receive” the reply.

  In that case, own TCAS II Interrogator will re-interrogate these aircraft.

  As a consequence:

[9] Monitoring interrogations are active interrogations, but always every 5 seconds independently of the range.

  - The number of DF 0 may be higher than expected (several DF 0 in the same surveillance period).
  - The number of UF 0 may be higher than the number of DF 0.
- During the video data recordings analysis with the RFAT tool, it has been noticed that an aircraft can receive several TCAS interrogations (UF 0) from the same aircraft in a very short period of time (the signal power is used to determine that TCAS interrogations are coming from the same aircraft). An aircraft may be re-interrogated by the same aircraft during the same surveillance period. The interrogated aircraft may reply to one or to several received TCAS interrogations.
- To simulate re-interrogation, the number of DF 0 replied by every aircraft is increased by 15%.

Interference Limiting:

The Interference Limiting has been partially implemented in the EUROCONTRL RF Model for TCAS II equipment at or below 18000 ft. The own TCAS II counts the number of other TCAS II airborne interrogators within detection range (30 NM), within 6 NM and within 3 NM.

Then the radiated power if the own TCAS II is adapted conforming to the first inequalities provided in §2.2.3.6.1 of ED-143:

$$1)\quad \sum_{i=1}^{I}\left[\frac{P(i)}{250\,\text{watts}}\right]^{\alpha} \le \text{the smaller of}\left[\frac{280}{NTA+1},\frac{11}{\alpha^2}\right]$$

Note: the power used in the Model for TCAS II and TCAS II EXT is 57 dBm.

Note: there is no limitation on the number of Mode S aircraft tracked by a TCAS II equipped aircraft. The analysis of exercise results showed that the maximum number of aircraft tracked by a TCAS II equipped aircraft is 54.

Active Interrogation (ACT)

If own TCAS II and interrogated aircraft are below 18000 ft and the range ≤ 4 NM

Then interrogation every second

If own TCAS II and interrogated aircraft are below 18000 ft, the range > 4 NM and the range ≤ 55 NM

Then interrogation every 5 seconds

If own TCAS II or interrogated aircraft are above 18000 ft and the range ≤ 11 NM

Then interrogation every second

If own TCAS II or interrogated aircraft are above 18000 ft, the range > 11 NM and the range ≤ 55 NM

Then interrogation every 5 seconds

Extended Hybrid Surveillance (DO-300A)

If own TCAS II EXT Interrogator is on the ground, then

- it passively monitors all ADS-B aircraft

- it monitors non ADS-B aircraft within ±3,000 ft of own aircraft in an approximate surveillance range of 3 NM (highest density terminal areas to support reliable ground TCAS surveillance) to 14 NM (very low density airspace) every 5 seconds.

If own TCAS II EXT Interrogator is at or below 2000 ft, then:

- it passively monitors all ADS-B aircraft on the ground in the surveillance range (up to 55 NM).
- it monitors non ADS-B aircraft on the ground in the surveillance range (up to 55 NM) every 5 seconds.
- it tracks airborne ADS-B aircraft within ±10,000 ft of own aircraft.

  See *ADS-B tracking with DO-300A* paragraph for more information.
- it interrogates airborne non ADS-B aircraft within ±10,000 ft of own aircraft and in the surveillance range (55 NM) with active interrogations (the interrogation rate depends on the range, see *Active Interrogation (ACT)* paragraph for more information about active interrogations).

Note: the line of sight of an aircraft flying at 2000 ft is theoretically limited to 55 NM that means that an aircraft flying at 2000 ft can see another aircraft which is on the ground (at 0 ft) up to a distance of 55 NM.

If own TCAS Interrogator is above 2000 ft, then:

- it does NOT interrogate aircraft on the ground
- it tracks airborne ADS-B aircraft within ±10,000 ft of own aircraft.

  See *ADS-B tracking with DO-300A* paragraph for more information.
- it interrogates airborne non ADS-B aircraft within ±10,000 ft of own aircraft and in the surveillance range (55NM) with active interrogations.

  See *ACT (Active Interrogation)* paragraph for more information about active interrogations.

ADS-B tracking with DO-300A

If own TCAS and interrogated aircraft are below 18000 ft, and are approaching

- If range > 30 NM, then Extended Hybrid Surveillance (EXT) → no interrogation
- If 7NM < range ≤ 30 NM, then Hybrid Surveillance (HYB)
- If range ≤ 7 NM, then active interrogations

If own TCAS and interrogated aircraft are below 18000 ft, and are moving away

- If range > 37 NM, then Extended Hybrid Surveillance (EXT) → no interrogation
- If 5.1 NM < range ≤ 37 NM, then Hybrid Surveillance (HYB)
- If range ≤ 5.1 NM, then active interrogations

If own TCAS or interrogated aircraft is above 18000 ft, and aircraft are approaching

- If range > 33 NM, then Extended Hybrid Surveillance (EXT) → no interrogation
- If 12 NM < range ≤ 33 NM, then Hybrid Surveillance (HYB)
- If range ≤ 12 NM, then active interrogations

If own TCAS or interrogated aircraft is above 18000 ft, and aircraft are moving away

- If range > 37 NM, then Extended Hybrid Surveillance (EXT) → no interrogation
- If 4.2 NM < range ≤ 37 NM, then Hybrid Surveillance (HYB)
- If range ≤ 4.2 NM, then active interrogations

HYB (Hybrid Surveillance)

In hybrid surveillance, the range rate of both aircraft is computed. Then, depending on this range rate and the range between the two aircraft, the interval between revalidations is provided according to Table 2 of page 29 of DO-300A.

If the interval between revalidations is set to "A", then Active Interrogation.

EXT (Extended Hybrid Surveillance)

No interrogations

RF Model Parameters for TCAS Simulation

Boundary	**Value – Low Altitude (below 18 000 ft)**
Altitude (own on ground)	3 000 ft
Altitude (own in the air)	10 000 ft
Surveillance volume boundary range (own on ground)	3 NM / 14 NM (criteria TBD)
Surveillance volume boundary range (own in the air)	55 NM
EXT → HYB	30 NM
HYB → EXT	37 NM
HYB → Active	7.0 NM
Active → HYB	5.1 NM
Active reduced / Active 1Hz	As in original Eurocontrol model
Boundary	**Value – High Altitude (above 18 000 ft)**
Altitude (own in the air)	10 000 ft
Surveillance volume boundary range (own in the air)	55 NM
EXT → HYB	33 NM
HYB → EXT	37 NM
HYB → Active	12 NM
Active → HYB	4.2 NM
Active reduced / Active 1Hz	N/A (reduced not required and not observed in high altitudes)

Table 19: Set of parameters for Exercise 3

6.3.2.2.2 RF Model Aircraft Scenario

A snapshot of the air traffic in the core European airspace detected by Mode S radar (in Asterix Category 48 format) on the 17 September 2014 at UTC 14h 33mn 20sec is used to validate the EUROCONTROL RF Model and to generate the Aircraft Scenarios that has been used to evaluate the overall impact of TCAS II EXT on 1090 MHz RF load.

The EUROCONTROL RF Model uses the capabilities reported in the BDS 1,0 (bit 16, bit 37, bit 39 and bit 40) to determine the TCAS equipment of an aircraft. However, the Model has to take into account that not all aircraft are Mode S equipped. In addition, for whatever reason, Mode S aircraft may not be able to provide the content of BDS 1,0.

- SSR aircraft are not equipped with TCAS (with a probability of 75%) or TCAS I equipped (with a probability of 25%)
- Aircraft which do not report the BDS 1,0
  - Aircraft with altitude ≤ 5000 ft are not equipped with TCAS
  - Aircraft with altitude > 5000 ft are not equipped with TCAS (with a probability of 10%) or TCAS I equipped (with a probability of 90%)
- Aircraft reporting a non-operational TCAS flight in the BDS 1,0 (bit 16 = 0 in the reported BDS 1,0)
  - Aircraft with altitude ≤ 5000 ft are not equipped with TCAS (411 aircraft)
  - Aircraft with altitude > 5000 ft are not equipped with TCAS (with a probability of 10%) or TCAS II equipped (with a probability of 90 %)
- Aircraft with bit 16 = 1 and bit 37 = 0 in the reported BDS 1,0 are TCAS II equipped (version depending on bit 39 and bit 40).
- Aircraft with bit 16 = 1 and bit 37 = 1 in the reported BDS 1,0 are TCAS II Hybrid Surveillance (HYB) equipped

This snapshot is depicted in the picture below (1279 aircraft):

- Yellow Square are not equipped with TCAS (438 aircraft)
- Blue aircraft are TCAS I equipped aircraft (21 aircraft)
- Green aircraft are TCAS II equipped aircraft (701 aircraft)
- Red aircraft are TCAS II Hybrid Surveillance (HYB) equipped aircraft (119 aircraft)

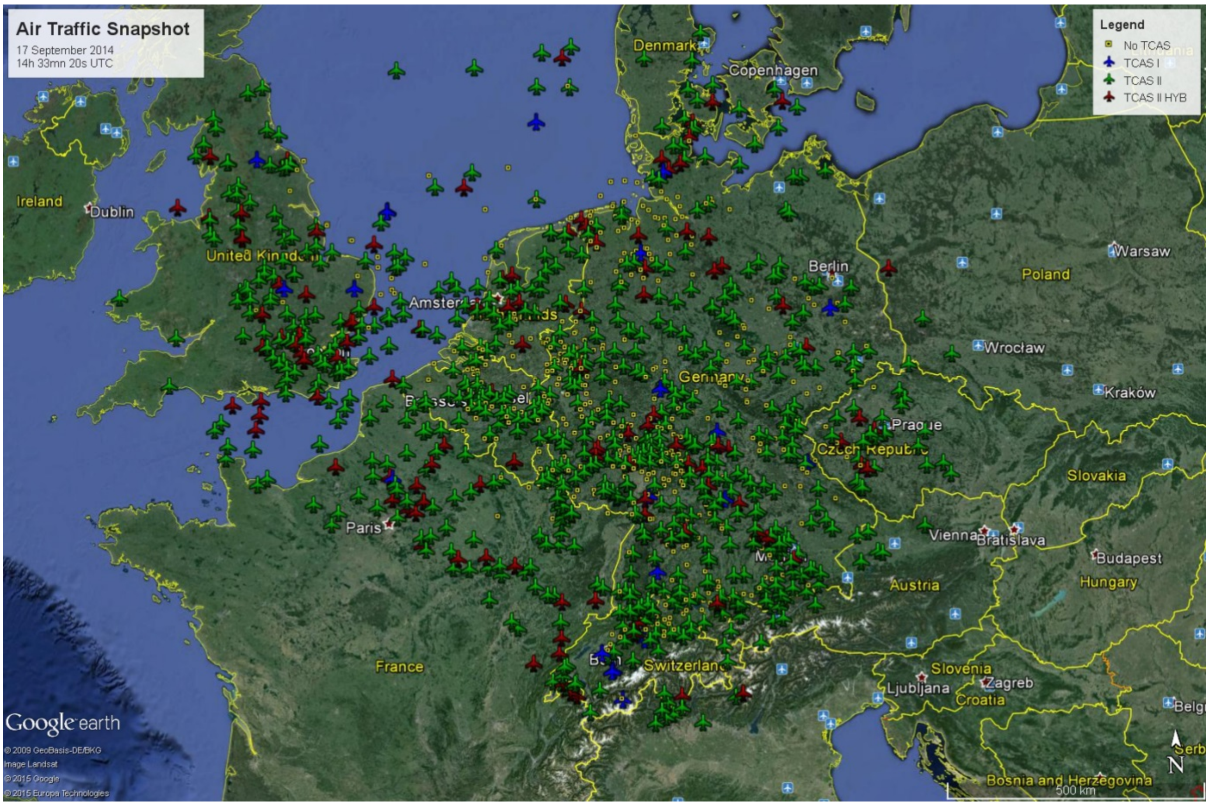

Figure 21: Snapshot of air traffic in the core European airspace

In this exercise, the RF Model has been used to evaluate the overall impact of TCAS II interrogations on 1090 MHz RF load with different Aircraft Scenarios:

- Scenario 1: TCAS II and TCAS II HYB aircraft of the snapshot have been set to TCAS II (no Hybrid Surveillance (HYB), no Extended Hybrid Surveillance (EXT)).

- Scenario 2: TCAS II and TCAS II HYB aircraft of the snapshot have been set to TCAS II Extended Hybrid Surveillance (EXT). In addition, all Mode S aircrafts are also ADS-B level 2 equipped.

However this snapshot may only contain very few aircraft on the ground (or none depending on the airports) as it is based on recorded data from en-route Mode S radar (not from approach Mode S radar located close to the airports). In order to evaluate the impact of ground aircraft on TCAS II, 20 fake ground aircraft have been added at Frankfurt airport.

As a consequence, 2 Aircraft Scenarios have been added:

- Scenario 3: Scenario 1 + 20 fake ground aircraft at Frankfurt Airport, which are TCAS II equipped.

- Scenario 4: Scenario 2 + 20 fake ground aircraft at Frankfurt Airport, which are TCAS II EXT equipped.

The analysis of exercise results (later in the document) has shown that regions with the highest DF 0 reply rate are located around airports, and in particular around Frankfurt airport and London airports (London City, London Gatwick, London Heathrow, Luton, and Stansted).

In order to evaluate the impact of ground aircraft on TCAS II, 20 fake ground aircraft have been added at Frankfurt airport. Fake ground aircraft have not been added to London airports (or to any other airport) as that could have a large impact on the aircraft scenarios. However results around Frankfurt airport and London airports have been compared to evaluate the impact of these fake ground aircraft.

6.3.2.2.3 RF Model Validation

In order to validate the RF Model, the results of the RF Model simulations are compared to the number of TCAS messages transmitted in 1030 MHz and 1090 MHz video data recordings made at Brussels (same date, same time). The RF Analyser Tool (RFAT) is used to analyse the video data recordings.

The RF Model simulates the number of DF 0 replied by every aircraft in the Aircraft Scenarios per second (reply rate in Hz). In the model, a DF 0 is sent by an aircraft after it has received a UF 0 which was addressed to it. As a consequence, the number of DF 0 sent by an aircraft is the same as the number of UF 0 received by this aircraft. This number is then increased to simulate the re-interrogation (as explained in §6.3.2.1.1.).

In the video data recordings analysed with the RFAT, we can compare this number to the number of DF 0 sent by an aircraft on the 1090 MHz RF band or to the number of UF 0 sent to an aircraft on the 1030 MHz RF band.

On the 1090 MHz, the range of the aircraft which emits DF 0 is known, whereas the range of aircraft which emit UF 0 on 1030 MHz is not known. In addition the number of UF 0 may be higher that the number of DF 0 as already indicated in the paragraph about re-interrogation (see §6.3.2.1.1.).

But the 1030 MHz RF band is less occupied than the 1090 MHz RF band, which means that it is easier to decode the 1030 MHz RF band (less garbling). That is why the number of TCAS messages simulated by the RF Model have been compared to the number of UF 0 contained in the 1030 MHz video data recording.

During this exercise, we noticed that it was not so easy to simulate the real traffic messages. In particular, the number of re-interrogation of track messages and acquisition messages was sometime higher than expected and difficult to predict.

Table 20 compares the number of UF 0 (DF 0) computed by the RF Model to the number of UF 0, from the 1030 MHz video data recording, sent to aircraft which are in a range of 50 NM from the video data recording point, where:

- the *Difference* column is a percentage computed as follow:

  (Number of UF0 (RF Model) - Number of UF0 (Video)) / Number of UF0 (Video) * 100

- the *Cumulated Difference* column is the difference (computed above) cumulated for all aircraft at a given range or closer (i.e. for all lines above and the line with the computed value)

At 18.53 NM, the cumulated difference is close to 0 (0.23), which means that the UF 0 interrogation rate recorded and analysed with the RFAT is almost equal to the UF 0 interrogation rate simulated by the RF Model for all the aircraft which are within 18.53 NM from the recording point. This cumulated difference remains very close to 0 for all aircraft which are at a distance from 18.53 NM to 26.36 NM of the recording point.

However, we notice that the number of UF 0 interrogation per second simulated by the RF Model for aircraft at very close range is generally lower to what is measured, whereas it is the contrary at longer range. This is most probably because we do not receive (or decode) correctly all UF 0 addressed to aircraft which are at longer range.

The different parameters of the RF Model could be tuned (in particular the Re-interrogation rate and the Acquisition message rate) to try to be closer to the recorded reality.

ModeS Aircraft	Alt (ft)	Ground	Range	UF 0 (Video)	UF 0 (RF Model)	Difference	Cumulated Difference
4AC945	600	NO	1.02	5.60	4.66	-16.83	-16.83
44CE63	225	YES	1.30	3.67	1.90	-48.25	-29.26
3C5EEF	31100	NO	2.66	11.43	8.05	-29.59	-29.44
4B1A57	6150	NO	3.66	4.63	6.10	31.55	-18.29
405E66	2425	NO	6.77	4.03	4.49	11.20	-14.24

3C6DCC	33975	NO	8.82	7.12	6.50	-8.70	-13.16
44C1E3	800	NO	9.09	3.93	4.08	3.79	-11.51
484F7F	28550	NO	9.09	5.73	7.30	27.37	-6.68
399053	1400	NO	10.32	5.13	4.89	-4.79	-6.49
406542	38000	NO	10.36	6.10	7.19	17.83	-3.91
44A9A3	1100	NO	10.62	6.68	3.68	-44.94	-8.19
8961A5	9000	NO	11.24	4.55	4.89	7.42	-7.15
45A593	1050	NO	11.34	5.57	3.68	-33.89	-9.16
400867	33000	NO	11.44	8.15	7.65	-6.17	-8.86
44B2CA	1500	NO	11.92	5.38	3.68	-31.64	-10.26
4CA6FE	5375	NO	13.19	4.13	3.97	-4.01	-9.98
451E8E	34000	NO	13.20	5.83	7.36	26.17	-7.82
3C544C	36000	NO	14.49	5.35	8.97	67.66	-3.90
44F692	3100	NO	15.29	4.60	4.31	-6.25	-4.00
4BA8CD	9850	NO	15.73	6.52	5.00	-23.24	-5.10
40067C	33000	NO	16.29	6.98	6.79	-2.84	-4.97
AC6CDA	4100	NO	16.64	1.47	4.37	197.95	-2.54
44D9C9	1400	NO	16.78	3.15	5.12	62.46	-0.91
484135	26425	NO	18.53	4.13	5.58	34.94	0.23
343501	22900	NO	19.39	3.82	5.23	37.10	1.28
44C1E5	1100	YES	20.21	5.02	1.73	-65.61	-1.14
43E8AE	2100	NO	20.36	4.05	3.68	-9.14	-1.37
44C0A7	1600	NO	21.42	2.63	3.97	50.66	-0.42
A1088E	5825	NO	22.10	2.52	4.20	66.79	0.72
4B10D6	9800	NO	22.98	3.80	5.12	34.67	1.57
44C253	1900	NO	23.04	4.17	3.57	-14.44	1.14
449C05	1050	YES	24.85	2.90	1.90	-34.57	0.49
44B650	1200	YES	25.41	2.80	1.61	-42.50	-0.25
4B1F14	7700	NO	25.54	2.43	4.14	70.14	0.79
44058F	4425	NO	26.36	3.77	3.68	-2.30	0.72
3CE38D	43000	NO	27.46	2.70	4.83	78.89	1.96
44B46A	800	NO	28.74	1.67	3.97	138.05	3.28
4008E1	31200	NO	29.39	4.55	5.52	21.32	3.74
406B9E	38975	NO	30.25	5.40	4.54	-15.88	3.16
393D23	19000	NO	31.49	4.95	5.06	2.22	3.13
44CE70	15150	NO	31.54	3.23	5.58	72.50	4.31
449DED	4200	NO	31.70	3.13	4.20	33.96	4.79
4492E4	15875	NO	32.11	4.43	3.74	-15.70	4.33
3986EE	37000	NO	32.14	3.83	5.41	41.00	5.03
4005A4	38000	NO	32.15	5.07	5.92	16.89	5.32
44CD2C	1600	YES	33.90	2.35	1.84	-21.70	5.02
484536	3100	NO	33.98	1.58	3.68	132.42	5.98
484188	17575	NO	34.55	5.13	3.45	-32.79	5.05
448E24	2100	NO	36.13	0.98	3.45	250.85	6.17

3C6DCB	35725	NO	36.34	4.50	5.98	32.89	6.71
44F146	3700	NO	40.13	2.53	3.68	45.26	7.15
44B2C1	1625	YES	41.26	1.95	2.01	3.21	7.11
4064A4	36000	NO	41.36	1.53	8.17	432.50	9.98
71BD96	36250	NO	41.95	5.00	7.07	41.45	10.66
48476E	1600	NO	42.25	1.93	3.39	75.47	11.20
44F04C	4000	NO	42.84	2.33	4.14	77.43	11.85
406ADC	1200	NO	43.52	2.00	3.16	58.13	12.24
45AC30	35025	NO	45.22	6.55	5.81	-11.34	11.61
4850F1	1500	NO	47.26	2.38	2.88	20.63	11.69
400993	34975	NO	47.39	3.07	6.50	111.88	12.92
4845A8	1700	NO	47.43	1.17	2.13	82.36	13.24
406222	30525	NO	47.48	2.88	7.07	145.29	14.74
449E13	13100	NO	48.06	1.70	2.70	58.97	15.03
4848DF	30000	NO	48.18	1.58	4.54	186.89	16.08

Table 20: Comparison of TCAS transmissions (RFAT – Model)

6.3.2.3 Deviation from the Planned Activities

N/A

6.3.3 Exercise Results

6.3.3.1 Summary of Exercise Results

Objective ID	Objective title	Success Criterion	Result	Details
OBJ-09.47-VALR-EHS1.0002	1090 MHz RF load reduction in European environment	Reduction of the 1090 MHz RF load in European environment with respect to the current situation.	Confirmed.	Simulations showed a reduction of DF 0 reply rate by up to 89% if TCAS II is replaced by TCAS II EXT for all TCAS II equipped aircraft and all Mode S aircraft are emitting extended squitter (ADS-B level 2)/

Table 21: Exercise #822 results summary

6.3.3.1.1 Results on concept clarification

N/A. Refer to section 4.1.1.

6.3.3.1.2 Results per KPA

Refer to section 4.1.2 for results per KPA.

6.3.3.1.3 Results impacting regulation and standardisation initiatives

N/A

6.3.3.2 Analysis of Exercise Results

6.3.3.2.1 Comparison of Scenario 1 and 3

Scenario 1: TCAS II and TCAS II HYB aircraft of the snapshot are set to TCAS II (no Hybrid Surveillance, no Extended Hybrid Surveillance).

The 10 aircraft with the highest DF 0 reply rate are located around Frankfurt airport (5 aircraft) and London airports (5 aircraft), as depicted in the picture below.

It appears that the points with highest TCAS II transmissions (DF 0), impacting the 1090 MHz RF load, are located around big airports.

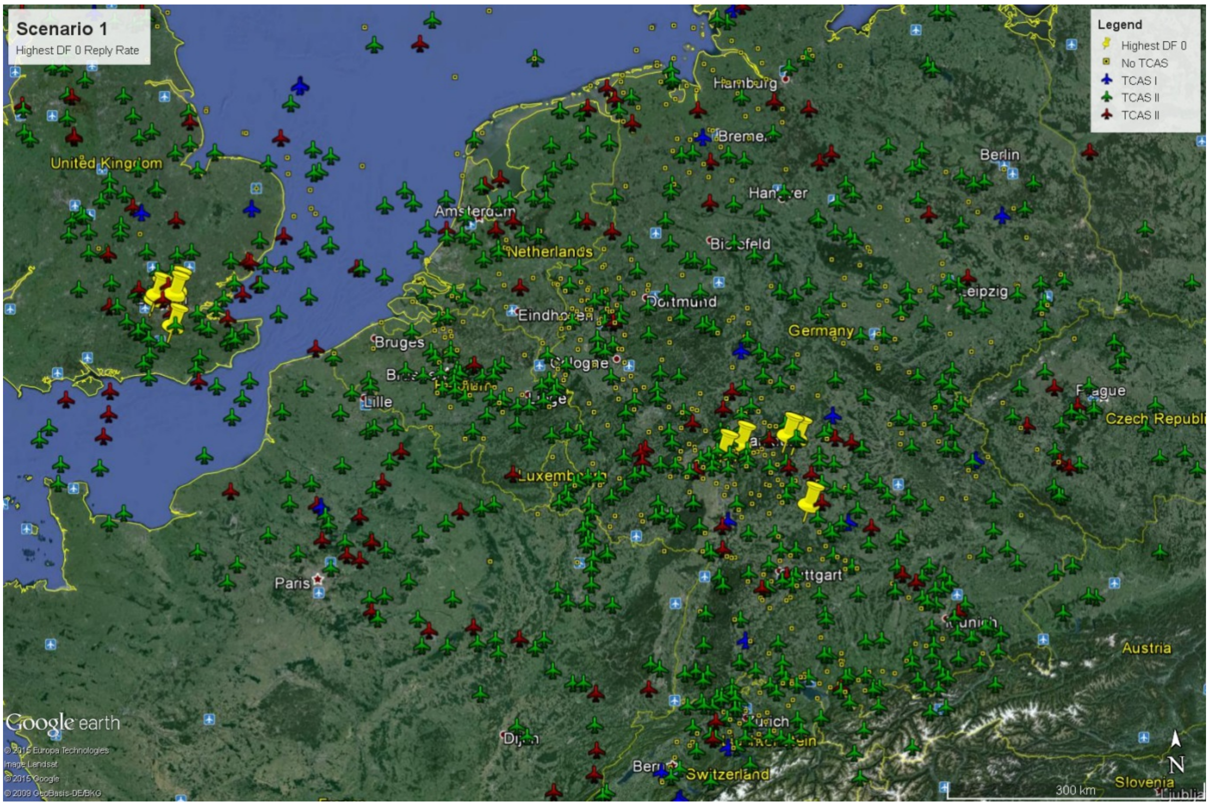

Figure 22: Aircraft with highest DF 0 reply rate for Scenario 1

More information about the 10 aircraft is provided in the table below.

We can notice that 4 aircraft on 10 (in red in the list) are at high altitude (above 18000ft). At high altitude aircraft are tracked once per second below a range of 11NM. Above that range, they are tracked every 5 seconds. As the number of aircraft is more important around big airports, it is normal that aircraft at high altitude are more interrogated.

Other aircraft (in black in the list) are at low altitude (below 18000ft). At low altitude aircraft are tracked once per second below a range of 4NM. Above that range, they are tracked every 5 seconds.

We can also notice that:

- 5 of the aircraft which are close to Frankfurt airport, 4 aircraft are at high altitude.
- 5 of the aircraft which are close to London airports, 5 aircraft are at low altitude.

That means that the traffic is not the same around Frankfurt airport and London airports.

The 2 aircraft with the highest DF 0 reply rate are approaching London airports.

Frankfurt airport (Latitude 50°, Longitude 8.5°) and London airports (Latitude 51.5°, Longitude -0.12°).

ModeS Address	Latitude (deg)	Longitude (deg)	Altitude (feet)	TCAS Type	Mode S TCAS replies (DF 0) in Hz
406A9D	51.626304	-0.232176	8000	TCAS 2	9.83
3986E5	50.057287	8.798618	32000	TCAS 2	10.01
4008F1	51.32495	0.054926	12725	TCAS 2	10.01
4007E5	51.689553	0.084092	7975	TCAS 2	10.01
3C6750	49.990277	8.526418	1950	TCAS 2	10.06
800B15	50.069588	9.655938	38000	TCAS 2	10.12
3C848F	50.100379	9.525266	34350	TCAS 2	10.41
3C664B	49.413414	9.74993	30075	TCAS 2	10.41
48415F	51.641675	0.053536	10450	TCAS 2	10.70
406319	51.581548	-0.262413	14950	TCAS 2	11.39

Table 22: 10 aircraft with highest DF 0 reply rate for Scenario 1

The aircraft highlighted in yellow are identified in Scenario 1 and in Scenario 3.

In addition to the DF 0 reply rate provided by aircraft, the RF Model also simulate the total number of DF 0 received by an omni-directional antenna located at different position (the MTL of the omni directional antenna is -84 dBm):

- omnidirectional antenna very close to Frankfurt airport
  - Latitude = 50, Longitude = 8.45 and Altitude = 150 m
  - Number of DF 0 received per second: 1613.13
- omnidirectional antenna between Frankfurt airport and London airports
  - Latitude = 50.5, Longitude = 5 and Altitude = 3050 m (10000 ft)
  - Number of DF 0 received per second: 643.43

The number of DF 0 received by the omni-directional antenna close to a big airport is much more important than away from airports.

<u>**Scenario 3**: Scenario 1 + 20 TCAS II equipped aircraft on the ground at Frankfurt airport</u>

The 10 aircraft with the highest DF 0 reply rate are mainly located around Frankfurt airport (8 aircraft), but also around London airports (2 aircraft), as depicted in the picture below.

As previously, it appears that the points with highest TCAS II transmissions (DF 0), impacting the 1090 MHz RF load, are located around big airports.

It appears also that ground aircraft have an important impact on TCAS II transmissions (DF 0), as 8 aircraft (of 10) with the highest DF 0 reply rate are now located around Frankfurt airport (most of them at low altitude) where 20 fake ground aircraft have been added in the Scenario 3.

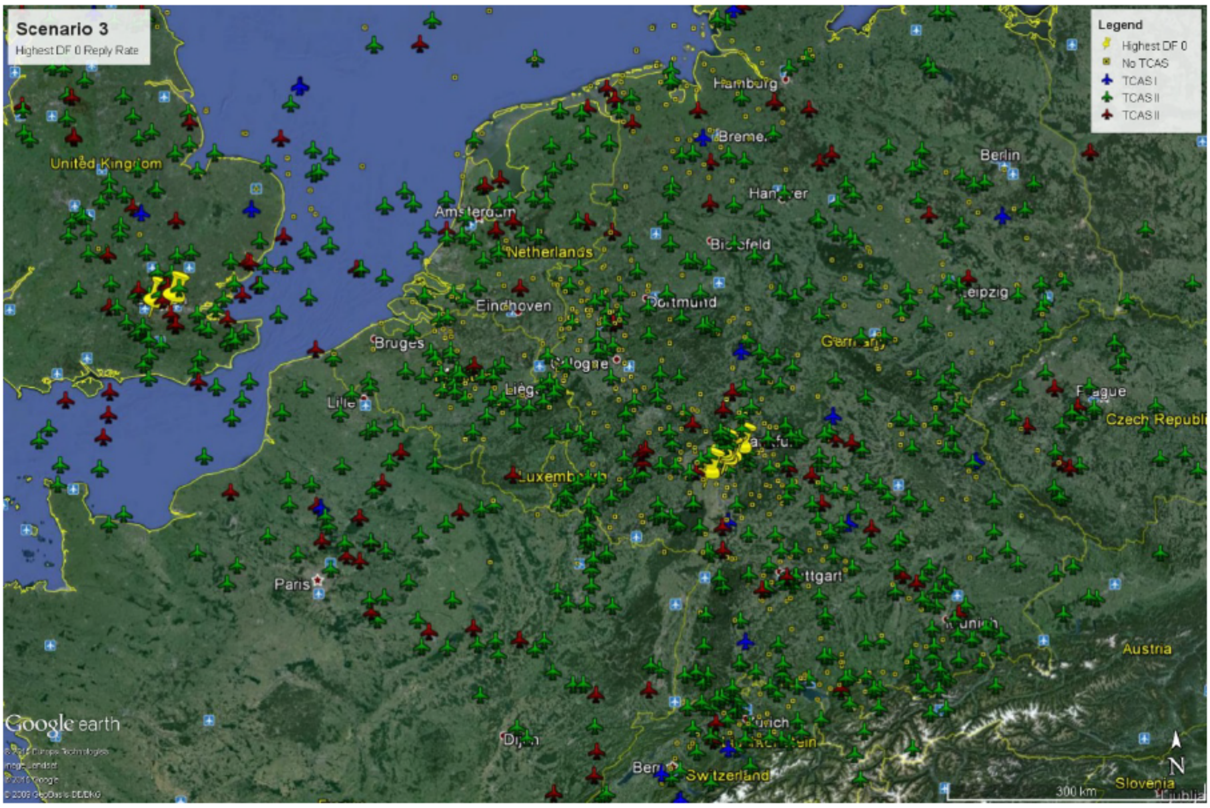

Figure 23: Aircraft with highest DF 0 reply rate for Scenario 3

More information about the 10 aircraft is provided in the table below.

We can notice that the 4 aircraft identified in Scenario 1 are still in the list for Scenario 3 (highlighted in yellow):

- The 2 aircraft with the highest DF 0 reply rate in Scenario 1 (approaching London airports).

  Note: the reply rate in Scenario 3 is identical (or almost) to the reply rate in Scenario 1

- 2 aircraft around Frankfurt airport, one at high altitude (32000 ft) and one at very low altitude (1950 ft).

  Note: the reply rate of the aircraft at low altitude is very impacted by the fake ground aircraft (10.06 Hz in Scenario 1 vs. 14.66 Hz in scenario 3), whereas the impact on the reply rate of the aircraft at high altitude is limited (10.01 Hz in Scenario 1 vs. 11.16 Hz in scenario 3),.

The 5 aircraft with the highest DF 0 reply rate in Scenario 3 are approaching Frankfurt airport at low altitude. This is a direct consequence of adding fake ground aircraft at Frankfurt airport.

Ground aircraft are more impacting aircraft which are at low altitude and close to the airport.

Frankfurt airport (Latitude 50°, Longitude 8.5°) and London airports (Latitude 51.5°, Longitude -0.12°).

ModeS Address	Latitude (deg)	Longitude (deg)	Altitude (feet)	TCAS Type	Mode S TCAS replies (DF 0) in Hz
740821	49.990353	8.553166	40000	TCAS 2	10.41
491255	49.834241	8.295667	13675	TCAS 2	10.70
48415F	51.641675	0.053536	10450	TCAS 2	10.70

3986E5	50.057287	8.798618	32000	TCAS 2	11.16
406319	51.581548	-0.262413	14950	TCAS 2	11.16
3D065A	49.975269	8.642779	1200	NO	11.44
501D18	50.019516	8.500447	825	TCAS 2	11.73
3C5461	49.94691	8.581313	3850	TCAS 2	11.79
3C6655	49.951062	8.58087	7925	TCAS 2	12.48
3C6750	49.990277	8.526418	1950	TCAS 2	14.66

Table 23: 10 aircraft with highest DF 0 reply rate for Scenario 3

The Scenario 3 is closer to the reality as it takes into account ground aircraft taxiing on the airport. That's why Scenario 1 is not used in the rest of the exercise.

It is expected to have much higher DF 0 reply rate for aircraft approaching London airports if fake ground aircraft were added at London airports (London City, London Gatwick, London Heathrow, Luton, and Stansted).

In addition to the DF 0 reply rate provided by aircraft, the RF Model also simulate the total number of DF 0 received by an omni-directional antenna located at different position (the MTL of the omni directional antenna is -84 dBm):

- omnidirectional antenna very close to Frankfurt Airport
  - Latitude = 50, Longitude = 8.45 and Altitude = 150 m
  - Number of DF 0 received per second: 1796.65
  - +11% compared to Scenario 1 due to fake ground aircraft
- omnidirectional antenna between Frankfurt airport and London airports
  - Latitude = 50.5, Longitude = 5 and Altitude = 3050 m (10000 ft)
  - Number of DF 0 received per second: 663.43
  - Same results as Scenario 1

As above, the number of DF 0 received by the omni-directional antenna close to a big airport is much more important than away from airports.

6.3.3.2.2 Comparison of Scenario 2 and 4

Scenario 2: TCAS II and TCAS II HYB aircraft of the snapshot are set to TCAS II Extended Hybrid Surveillance (EXT). In addition, all Mode S aircrafts are also ADS-B equipped.

The 10 aircraft with the highest DF 0 reply rate are located around Frankfurt airport (5 aircraft), Zurich Airport (3 aircraft), London airports (1 aircraft) and elsewhere as depicted in the picture below.

It seems that the points with highest TCAS II transmissions (DF 0) remain around big airports.

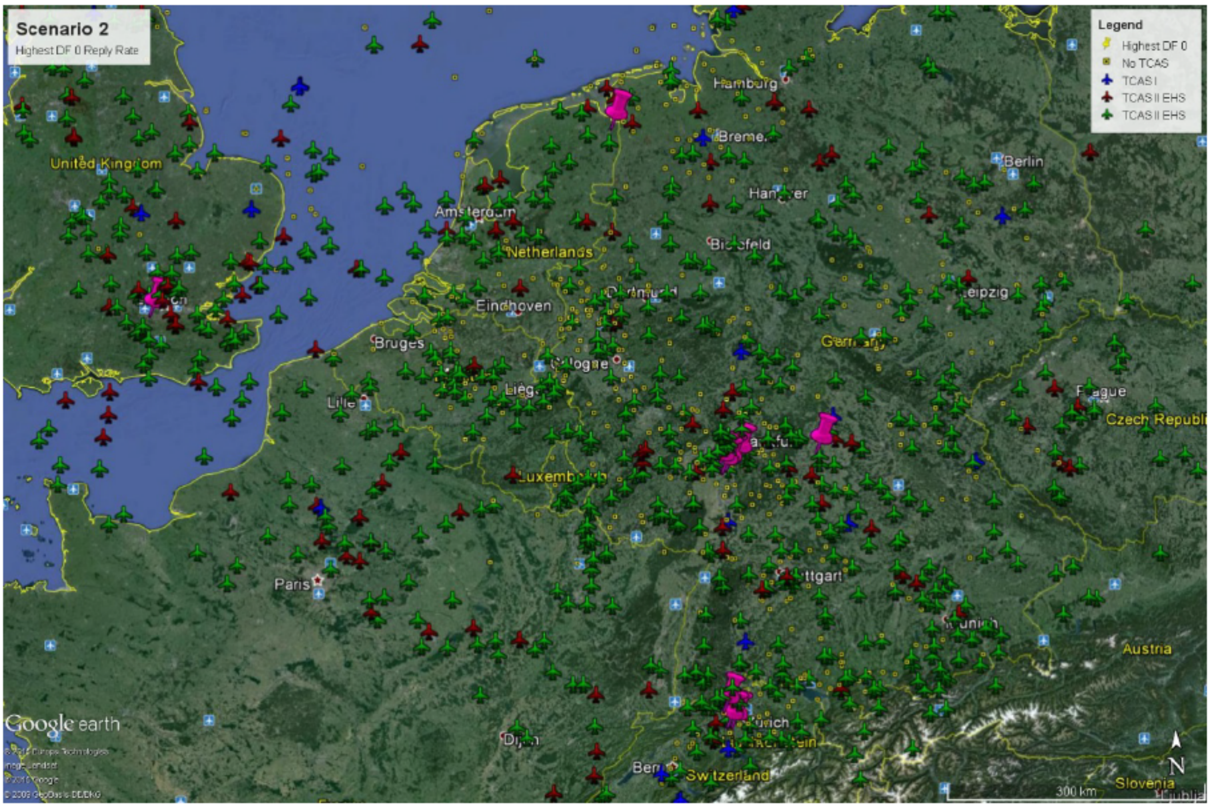

Figure 24: Aircraft with highest DF 0 reply rate for Scenario 2

More information about the 10 aircraft is provided in the table below.

We can notice that 3 aircraft on 10 (in red in the list) are at high altitude (above 18000 ft). Other aircraft (in black in the list) are at low altitude (below 18 000ft).

Aircraft around Zurich airport and London airports are at low altitude.

The aircraft with the highest DF 0 reply rate is approaching Frankfurt airport at low altitude.

Frankfurt airport (Latitude 50°, Longitude 8.5°), London airports (Latitude 51.5°, Longitude -0.12°) and Zurich airport ((Latitude 47.5°, Longitude 8.5°).

ModeS Address	Latitude (deg)	Longitude (deg)	Altitude (feet)	TCAS Type	Mode S TCAS replies (DF 0) in Hz
4D201D	47.464748	8.453138	14250	TCAS 2 EHS	2.84
400FDE	50.072111	10.032016	37975	TCAS 2 EHS	2.87
4B178D	47.633051	8.355175	4725	TCAS 2 EHS	2.96
3D065A	49.975269	8.642779	1200	NO	3.12
406319	51.581548	-0.262413	14950	TCAS 2 EHS	3.19
3C6655	49.951062	8.58087	7925	TCAS 2 EHS	3.25
4B1620	47.471291	8.390442	10500	TCAS 2 EHS	3.33
4AC8B8	53.368044	7.218227	38850	TCAS 2 EHS	3.62
3986E5	50.057287	8.798618	32000	TCAS 2 EHS	3.83
3C6750	49.990277	8.526418	1950	TCAS 2 EHS	4.03

Table 24: 10 aircraft with highest DF 0 reply rate for Scenario 2

Scenario 4: Scenario 2 + 20 TCAS II EXT equipped aircraft on the ground at Frankfurt airport.

The results obtained with Scenario 2 are identical to the results obtained with Scenario 4. TCAS II EXT equipped Aircraft on the ground monitor passively aircraft which are ADS-B equipped and are passively monitored by other TCAS II EXT. So ground TCAS II EXT do not impact the 1090MHz RF load.

That means that the 20 fake ground aircraft added at Frankfurt airport do not impact the TCAS II Extended Hybrid Surveillance. As a consequence, the TCAS EXT equipment of the aircraft with the highest DF 0 reply rate in Scenario 2 and Scenario 4 approaching Frankfurt airport at low altitude is not impacted by aircraft on the ground at Frankfurt airport.

6.3.3.2.3 Comparison of Scenario 3 and 4

Scenario 3: TCAS II and TCAS II HYB aircraft of the snapshot are set to TCAS II. 20 TCAS II equipped Aircraft added on the ground at Frankfurt airport.

Scenario 4: TCAS II and TCAS II HYB aircraft of the snapshot are set to TCAS II Extended Hybrid Surveillance (EXT). In addition, all Mode S aircrafts are also ADS-B equipped. 20 TCAS II EXT equipped Aircraft added on the ground at Frankfurt airport.

Below is provided the list of 10 aircraft with the highest DF 0 reply rate identified in Scenario 4.

The aircraft highlighted in yellow are also identified in Scenario 1 and in Scenario 3.

The aircraft highlighted in grey are also identified in Scenario 3.

Frankfurt airport (Latitude 50°, Longitude 8.5°), London airports (Latitude 51.5°, Longitude -0.12°) and Zurich airport ((Latitude 47.5°, Longitude 8.5°).

ModeS Address	Latitude (deg)	Longitude (deg)	Altitude (feet)	TCAS Type	Mode S TCAS replies (DF 0) in Hz
4D201D	47.464748	8.453138	14250	TCAS 2 EHS	2.84
400FDE	50.072111	10.032016	37975	TCAS 2 EHS	2.87
4B178D	47.633051	8.355175	4725	TCAS 2 EHS	2.96
3D065A	49.975269	8.642779	1200	NO	3.12
406319	51.581548	-0.262413	14950	TCAS 2 EHS	3.19
3C6655	49.951062	8.58087	7925	TCAS 2 EHS	3.25
4B1620	47.471291	8.390442	10500	TCAS 2 EHS	3.33
4AC8B8	53.368044	7.218227	38850	TCAS 2 EHS	3.62
3986E5	50.057287	8.798618	32000	TCAS 2 EHS	3.83
3C6750	49.990277	8.526418	1950	TCAS 2 EHS	4.03

Table 25: 10 aircraft with highest DF 0 reply rate for Scenario 2

We can notice that the 5 aircraft identified in Scenario 3 are still in the list for Scenario 4. That means that half of aircraft with highest DF 0 reply rate are the same, whatever the TCAS equipment (TCAS II or TCAS EXT):

- 3D065A at low altitude (1200ft) close to Frankfurt airport

  The DF 0 reply rate has decreased from 11.44Hz (Scenario 3) to 3.12Hz (Scenario 4), which means a reduction of 72.7%.

- 406319 at low altitude (14950ft) close to London airports

  The DF 0 reply rate has decreased from 11.16Hz (Scenario 3) to 3.19Hz (Scenario 4), which means a reduction of 71.4%.

- 3C6655 at low altitude (7924ft) close to Frankfurt airports

  The DF 0 reply rate has decreased from 12.48Hz (Scenario 3) to 3.25Hz (Scenario 4), which means a reduction of 74%.

- 3986E5 at high altitude (32000ft) close to Frankfurt airports

  The DF 0 reply rate has decreased from 11.16Hz (Scenario 3) to 3.83Hz (Scenario 4), which means a reduction of 65.7%.

- 3C6750 at low altitude (1950ft) close to Frankfurt airports

  The DF 0 reply rate has decreased from 14.66Hz (Scenario 3) to 4.03Hz (Scenario 4), which means a reduction of 72.5%.

The aircraft (Mode S = 3C6750) with the highest DF 0 reply rate in Scenario 4 is approaching Frankfurt at low altitude. This aircraft has the highest DF 0 reply rate in Scenario 3 and is also in the Scenario 1 list.

From the above analyse on aircraft with the highest DF reply rate, we can notice that the DF 0 reply rate has decreased by 65 % to 74 % when replacing TCAS II by TCAS II EXT + Full ADS-B level 2.

In addition to the DF 0 reply rate provided by aircraft, the RF Model also simulate the total number of DF 0 received by an omni-directional antenna located at different position (the MTL of the omni-directional antenna is -84dBm):

- omnidirectional antenna very close to Frankfurt Airport
  - Latitude = 50, Longitude = 8.45 and Altitude = 150 m
  - Number of DF 0 received per second: 201.87
  - -88.7 % compared to Scenario 3
- omnidirectional antenna between Frankfurt airport and London airports
  - Latitude = 50.5, Longitude = 5 and Altitude = 3050 m (10000 ft)
  - Number of DF 0 received per second: 71.34
  - -89 % compared to Scenario 3

As above, the number of DF 0 received by the omni-directional antenna close to a big airport is much more important than away from airports.

In addition, the number of DF 0 received in Scenario 4 (TCAS II EXT + full ADS-B level 2) is reduced by 89 % compared to Scenario 3 (TCAS II). This number is almost identical to the value provided below for the global overview (87.2 %).

6.3.3.2.3.1 Global Overview

There are 1279 aircraft in the air traffic snapshot. For both scenarios, 20 aircraft have been added on the ground at Frankfurt airport. In total, there are 1299 aircraft.

In addition aircraft with a TCAS II DF 0 reply rate equal to 0 are removed (76 SSR transponder equipped aircraft and 3 Mode S transponder equipped aircraft which are on the border). As a consequence, there are from now 1220 aircraft in the scenarios.

To get a global overview of TCAS II and TCAS II EXT impact on the 1090M Hz RF load, the DF 0 reply rate of all aircraft in each scenario have been added and compared:

- For Scenario 3, the total DF 0 reply rate = 4842.76 Hz
- For Scenario 4, the total DF 0 reply rate = 620.19 Hz

⇨ Reduction of DF 0 reply rate between Scenario 3 and Scenario 4: 87.2 %

Scenario 3 and Scenario 4 are extreme case where 100 % of aircraft are either TCAS II or TCAS II EXT and 100 % of aircraft are equipped with ADS-B level 2 working perfectly. The reply rate reduction computed by the RF Model will certainly never be reached, but provides a good trend. It shows that the rate of TCAS transmission on 1090MHz could drastically decrease if TCAS II EXT would replace TCAS II (and all aircraft equipped with ADS-B level 2).

6.3.3.2.3.2 Horizontal Comparison

Previously we have identified that the points with highest TCAS II transmissions (DF 0), impacting the 1090 MHz RF load, seemed to be located around big airports.

In Figure 25, the DF 0 reply rate (in Hz) of TCAS II equipped aircraft is displayed in a Latitude (x axis) vs. Longitude (y axis) graph.

It appears clearly that the areas where the DF 0 reply rate is the most important is around Frankfurt airport (Latitude 50°, Longitude 8.5°) and London airports (Latitude 51.5°, Longitude -0.12°), but also around Brussels airport (Latitude 51°, Longitude 4.5°) and Zurich airport (Latitude 47.5°, Longitude 8.5°). That confirms that highest TCAS II transmissions (DF 0) are located around big airports.

Reminder: Fake ground aircraft have been added to the original snapshot at Frankfurt airport.

We can also notice that DF 0 reply rate is relatively low for aircraft which are in border of the snapshot, where there are less aircraft.

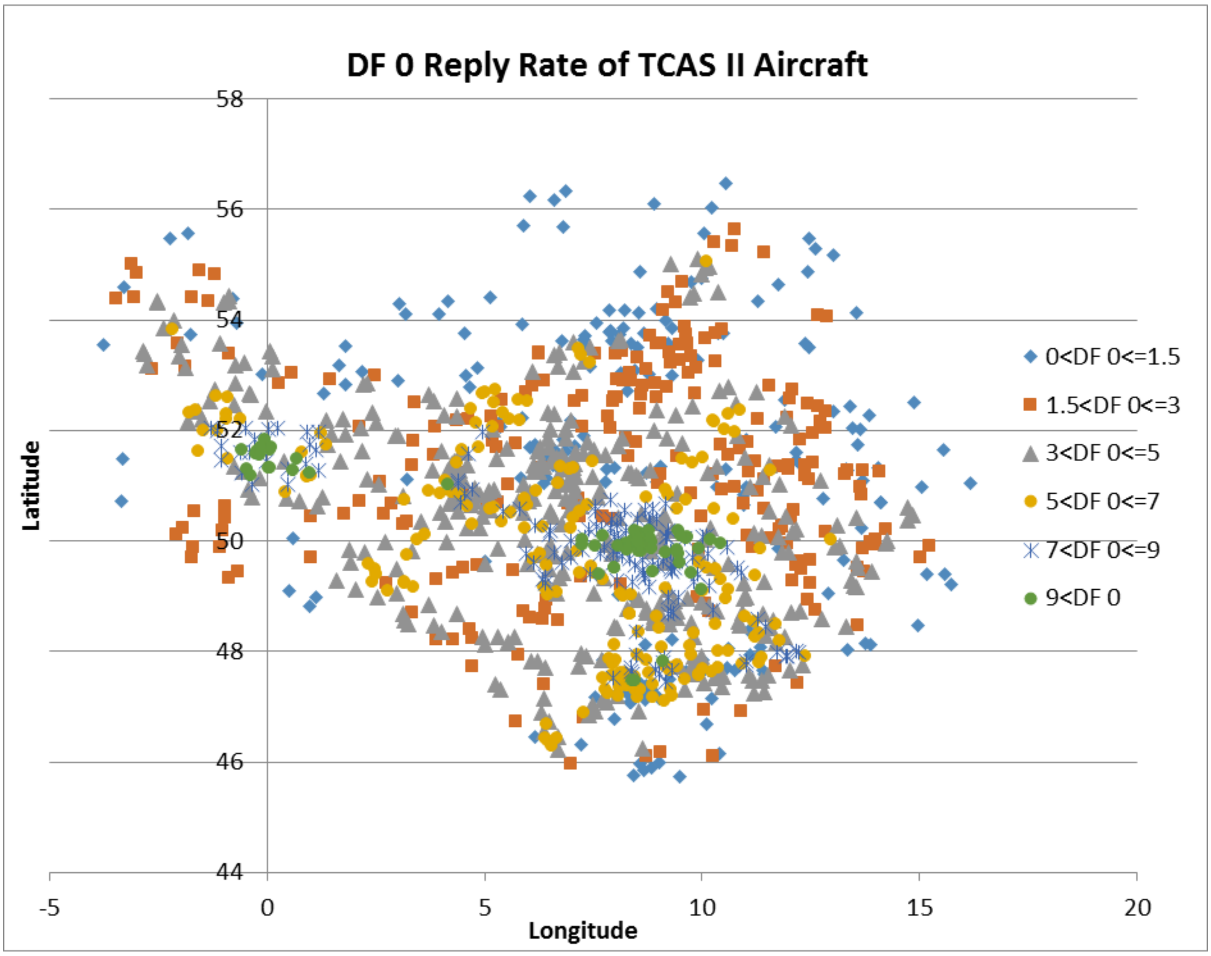

Figure 25: DF 0 Reply Rate of TCAS II Aircraft (Horizontal View)

When we compare the DF 0 reply rate (in Hz) of TCAS II to the DF 0 reply rate (in Hz) of TCAS II EXT equipped aircraft provided below, we see that the reply rate of TCAS II EXT is much lower.

In the TCAS II EXT graph, we can notice that an important part of DF 0 reply rate is below 0.5 Hz. We can also notice that the areas where the DF 0 reply rate is the most important are still around Frankfurt airport (Latitude 50°, Longitude 8.5°) and London airports (Latitude 51.5°, Longitude -0.12°), but also around Brussels airport (Latitude 51°, Longitude 4.5°) and Zurich airport (Latitude 47.5°, Longitude 8.5°).

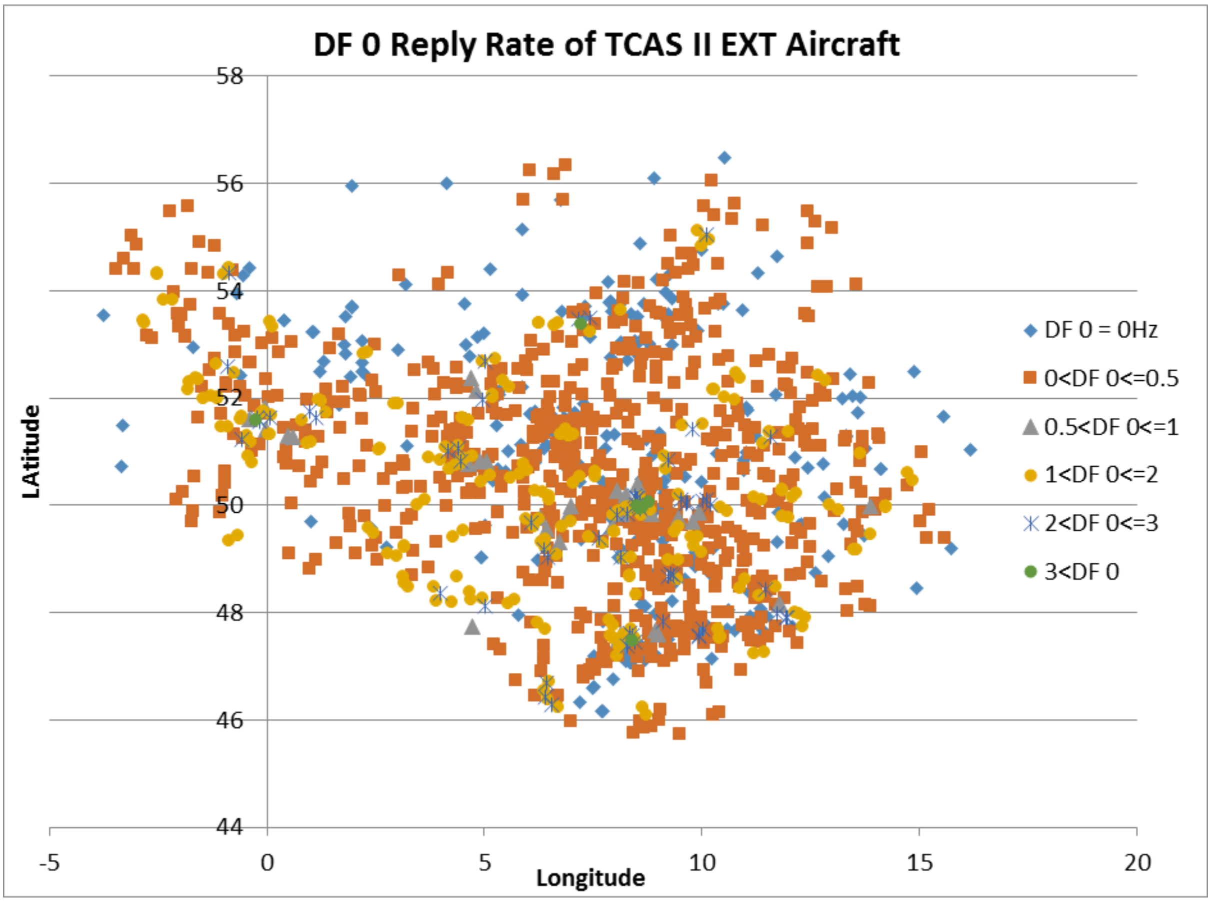

Figure 26: DF 0 Reply Rate of TCAS II EXT Aircraft (Horizontal View)

In the figure below we identify aircraft by aircraft the reduction of DF 0 reply rate if TCAS II is replaced by TCAS II EXT (and full ADS-B level 2). It is not very easy to identify the areas where this reduction is the most important. However it seems that the area where the reply rate reduction is the less important is not around airport.

Note: A reduction of 100 % means that the Mode S aircraft does not emit any DF 0. So that means also that this aircraft is not interrogated by any TCAS II EXT equipped aircraft.

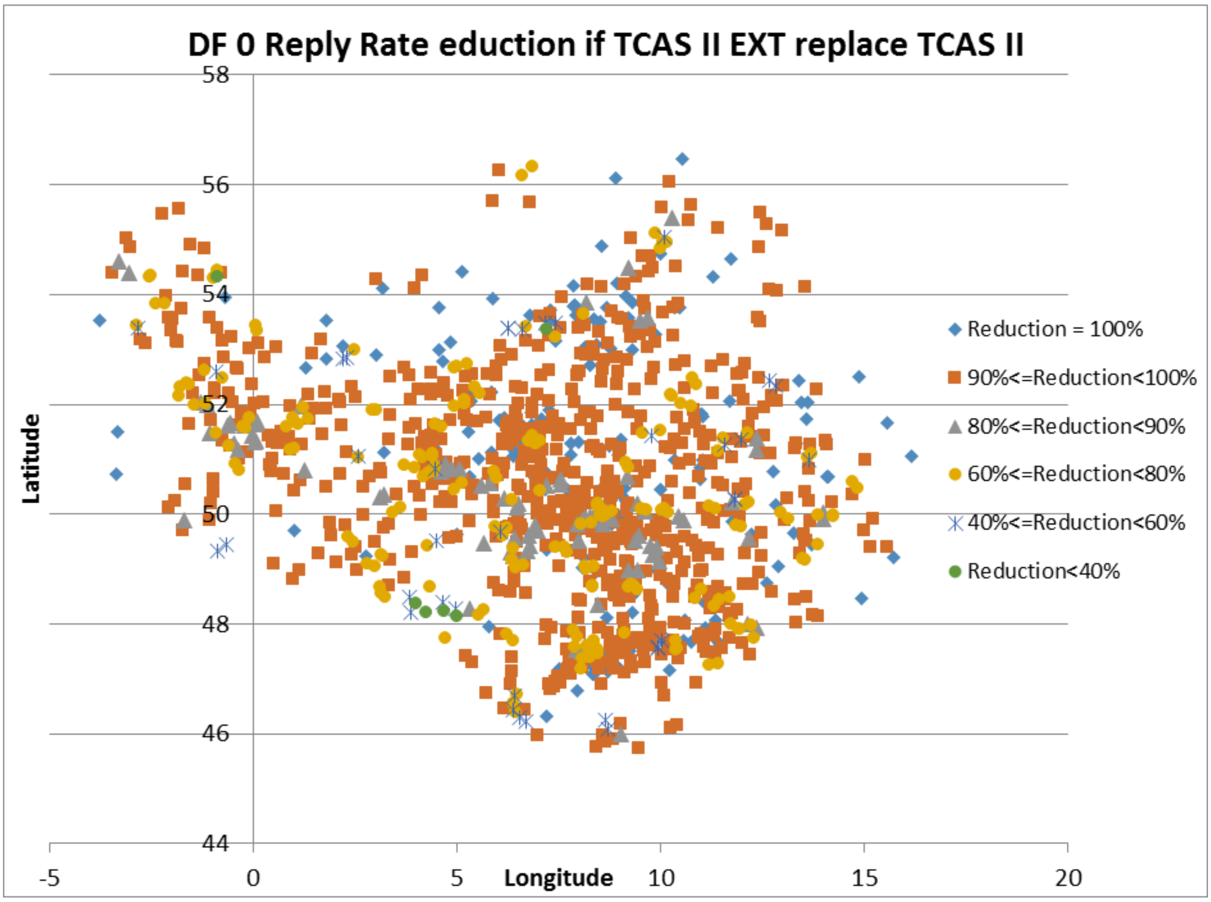

Figure 27: DF 0 Reply Rate Reduction (Horizontal View)

Table 26 provides the number of aircraft (and percentage) per DF 0 reply rate reduction band (total 1220 Mode S aircraft):

DF Reply Rate Reduction	No of Aircraft	Percentage
Reduction = 100%	210	17.21
90%<=Reduction<100%	686	56.23
80%<=Reduction<90%	88	7.21
60%<=Reduction<80%	192	15.74
40%<=Reduction<60%	37	3.03
Reduction<40%	7	0.57

Table 26: Reduction bands overview

For 17.21 % of aircraft, the reduction of DF 0 reply rate is equal to 100 % when TCAS II is replaced by TCAS II EXT (and full ADS-B level 2), which means that 17.21 % of aircraft don't reply to any UF 0.

For 73.44 % of aircraft, the reduction of DF 0 reply rate is superior to 90 % when TCAS II is replaced by TCAS II EXT (and full ADS-B level 2).

6.3.3.2.3.3 Vertical Comparison

Figure 28 provides, aircraft by aircraft, the reduction of DF 0 reply rate if TCAS II is replaced by TCAS II EXT (and full ADS-B level 2), in a vertical display, i.e. Longitude (x axis) vs Altitude (y axis).

From that graph, it seems that the reduction of DF 0 reply rate may be more important for aircraft below 5000 ft.

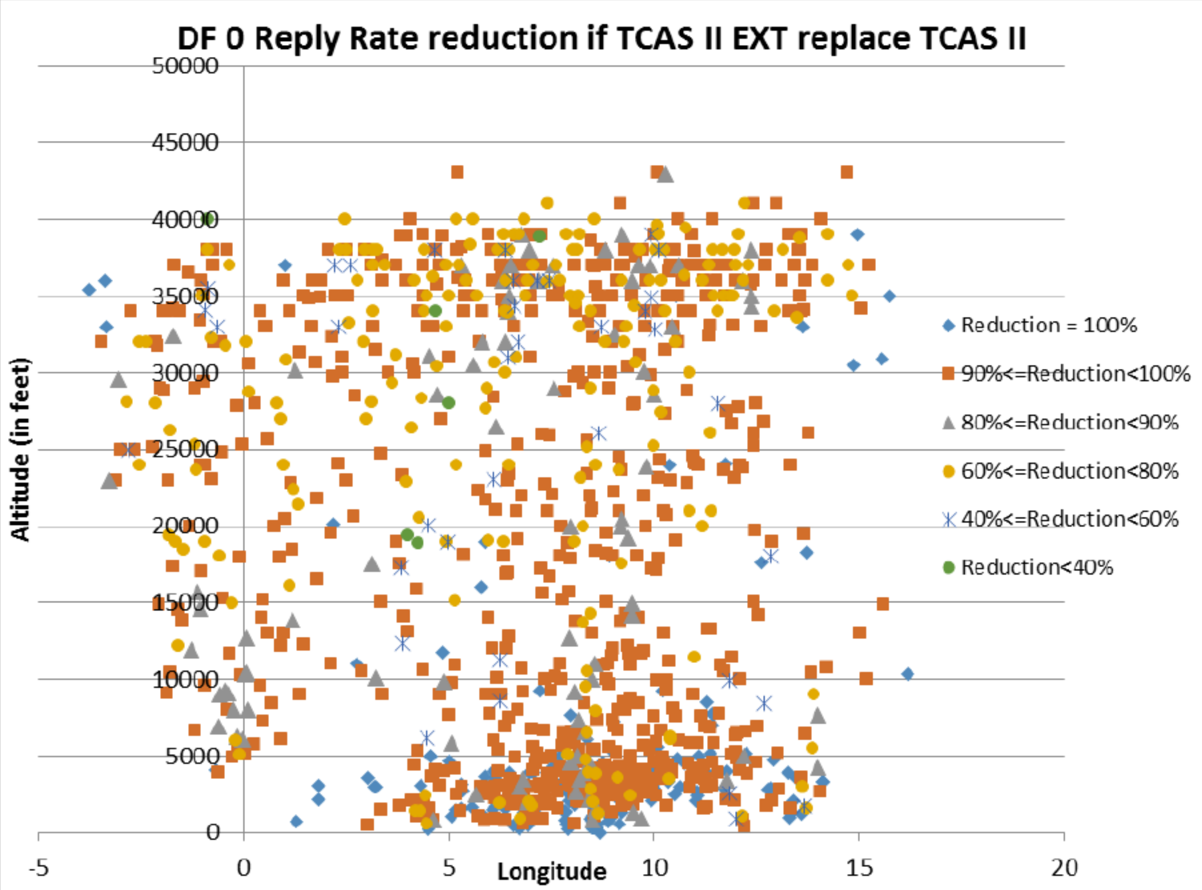

Figure 28: DF 0 Reply Rate Reduction (Vertical View)

Table 27 provides the number of aircraft (and percentage) per DF 0 reply rate reduction band depending on the altitude:

	<5000 ft		<10000 ft		All Altitude	
	Number	Percentage	Number	Percentage	Number	Percentage
Reduction = 100%	171	40.71	190	34.11	210	17.21
90%<=Reduction<100%	207	49.29	295	52.96	686	56.23
80%<=Reduction<90%	19	4.52	34	6.10	88	7.21
60%<=Reduction<80%	20	4.76	31	5.57	192	15.74
40%<=Reduction<60%	3	0.71	7	1.26	37	3.03
Reduction<40%	0	0.00	0	0.00	7	0.57
Total	420		557		1220	

Table 27: Reduction depending on altitude

For 73.44 % of aircraft, the reduction of DF 0 reply rate is superior to 90 % when TCAS II is replaced by TCAS II EXT (and full ADS-B level 2).

For 90 % of aircraft below 5000ft, the reduction of DF 0 reply rate is superior to 90 % when TCAS II is replaced by TCAS II EXT (and full ADS-B level 2).

As a consequence, it seems that the DF 0 reply rate reduction is more important for aircraft at low altitude. This is shown on the graph below which provides the reduction of DF 0 reply rate (x axis) versus the percentage of aircraft (y axis) if TCAS II is replaced by TCAS II EHS (and full ADS-B level 2).

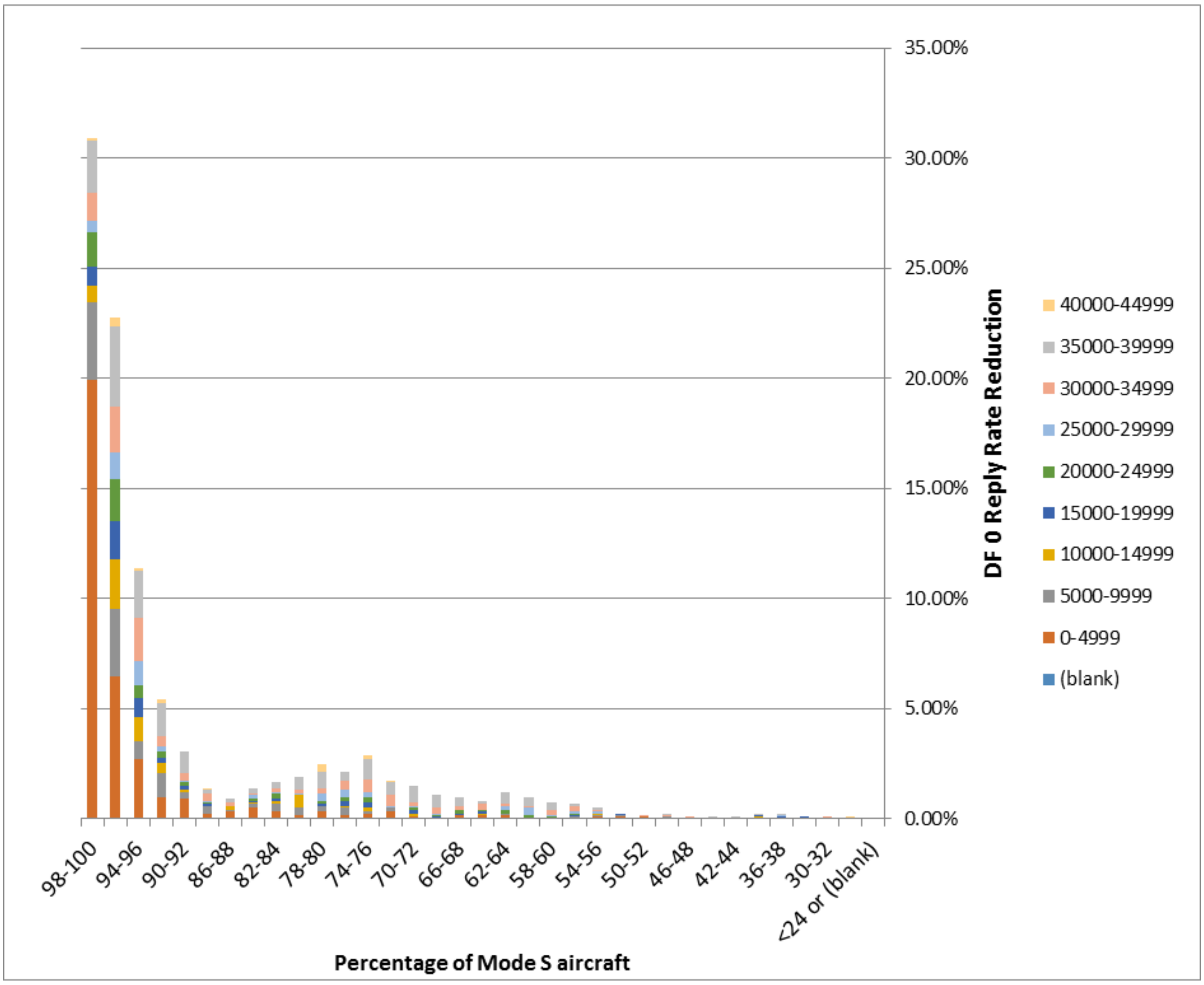

Figure 29: Percentage of aircraft with reduction of DF 0 Reply Rate per altitude band

The DF 0 Reply Rate reduction around 75 % is mainly due to Mode S aircraft flying at high altitude.

The graph below provides, aircraft by aircraft, the reduction of DF 0 reply rate if TCAS II is replaced by TCAS II EXT (and full ADS-B level 2), in a vertical display, i.e. Longitude (x axis) vs Altitude (y axis), at Longitude of Frankfurt airport (Longitude 8.5°). It seems indeed that the reduction of DF 0 rate is more important for aircraft below 5000 ft, as indicate above. Most of Mode S aircraft having a reduction = 100 % are below 5000 ft.

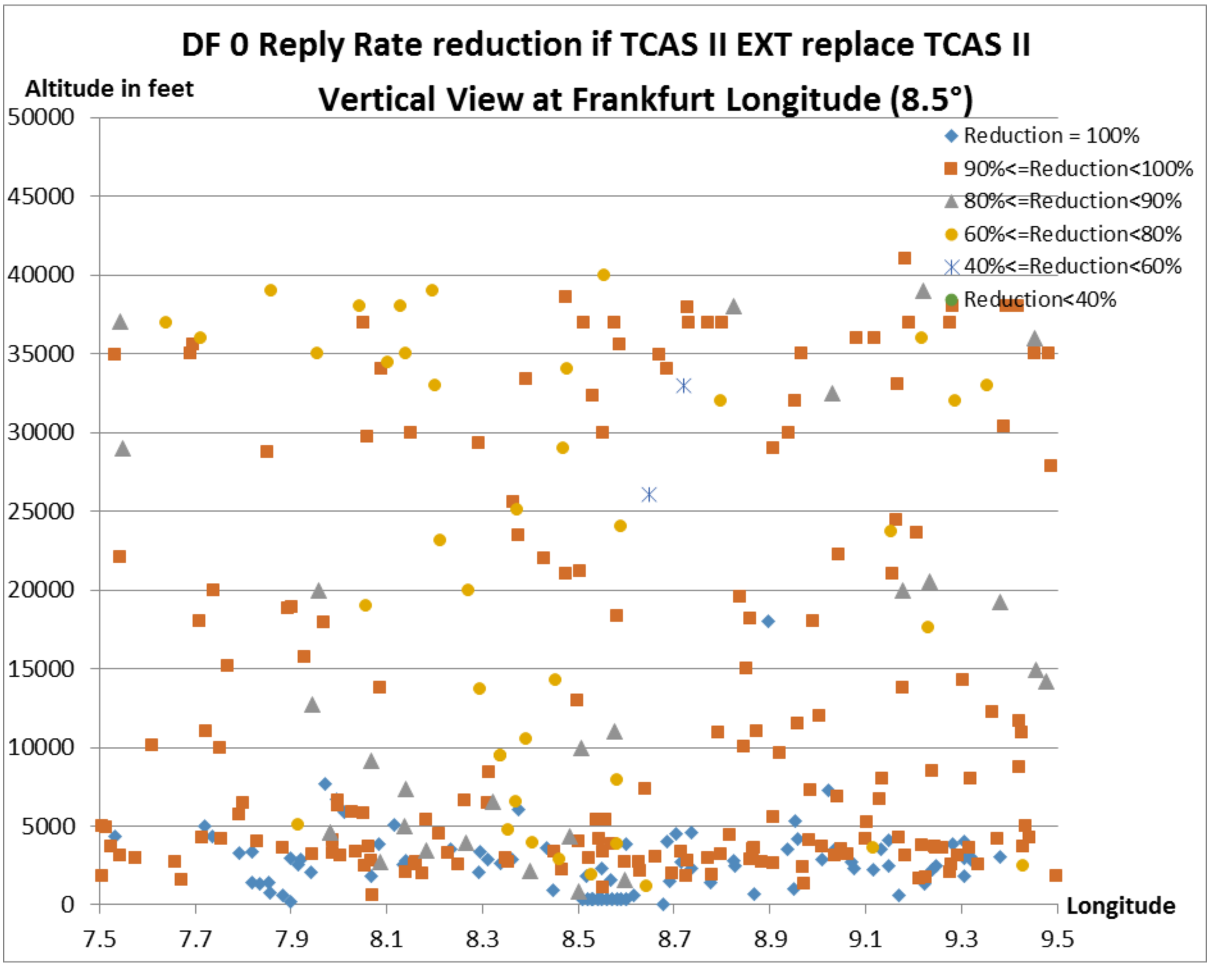

Figure 30: DF 0 Reply Rate Reduction around Frankfurt (Vertical View)

6.3.3.2.4 Unexpected Behaviours/Results

N/A

6.3.3.3 Confidence in Results of Validation Exercise

6.3.3.3.1 Quality of Validation Exercise Results

The results of Exercise #822 were obtained by EUROCONTROL experts using the EUROCONTROL RF Model which supports TCAS II interrogations, as specified in the “Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II)”, thus the project team is confident in the accuracy of the results obtained.

6.3.3.3.2 Significance of Validation Exercise Results

A snapshot of the air traffic in the core European airspace detected by Mode S radar (in Asterix Category 48 format) on the 17 September 2014 at UTC 14h 33mn 20sec was used to validate the EUROCONTROL RF Model and to generate the Aircraft Scenarios that has been used to evaluate the overall impact of TCAS II EXT on 1090 MHz RF load. There were 1279 aircraft in the air traffic snapshot. For both scenarios, 20 aircraft have been added on the ground at Frankfurt airport. In total, there were 1299 aircraft.

The simulations results obtained are considered to be statistically significant and operationally realistic.

6.3.4 Conclusions and Recommendations

6.3.4.1 Conclusions

The objective of the exercise was to evaluate the overall impact of TCAS II Extended Hybrid Surveillance (EXT) on RF load of 1090 MHz in core European airspace.

Simulations performed with the EUROCONTROL RF Model on typical aircraft traffic sample showed that the reduction of DF 0 reply rate could reach up to 89 % if:

- TCAS II is replaced by TCAS II EXT for all TCAS II equipped aircraft
- All Mode S aircraft are emitting extended squitter (ADS-B level 2)

This value (89 %) has been simulated at two different places (close to Frankfurt airport and above Belgium (between Frankfurt and London). This value is very close to the overall result (87.2 %) where aircraft on the border are less impacted by TCAS as there are less aircraft around.

The benefit to replace TCAS II by TCAS II EXT would be for all Mode S aircraft. However this reduction may be more important for aircraft flying at low altitude than for aircraft flying at high altitude. The benefit will appear only if aircraft are equipped with ADS-B level 2. There is no point to replace TCAS II by TCAS II EXT if aircraft are not equipped with ADS-B level 2.

It seems that the points with highest TCAS II transmissions (DF 0) would remain around big airports with TCAS II EXT, as it is currently the case for TCAS II.

6.3.4.2 Recommendations

The recommendations after completed Exercise #822 regarding future work are to

- Perform more flight test(s) through a core European airspace;
- Perform more testing session on the surface of a busy airport
- The implementation of extended hybrid surveillance capability is recommended to be taken into account by authorities when formulating the RF load reduction strategy.

7 References

7.1 Applicable Documents

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

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

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

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

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

7.2 Reference Documents

The following documents provide input/guidance/further information/other:

[6] **SESAR 9.47 D10:** Performance objectives and functional requirements for the use of improved hybrid surveillance in European environment, November 2012

[7] **SESAR 9.47 D12**: Validation Plan (Improved Hybrid Surveillance), May 2013

[8] **SESAR 9.47 D13:** Report on Improved Hybrid Surveillance validation – issue 1, March 2015

[9] **EUROCAE ED-143/RTCA DO-185B**: TCAS II MOPS (TCAS II version 7.1), published in 2008

[10] **EUROCAE ED-221/RTCA DO-300A**: MINIMUM OPERATIONAL PERFORMANCE STANDARDS (MOPS) FOR TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM II (TCAS II) HYBRID SURVEILLANCE

[11] FAA TCAS Surveillance update presentation to EUROCAE WG75 4/5 September 2012

[12] SESAR Safety Reference Material
https://extranet.sesarju.eu/Programme%20Library/Forms/Procedures%20and%20Guidelines.aspx

Appendix A KPA Templates

Not Applicable

Appendix B Additional Improved Hybrid Surveillance Flight Tests

The flight tests performed in EXE-09.47-VP-821 of this report were performed on availability basis. At the time when the 1st issue of this document [8] was delivered, all recorded data available were collected in the vicinity of the Toulouse airport at altitudes below 15 000 ft. The objective was however to perform flight tests also in high altitudes and core European airspaces. This appendix, which was not present in the first issue of this report, provides results of additional flight tests that were conducted since VALR – 1st issue [8] delivery.

The structure of this appendix is similar to that of Chapters 6.1 and 6.2, but common information (e.g. Exercise Preparation) is omitted.

A

B

B.1 Conduct of Additional Flight Tests

B.1.1 Flight Tests Execution

The flight tests number 9 and 10 were performed by Airbus in Toulouse area, however, the altitude (in substantial part of these two flights) exceeded 18 000 ft[10].

The remaining flight tests were conducted by Honeywell at various places in Europe:

- 11 – Ground recording at Birmingham airport in United Kingdom.
- 12 – From Birmingham across Norway and Sweden to Helsinki (Finland).
- 13 – From Helsinki across Finland and Norway to Island.
- 14 – From Island across Ireland to João Paulo II Airport (Açores, Portugal).

No.	Date	Duration on ground	Duration in the air	Duration total	Time spent above 18 000 ft
9	22 April 2015	0 s	1724 s --- 00:28:44	1724 s --- 00:28:44	00:26:25
10	23 April 2015	639 s --- 00:10:39	8475 s --- 02:21:15	9114 s --- 02:31:54	01:29:15
11	28 September 2015	4988 s --- 01:23:08	0	4988 s --- 01:23:08	0
12	3 October 2015	680 s --- 00:11:21	9405 s --- 02:36:45	10085 s --- 02:48:05	01:57:57
13	5 October 2015	1549s --- 00:25:50	3918 s --- 01:05:18	5467 s --- 01:31:07	00:53:16
14	6 October 2015	7528 s ---	13291 s ---	20820 s ---	02:48:30

[10] In DO-185B, some requirements are set differently for aircraft above this altitude.

No.	Date	Duration on ground	Duration in the air	Duration total	Time spent above 18 000 ft
		02:05:28	03:41:31	05:47:00	
Total		**15386 '04:16:26'**	**36813 '10:13:33'**	**52199 '14:29:59'**	**07:35:23**

Table 28: Additional flight tests overview.

B.1.2 Exercise results

In this section an update of the original benefit analysis is provided. While in the first issue the focus was on surveillance methods used for tracking aircraft, this extended analysis concentrates on global communication load estimations. Unlike in the first (analytical) approach, the newly presented results consider:

- Interrogations and replies generated outside of the established track periods: This includes acquisition attempts (including unsuccessful ones) and dormancy interrogations.
- Separate estimations of 1030 MHz load (interrogations, UF = 0) and 1090 MHz load (interrogation replies, DF = 0). While a successful interrogation reply certainly impacts both 1030 and 1090 MHz links, an unsuccessful interrogation attempt is guaranteed to impact 1030 MHz link only. Its impact on 1090 MHz is not guaranteed: if a reply is not received, there are two possibilities:
    - The reply was not even sent (only 1030 MHz link was used).
    - The reply was sent, but was not received and decoded correctly (both 1030 MHz and 1090 MHz links were used).

  Therefore, focusing on all interrogation attempts is needed to a reliably measure 1030 MHz load.

  To obtain a reasonable estimation of 1090 MHz usage, the benefit analysis has to be performed twice: once for all replies, and once for successful replies only. These two results than provide boundaries for a realistic estimation of 1090 MHz benefit.

B.1.2.1 Approach description

TCAS communication on Mode S link consists of interrogations (UF=0, 1030 MHz) and replies (DF=0, 1090 MHz).

The approach, which is common for both 1030 MHz and 1090 MHz load estimations, is as follows:

- The traffic sample is divided into the following groups:
    - Sample A: Mode S equipped traffic (without ADS-B Out) that is tracked by TCAS, including track acquisition attempts (successful and unsuccessful). This is the traffic that is tracked according to DO-185B and without any benefit brought by DO-300A.
    - Sample B: ADS-B Out equipped traffic that is tracked by TCAS, including track acquisition attempts (successful and unsuccessful). This is the traffic that can be tracked using the new DO-300A surveillance methods (EXT and HYB).

- All other traffic (i.e. aircraft without Mode S or not relevant for TCAS tracking) is excluded from the analysis.

- The objective is to compare communication load of sample A and sample B. Due to availability of large and representative data, such a comparison is considered more accurate than the original one from Exercise #821 of this report, especially due to inclusion of all types of interrogations and replies (as described above). Average communication load per target can thus be estimated for sample A and B and compared. The difference shows clear benefits introduced by DO-300A with respect to DO-185B.

B.1.2.2 Estimation of 1030 MHz load savings

Figure 31 provides the results obtained using the analysis described above. For each flight test, the average number of interrogations (of all types) per aircraft derived from sample A is denoted by a blue bar. The average number derived from sample B is denoted by a red bar. Green bars show the percentage of savings.

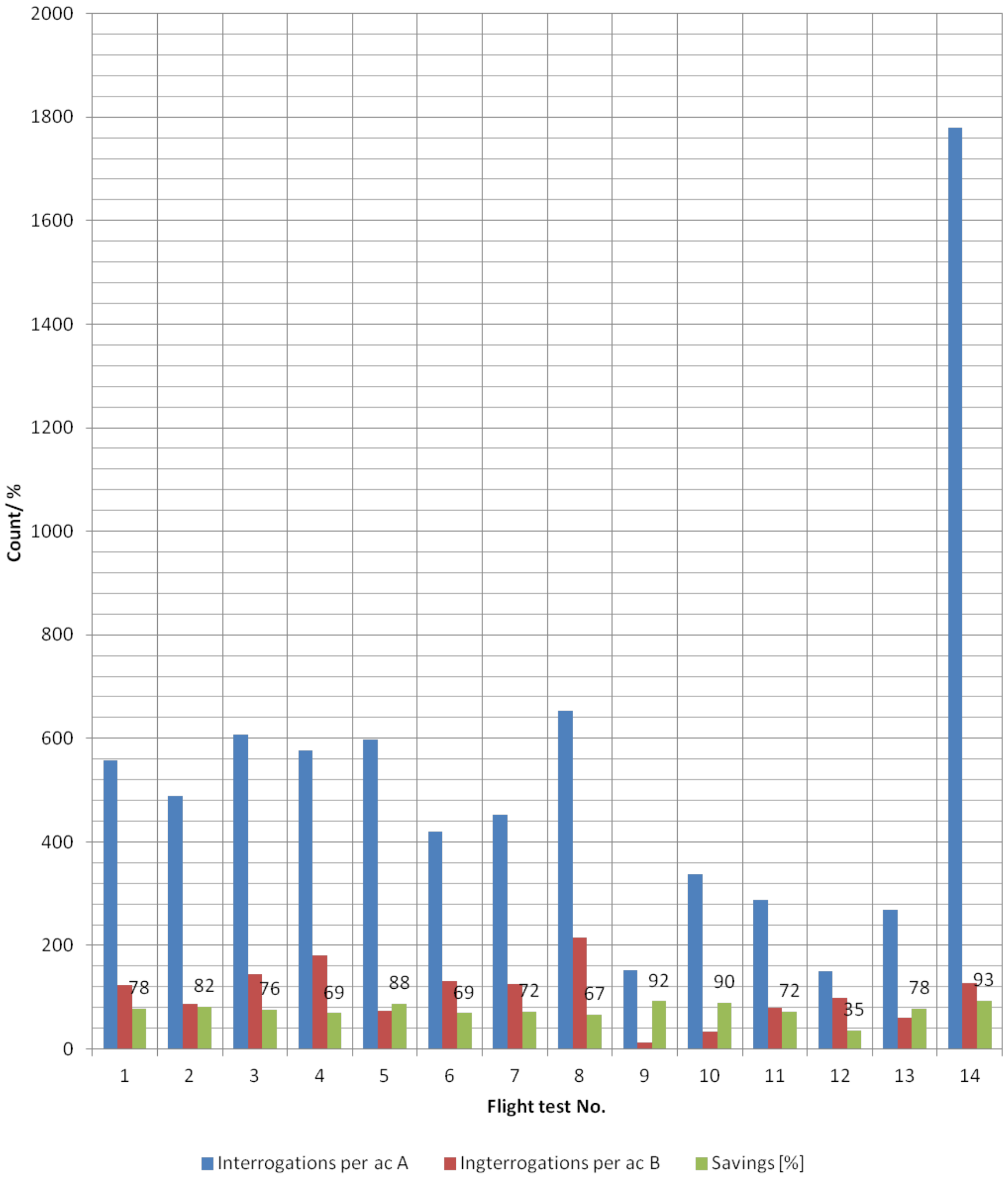

Figure 31: Average number of all interrogations per aircraft for samples A and B and the savings (labelled).

The result based on all available data (i.e. all 14 flight tests) is 82 % of savings.

B.1.2.3 Estimation of 1090 MHz load savings

Figure 32 provides comparison similarly to Figure 31, but in this case only successfully received and decoded interrogation replies are analysed. It can be observed that the portion of successful replies is relatively small. However, the overall saving estimation is surprisingly close to that of 1030 MHz savings.

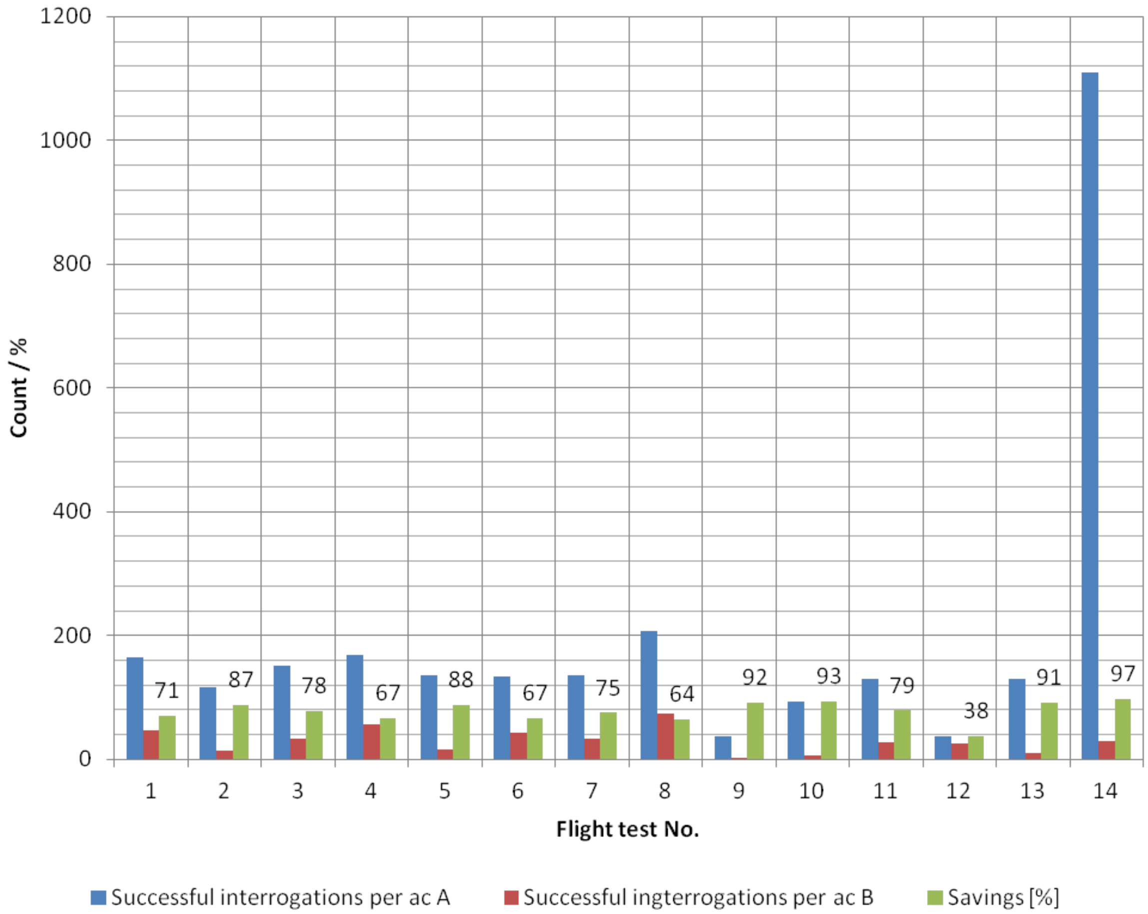

Figure 32: Average number of successful replies per aircraft for samples A and B and the savings (labelled).

The result based on all available data (i.e. all 14 flight tests) is 84 % of savings.

Remark: The sample size of A and B is equal for 1030 MHz and 1090 MHz estimation, even though there are intruders from which no successful interrogation reply is received. It is not possible to exclude an intruder from the sample due to having no successful reply from it as long as the target is tracked (or there are acquisition attempts to start tracking): if we did so, we would exclude also targets that are tracked passively all the time (and which are not interrogated at all), i.e. targets that bring most benefits.

B.2 Discussion

The main objective of this study was to estimate benefits brought by DO-300A to 1090 MHz load. The results were elaborated for all interrogations and for successful interrogations/replies separately. The 1030 MHz usage is impacted by all interrogations and the estimated savings for 1030 MHz load are approximately 82 %. Considering only successful interrogations, which impact both 1030 MHz and 1090 MHz load, the result estimation is 84 %. These two values are relatively close to each other, which supports our previous assumption that the ratio between successful and unsuccessful interrogations is equal for TCAS complying with DO-185B and DO-300A. It can be estimated that the savings of 1090 MHz load is approximately 83 %. This value is higher than that of preliminary benefit analysis conducted in Exercise #821 of this report. However, it is not a surprising result since the original estimation was considered conservative as it did not take into account several factors which are already included in this updated methodology.

It can be observed that the savings vary from 35 % up to 97 % with smaller savings obtained when the original communication demand was not high. On the other hand, the biggest savings (flight test 14) are obtained in cases that are extremely demanding when only DO-185B surveillance methods are used.

-END OF DOCUMENT-