Technical report, composite cooperative surveillance studies

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Abstract

The present document describes the first set of specifications for the Composite Cooperative Surveillance System. The specifications address the functional ADS-B and WAM Ground Surveillance Domain without addressing any physical implementation. It includes the following key information: Scope and context of the Composite Cooperative Surveillance System, Generic requirements for Composite Cooperative Surveillance System and Specific requirements for the different systems under analysis in the project. The document serves as input to the subsequent project tasks, which will further elaborate detailed specifications for the Composite Cooperative Surveillance System. It will be revisited as appropriate in the course of the project work on Task 006.

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Executive summary

The present document describes the first set of specifications for the Composite Cooperative Surveillance System. This is the first set of requirements and they have been derived from the available related standards, ED-142 (ref.[4]) and ED-129A (ref. [5]), guidance material for the use of composite WAM – ADS-B data [6], ESAV published material [3] and specific implementation needs for the NATS studies. The specifications address the functional ADS-B Ground Surveillance Domain without addressing any physical implementation.

It includes the following key information:

- Scope and context of the Composite Cooperative Surveillance System,
- Generic requirements for Composite Cooperative Surveillance System.
- Particular requirements for each of the systems under analysis in the project.

The project will study the benefit of the so-called Composite Cooperative Surveillance Systems, which will use data coming from validated ADS-B targets to complement the information of the WAM dataflow. ADS-B targets will be validated using different methods developed in 15.4.5 projects i.e. WAM validation, TDOA validation or Range validation (ref.[11] [12] [13]). In addition, the project will evaluate the benefit of this systems working in different configurations and compare the results obtained in standard (active) and passive WAM configurations operating in similar conditions. The configuration and functionalities to be tested at high level are:

- Compliance with GEN-SUR
- Compliance with the future EUROCAE standard for Composite WAM-ADS-B systems
- Passive acquisition
- Ranging assessments with comparison to passive WAM
- DAP extraction assessments
- ADD comparison and population assessment
- Performance assessment for 5NM, 3NM, 2.5NM and 2NM separation
- User acceptance trials,
- MST integration.
- Identifying ADS-B candidate spoof alerts.
- Study the reduction of RF usage due to the use of composite WAM – ADS-B data.

In this document high level requirements are defined for the INDRA-DFS and for the NATS systems. This requirements will be revisited as appropriate on 15.04.02 Task 006-D08 (ref. [9]), allocating requirements to each of the system components.

1 Introduction

1.1 Purpose of the document

This document describes the high-level requirements for the Composite Cooperative Surveillance System developed and tested inside the project.

1.2 Intended readership

The audience of this document includes

- Project 15.04.02 Integrated Surveillance sensor technologies project members
- Project 15.01.06 Spectrum Management & Impact Assessment members
- Project 15.04.06 Improved 1090MHz ADS-B Ground station capacity and security project members
- Project 15.01.07 CNS System of System definition and roadmap project members
- Projects 15.04.05 a & b Surveillance ground system enhancements for ADS-B
- Standardization bodies (EUROCAE, RTCA)…
- ANSPs

1.3 Inputs from other projects & EUROCAE activities

The following on-going and past activities have contributed to establishing the high level requirements for the Composite Cooperative Surveillance System:

- EUROCONTROL CASCADE Program.
- EUROCAE WG51-SG4. This WG is developing guidance about the use of WAM and ADS-B systems to provide composite surveillance. The work of this WG, initially expected as a new EUROCAE specification and finally to be included as annex to the existing ones [4] and [5] is taken as a direct input for the project, with attention to the functional requirements. At the moment this document was written, the new EUROCAE specifications ED-129B and ED-142A were not published yet. The working paper ADS-B / WAM "Composite" Provisions for Inclusion within ED-129B & ED-142A is anyway an input for this document as well.
- Projects 15.4.5.A and 15.4.5.B. Methods for ADS-B data validation have been defined and tested in 15.4.5 projects (ref.[11] [12] [13]). Some of these methods directly related to WAM systems will be implemented in the composite cooperative surveillance system.
- These inputs are cognisant of the validation activities undertaken by NATS in the CRISTAL RAD HD project as funded through the EUROCONTROL CASCADE programme.

1.4 Requirements Definitions – General Guidance

Requirements have been developed according to the SESAR Requirements and V&V Guidelines [1].

They are broken down according to the source of the requirements and or to the platform in which they will be tested.

The layout follows the description in [2]

In accordance with the guidelines in [2], requirement identifiers follow the scheme:

REQ-15.04.02-D06-00xx.yyyy, where:

xx	Meaning
10	General requirements (GEN-SUR – EUROCAE)
20	NATS CRSTL requirement
30	INDRA DFS requirement

Table 1: Requirement Identifier Allocation

As agreed during the technical kick of meeting of this project, this document has been created using the generic project deliverable template. Inside the task the team followed as much as possible the requirement structure defined for the TS template. However with this kind of template, toolbox does not work with complete functionalities and the Requirement definition is not exactly the same as in a Technical Specification. Traceability of requisites will be included in this specification to ensure that each requirement is covered at least by one of the developed systems.

1.5 Glossary of terms

A common understanding of the definitions of the following terms as applied in the context of this document is considered necessary:

- WAM system: Wide Area Multilateration System.
- Multilateration System: One method of locating an aircraft using the transponder signal is multilateration. In this technique, the transponder signal from the aircraft is received at multiple receivers at known locations. The signal arrives at the receivers at different times due to the different separation distances from the target. The TDOA can be calculated in a number of different ways, including cross-correlation of captured waveforms and differences between absolute Time of Arrival (TOA) measurements, and forms the basis of the multilateration technique. (Note that in Multilateration System which uses active Interrogation, this so-called 'time-hyperbolic method' can also be augmented by other techniques).

  A *Multilateration System* is any group of equipment configured to provide position and identification derived from target-transmitted signals using Time Difference of Arrival (*TDOA*) techniques.
- ADS-B: Automatic Dependent Surveillance – Broadcast (ADS-B) is a means by which aircraft, aerodrome vehicles and other objects automatically transmit and/or receive identification, position, velocity and additional data in a broadcast mode via a data link
- Composite Surveillance System: A Composite Surveillance system is also, more correctly, known as a Composite (ADS-B and WAM) Surveillance System.
- Composite (ADS-B and WAM) Surveillance System: A surveillance system which exploits the synergies between two similar but different surveillance techniques – ADS-B and WAM. In

their standalone form they are both distributed cooperative surveillance systems. The term composite is used to signify that various system components, physical and logical, are shared. Shared information from WAM and ADS-B processing is used to supplement the basic levels of performance that are to be achieved by each system in their standalone mode in particular with respect to reducing WAM active interrogation rates, providing additional confidence information on ADS-B horizontal position information (including spoofing) and enhancing overall data continuity performance. For the aim of this project, the Composite Surveillance system is composed by a Composite Surveillance Sensor and a Multi sensor Tracker.

- Composite Surveillance Sensor: Surveillance elements that provide ADS-B, WAM and composite data flows.
- Multi Sensor Tracker: Central fusion node for the processing of the surveillance data.
- Ranging: Technique used in multilateration systems to determine the distance of a target to one or more transmitting elements.
- Partial position: In the scope of this document is defined as the points of the space for which their distance difference (and consequently the time difference of arrival (TDOA)) to two receivers is lower than a fixed value. This defines a number of hyperbolas on which the position is contained. Predicted Position: A position obtained from an extrapolation process when operating in periodic mode such that output data generated on each output period is applicable at the time of output. Two types are considered:
  - Smoothed Periodic Predicted Mode based on previous position detections of several output periods.
  - Consolidated Periodic Predicted Mode is based on previous position detections within the most recent output period.
- Pre-tracked Data: Data derived from a ‘measurement’ or a plot derived directly from ‘measured’ data i.e. not tracked, smoothed or predicted output at a periodic rate or data driven time-stamped with the time of applicability of the ‘measurement’.
- Tracked data: Pre-tracked data that has had a supplementary tracking processing stage applied to it to obtain a predicted position.

1.6 Acronyms and Terminology

Term	Definition
ADD	Aircraft Derived Data
ADS-B	Automatic Dependent Surveillance - Broadcast
AG	Air-Ground
ANSP	Air Navigation Service Provider

ARTAS	ATM suRveillance Tracker And Server
ATC	Air Traffic Control
ATM	Air Traffic Management
CASCADE	Co-operative ATS through Surveillance and Communication Applications Deployed in ECAC
CAT	Category
CMS	Control and Monitoring System (includes Remote Control and Monitoring)
CPS	Centralized Processor System
CRISTAL	Co-operative Validation of Surveillance Techniques and Applications of Package I
DAP	Downlinked Aircraft Parameter
GEN SUR SPR	Generic Surveillance Safety and Performance Requirements
ICAO	International Civil Aviation Organisation
MLAT	Multi-lateration
MRT	Multi-Radar Tracker
MSDF	Multi-Sensor Data Fusion
MSPSR	Mutli-Static Primary Surveillance Radar
MST	Multi-Sensor Tracker
MTBCF	Mean Time Between Critical Failure
MTTR	Mean Time To Repair

NM	Nautical Mile (1852 metres)
NSA	National Supervisory Authority
PD	Probability of Detection
PSR	Primary Surveillance Radar
RF	Radio Frequency
RRRS	Radar Record and Replay System
Rx	Receiver
SESAR	Single European Sky ATM Research Programme
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
SSR	Secondary Surveillance Radar
TDOA	Time Difference of Arrival
TMA	Terminal Manoeuvring Area
TS	Technical Specification
Tx	Transmitter
TXU	Transmitting Unit
WAM	Wide Area Multilateration

WGS84	World Geodetic System 84

2 Composite WAM ADS-B System description

Air traffic surveillance systems use both cooperative and non-cooperative techniques to locate aircraft. While non-cooperative techniques rely on the reflection of energy directed at the aircraft, cooperative techniques require the carriage of a transponder or transmitter device on board the aircraft. Systems using the signals broadcast from such transponders / transmitters are classified as a dependant technology, as the ground surveillance systems derive all surveillance information from the decoded message content to determine aircraft identity and 3D position.

The table below summarises the categories that the various existing and new ground-based air traffic Surveillance sensors fall into:

<table>
<tr><td colspan="2"></td><td>Air traffic surveillance sensor</td></tr>
<tr><td colspan="2">Independent
Non cooperative</td><td>Primary Surveillance Radar (PSR)
Multi-Static Primary Surveillance Radar (MSPSR) (Under development)</td></tr>
<tr><td rowspan="2">Cooperative</td><td>Independent</td><td>Secondary Surveillance Radar (SSR) (Mode A/C and Mode S)
Wide Area Multilateration (WAM) system
MultiLATeration (MLAT) system</td></tr>
<tr><td>Dependent</td><td>Automatic Dependent Surveillance Broadcast (ADS-B)</td></tr>
</table>

Figure 1: Categories of air traffic surveillance sensors

It is clear that this classification scheme applies only for the horizontal position. The barometric altitude is always cooperative dependent. Also the range measurement for Mode-A/C/S radars depends on the pre-knowledge of the transponder delay between receiving an interrogation and transmitting the answer. A WAM system working in a passive mode does not rely on the knowledge of this transponder delay, where an active WAM system clearly relies on this knowledge.

Within a Cooperative Independent Surveillance System signals are broadcast from the transponders / transmitter devices of a cooperative aircraft as a result of a trigger interrogation or in support of ACAS or automatically in ADS-B. The ground surveillance system both decodes message content and uses measured parameters to determine aircraft identity and horizontal position, the horizontal position measurement process is 'independent' of aircraft derived information.

SSR, ADS-B (Automatic Dependent Surveillance – Broadcast) and WAM (Wide Area Multilateration) systems are 'Cooperative Surveillance Systems', as they are reliant on signals broadcast from aircraft transmitters/transponders.

A Composite ADS-B and WAM Surveillance System is a surveillance system that exploits the similarities between the two surveillance techniques and combines them into a single system. The term composite is used to signify that various system components and data items are shared whilst ensuring that the required degree of channel autonomy/independence is retained.

2.1 Benefits offered by Composite (ADS-B and WAM) Surveillance

A Composite ADS-B and WAM Surveillance System is a surveillance system which is designed to exploit the synergies between two similar but different surveillance techniques – ADS-B and WAM.

In addition to cost savings, achieved through the co-mounting of system components into a single unit and the associated savings in terms of site costs, communications and efficient utilization of certain common components, the exploitation of synergies between the two surveillance techniques also supports a number of performance enhancements. These include:

- Use of ADS-B message information (excluding position) in the WAM system to support a reduction in the 1030 and 1090 MHz usage by the WAM components:
    - The use of ADS-B data to support passive acquisition of an aircraft reduces the 1030/1090 MHz footprint of a WAM surveillance system.
    - The commonality between aircraft derived parameters[1] that are available within an aircraft's ADS-B and Mode S transmission supports a reduction in the number of 1030 MHz interrogations made by the WAM surveillance channel.
    - Through the techniques described in the two bullet points above the performance of the WAM Surveillance Channel is enhanced from a 1030 MHz RF perspective. Of significant importance is the fact that overall ATM system performance is improved through reduced transponder occupancy and the consequent benefits this brings.
- The availability of 'raw' RF and timing data within the Composite Surveillance System provides information that is not available in other components of a surveillance infrastructure or in standard ADS-B receivers. The information can be used to derive additional indicators:
    - Ground based 'confidence/credibility' measure of the positional information contained within an aircraft's ADS-B messages based upon the timing data present in the system and derived through an analysis of the time at which ADS-B signals were received at 2 or more time synchronized receivers. Whilst this could be of particular interest during the transition to an ADS-B operational environment it also offers the potential of providing longer term benefits such as the early identification of anomalous avionic behavior.
    - The credibility assessment can also provide a means to identify spoofed 'ADS-B transmissions' that have been maliciously introduced into the RF environment. This can be based upon the mechanism described above although the reception of an ADS-B signal at only 1 receiver when line of sight was expected from multiple sites can also provide a credibility indication.
    - The availability of additional data within the system can also be used to support optional means to provide additional security mitigation techniques in a cost effective manner - although these are currently considered as beyond the scope of this technical specification.
- A comparison of ADS-B and WAM data can be used to:
    - Support the initial tuning and commissioning of the WAM system.

[1] For consistency the term Aircraft Derived Data (ADD) is used within this document. This embraces the ADD broadcast within an ADS-B configuration and also the Downlinked Aircraft Parameters (DAPs) – a term used to denote the information extracted from BDS registers through Mode S Enhanced Surveillance (EHS)

o Monitoring: by improving (long term) performance monitoring and alerting of faults in the WAM system. This includes supplementing the WAM channels BITE by using the comparison between the ADS-B position and WAM channel data (particularly concerning expected antenna coverage and time difference of arrival) to alert in the event of timing drift or component failure. For example, if a discrepancy is only apparent in part of the WAM coverage, then it is likely that it is due to a WAM failure condition.

- To improve the performance of the ADS-B channel:

  o By enabling the allowance of temporary (i.e. short- to medium-duration) reductions in ADS-B quality indicator values, in particular regarding the measurement integrity NIC bound. These temporary reductions would be mitigated by the establishment of an ADS / WAM cross-integrity containment bound that can be associated with the ADS-B data. It is to be noted that a failure in the ADS-B / WAM cross-integrity comparison indication does not take precedence over the ADS-B measurement integrity information (as it might be the WAM channel that is in failure);

  o by resolving ADS-B data-to-track association issues related to non-unique 24-bit addresses;

  o by calculating the (mean) ADS-B uncompensated latency that is induced on-board on the ADS-B horizontal position, i.e. in order to reduce the effects on the resulting along-track horizontal position error;

- Safety: by identifying incorrect ADS-B measurement integrity indications (i.e. under failed ADS-B / WAM comparison conditions);

Editorial Note: applicability to be discussed.

- Security: by identifying spoofed ADS-B targets;

- Monitoring: by supporting the detection of ADS-B avionics anomalies, likely to be indicated by ADS-B / WAM comparison failure conditions sustained over a longer period.

- To keep the electromagnetic interferences as low as possible and to limit the transponder occupancy caused by a WAM system, the WAM part of the composite system may only be used for verification purposes for the position as well as secondary attributes. For the secondary attributes, especially the barometric altitude which is of much more criticality than e.g. the callsign-in-flight, can be confirmed in a similar manner as if a rotating sensor would be present. For a single transceiver unit it is not possible to confirm the complete horizontal position, but proper ranging can be conducted. Even low interrogation rates as one interrogation per minute or two appear to be sufficient for this validation purpose. In this almost passive configuration the performance is achieved by ADS-B, the WAM system has a validation task to fulfill.

It is important to note that the 2D position measurement undertaken within and output by the Wide Area Multilateration element of a Composite Surveillance System remains independent of the 2D positional information contained in the ADS-B message broadcast from the aircraft.

2.2 Basic Assumptions

The design of the Composite ADS-B and WAM Surveillance System was developed in accordance with the following:

- It is assumed that the two channels of data output from the Composite Surveillance System (an ADS-B data stream and a WAM data stream) are passed to the ATM infrastructure for subsequent processing – such as a multi-sensor tracker.

- o Thus, a design objective for the Composite Surveillance System is not to repeat functionality that can be assumed to be conducted in subsequent processing stages.
- o Performance achieved by a Composite Surveillance System is to be assessed on the basis of system performance i.e. with consideration of both surveillance channels.

• Each surveillance channel, the ADS-B channel and the WAM channel, are to achieve the required level of performance in their standalone mode without recourse to data sharing. From ADS-B point of view, the performance as standalone is defined in ED129A [5], on the other hand, from WAM point of view is defined in ED142 [4].

- o Composite processing enhances basic performance rather than being necessary to achieve the required level of performance.
- o Positional information of the ADS-B and WAM channels in the sensor is not altered by the composite processing.

• ADS-B surveillance channel data is supplemented with additional indicators included in the ASTERIX category 021 [7] .

• For all the analysis performed in this project 100% of aircraft to be analyzed are appropriately equipped with a minimum of SSR transponder through to also ED-102 or ED-102A ADS-B and that non equipped aircraft (or aircraft experiencing avionic failure/transponder anomalies) are not included in the analysis.

- The objective of the “Composite” ADS-B / WAM provisions is not to extend the coverage of the WAM system. i.e. by allowing ADS-B data to be used as an in-fill to a missing WAM sensor or to improve the continuity of a WAM track by filling in with ADS-B horizontal position data.
- In order to ensure co-channel independence, WAM horizontal position measurements must not be affected by possible errors in the ADS-B horizontal position information. Therefore, the latter (as well as ADS-B Geometric Altitude information) is not to be used for establishing WAM horizontal position fixes, nor are co-channel horizontal position data to be fused at “SUR Sensor” level.

2.3 Surveillance Coverage Volumes

Within the coverage of a Composite ADS-B and WAM surveillance system, several volumes can be identified:

• Volume 1: A core volume of airspace where there is both ADS-B and WAM coverage and WAM is accepted to meet the requirements to be used to support separation minima. This volume includes also interrogation coverage.

• Volume 2: Outside the proven WAM coverage there is an area where WAM does not meet the requirements for supporting the separation minima by itself; however the WAM system can still perform TDOA measurements (i.e. this volume is covered by at least two receiver units) and track data can continue to be output to provide situational awareness to controllers. This volume may be located outside the core volume or could be gaps of coverage surrounded by it.

• Volume 3: Rest of the coverage, potentially outer but also lower limits of coverage. It is covered by ADS-B only.

In the core volume (Volume 1) WAM and ADS-B can provide independent surveillance ‘layers’. WAM can benefit from ADS-B data to reduce interrogation rate.

In the inter-mediate volumes, (Volume 2) ADS-B may benefit from ADS-B validation methods, such as TDOA measurements or range validation (providing independent integrity measurements and detection of 'spoofing').

Rest of coverage (Volume 3) could be used for early track initiation, in the composite system with respect to WAM. In this volume, ADS-B validated information could be used when no WAM information is available.

2.4 System Configuration and Component Parts

In simplistic terms the Composite Surveillance system is a distributed network of time synchronized ground-based 1090 MHz receivers passing data to a Centralised Processor System (CPS). The CPS processes and consolidates the data received and outputs surveillance data for integration within subsequent surveillance data processing systems of the ANSPs ATM infrastructure or for integration within a local display suite.

As for both ADS-B and WAM deployments the number of 1090 MHz receivers and the locations chosen for the network of the ground based components influences the system performance – particularly the provision of surveillance coverage at lower altitudes.

Composite ADS-B and WAM surveillance systems typically consist of the following main ground components (see Figure 1-2):

- Ground Station Components – deployed in a distributed nature. (A suite of 1090 MHz receivers plus, optionally, 1030 MHz transmitter(s))

- Central Processor System - configurable to include those components required to support optional functionality e.g. active 1030 MHz interrogations, output to a legacy display etc. Some association functions can be performed inside the Central Processor System in the Composite surveillance sensor. This functionality will be executed in the CPS and will be performed with position calculation and association of information objectives. Pre-ASTERIX association is performed in the CPS. The tracking function inside the surveillance sensor different than the one used in the tracker.

- MSDF Tracker: Element to perform post ASTERIX tracking. This component is not included in the Composite WAM – ADS-B sensor.

- Control and Monitoring System: The CMS elements of the system perform the specified control and monitoring system functions of the system.

- Network connections: Communication links between the distributed component parts of the Composite Surveillance System and its CPS.

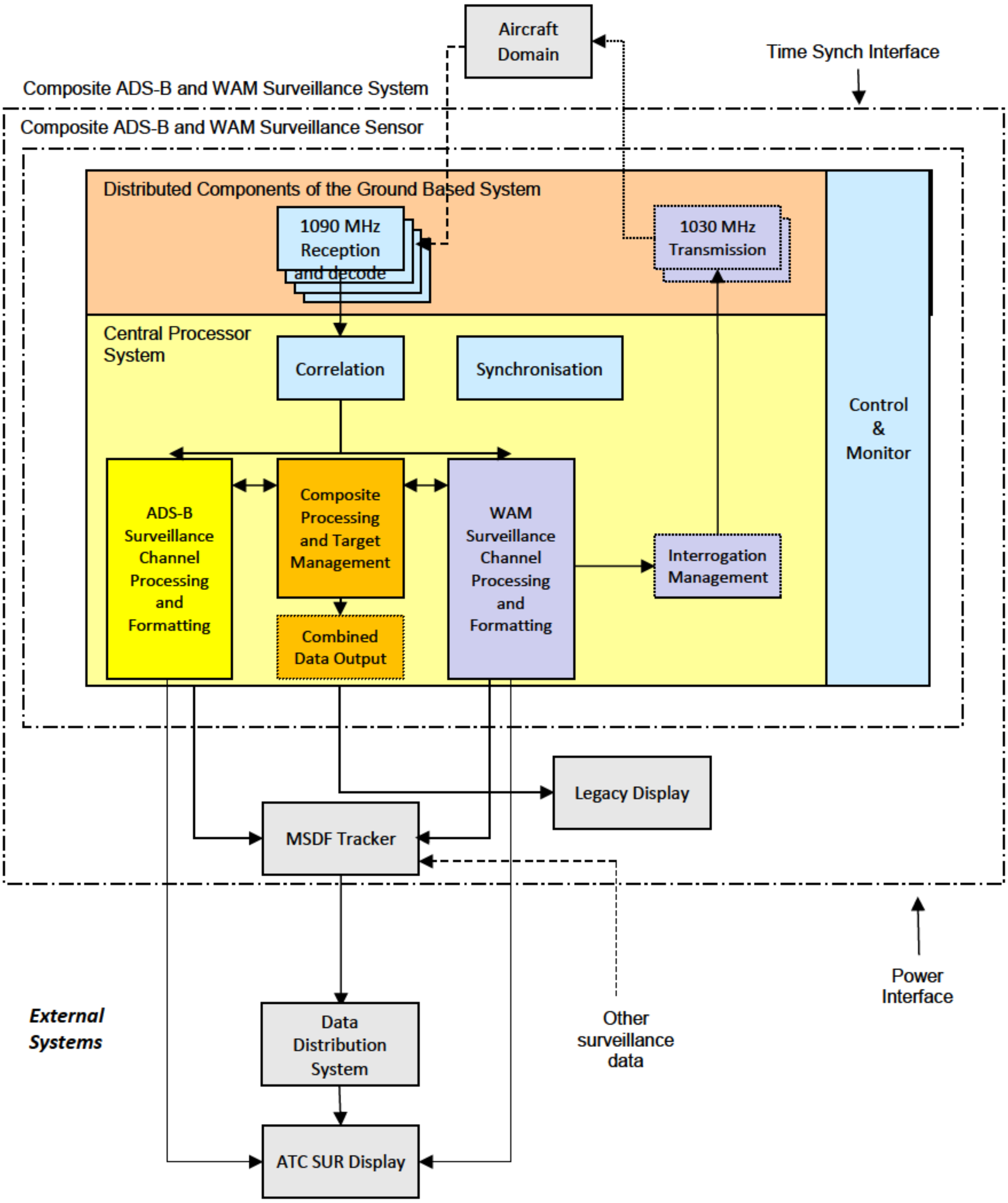

Figure 2: Functional description of a generic composite WAM – ADS-B Surveillance system

The above figure represents a diagram which aims to focus on the ADS-B, WAM and MSDF Tracker data that reaches the Air Traffic Controller Surveillance Display.

Legend to the above figure:

- Units contained within dotted cells are optional components

- Units shaded in grey are external systems outside the scope of a composite WAM – ADS-B Surveillance System.

2.4.1 Functionality of the Distributed Component Parts of the System

The signal acquisition side of the Composite Surveillance system is a network of 1090 MHz receivers/remote processors.

Whilst the ground based ADS-B element of a Composite Surveillance System is purely passive it may be necessary to include an active 1030 MHz transmitter(s) to achieve the required level of performance of the WAM elements. An interrogator might be used to confirm ADS-B data like barometric height, to excite transponders when required or to process a simple cross validation of the range of the ADS-B target.

2.4.1.1 1090 MHz Receiver Units:

To support wide area multilateration techniques a number of receivers are to be deployed in a distributed manner. For a 3D position, four are the theoretical minima, and 3 in the case that the system will rely on barometric height.

Their distribution will influence the 3D volume of airspace within which an ATS Separation Service derived from the WAM system can be provided. ADS-B data to support an ATS Surveillance Service can be provided by one or more receivers. Whilst deploying more ADS-B receivers may increase the PD or the ADS-B coverage volume and hence provide an improved continuity of service in the event of a ground station hardware failure it does introduce additional cost burdens.

Thus whilst it is considered to be most advantageous for common system coverage to have ADS-B and WAM together it may be deemed unnecessary to provide excessive duplication of either ADS-B or WAM remote processing components. Manufacturers may therefore propose a Composite ADS-B and WAM Surveillance System which includes a mixture of types of receiver stations (Composite (ADS-B and WAM) or ADS-B sole or WAM sole).

The distributed nature of the 1090 MHz receivers means that the network may be designed to include spare ground station capacity to ensure that the required system detection performance is achieved even when one or more receivers is off line for maintenance or repair.

The interface between the 1090 MHz receiver units and the Central Processor System is not defined within this technical specification.

The two main tasks of the Receiving Unit are:

- to receive signals from target SSR/Mode-S transponders/ Extended Squitter (ADS-B) transmitters at 1090 MHz, digitize the signals, measure TOA, and transfer the digitized data over a suitable communications data link to the Central Processor System (CPS) and
- To format ADS-B signals for direct transmission to subsequent processing stages.

2.4.1.2 1030 MHz Transmitting Unit(s) (TXU) - OPTIONAL

WAM systems can be deployed in Passive or Active configurations, and in some cases will be used as a combination of both. In the Passive form WAM can rely on the reception of 1090 MHz signals being broadcast from the aircrafts' SSR transponder. This includes ACAS transmissions, Extended Squitter (ADS-B) broadcasts and Mode S /SSR replies originating from other active surveillance sources. In the passive mode of operation certain data items, in particular barometric height, identity and EHS parameters may not be available at sufficient rates to support the required ATS Surveillance Service.

The above limitation can be addressed by using WAM in an Active configuration. In the Active form the WAM systems are configured with 1030 MHz Transmitting Units (Mode S / SSR interrogators).

The main task of the *Transmitting Unit* is to interrogate target SSR/Mode-S transponders, in accordance with the schedule received from the Central Processor System.

2.4.1.3 Central Processor System (CPS)

The CPS is the node within the system where the information from multiple receiving stations is collated for the purposes of determining WAM target position through *TDOA* calculation, and assembling target reports for output from the WAM channel of the composite system. The CPS performs a similar role in consolidating the separate streams of ADS-B data into a single consolidated output from the ADS-B channel of the composite system.

Both the ADS-B and the WAM surveillance channels of a Composite ADS-B and WAM Surveillance System can operate independently. Indeed they are required to achieve the necessary level of performance in a standalone manner without any exchange of data between the two channels[2]. However there are a range of benefits that sharing of data between the two channels can realise.

A key benefit that the sharing of such data can provide is the creation of an additional ground based ‘confidence’ measure of the positional information contained within an aircraft’s ADS-B messages. By comparing the WAM calculated position of an aircraft with the position that the aircraft broadcast via its ADS-B transmission, taking account of the expected accuracies of the WAM and ADS-B positions, it is possible to derive additional ‘confidence’ information for the ADS-B horizontal position. Even when there are as few as two receivers equipped with time stamp capability of the ADS-B messages, it is possible to compare the partial position solution (i.e. hyperbole) with the ADS-B position to achieve some measure of confidence[3]. In the case of active systems, it is possible to compare the partial position solution (i.e. Ellipsoid) with the ADS-B position.

2.4.1.4 Network connections

The communication links between the distributed component parts of the Composite Surveillance System and its CPS may be either dedicated links with fixed transmission delays, or communication infrastructure provided by a 3rd party supplier. The type of network connection used will generally be dictated by the timing method used by the WAM elements of the system, governed by minimum latency requirements to maintain timing synchronisation and consistency between disparate remote units.

2.4.1.5 Control and Monitoring System (CMS)

The CMS elements of the system perform the specified control and monitoring system functions of the system.

[2] However, the use of ADDs to reduce Mode S interrogations and also use of ADS-B data to support passive acquisition are acceptable

[3] It is to be noted that if the ADS-B signal is only received at a single receiver when the declared ADS-B position is in coverage range and visibility of a number of receivers then this could also be taken to indicate a broadcast of a suspicious nature,

The Remote Control and Monitoring Systems may be duplicated to ensure that the required system Mean Time Between Critical Failures is achieved.

2.4.1.6 MSDF Tracker

The PHOENIX MSDF tracker is a multi-target tracker capable of processing various input data reaching from classic rotating radars with a scantime in the range of 5 s to 12 s, MLAT data with typical scantimes from 1 s to 4 s, SMR as well as ADS-B. The tracker is capable to make transitions between these different types of sensors and adapts automatically to the different sensor characteristics.

Furthermore the MSDF tracker is responsible for bias estimation of rotating sensors as well as to partially monitor the integrity of ADS-B data.

3 Composite WAM ADS-B System description

For the evaluation of the benefits of a Composite WAM-ADSB system, different sets of System requirements have been defined.

The layout follows the description in [2]

In accordance with the guidelines in [2], requirement identifiers follow the scheme:

REQ-15.04.02-D06-00xx.yyyy, where:

xx	Meaning
10	General requirements (GEN-SUR – EUROCAE)
20	NATS CRSTL requirement
30	INDRA DFS requirement

Table 2: Requirement Identifier Allocation

A first set of system requirements is derived from the EUROCAE documentation already existing and that is related to WAM and ADS-B systems. For the aim of the project, not all requirements included in such document will be tested, as they are considered as a baseline for the project. The analysis will be focused on the evaluation of the performances of the prototypes and the capability of improvement using the described techniques (e.g. DAPs, use and creation of ADD, and use of composite WAM – ADS-B data). Whilst ED-142(A) [4] and ED-129 (A/B) [5] include SWAL this development will be of prototype quality and not fully adhering to SWAL or other similar requirements.

At the time of creation of this deliverable, not all the inputs are ready to be used. Requirements developed in this document will be re-visited in D8 [9] when the EUROCAE documentation relative to the composite WAM-ADSB surveillance system is in a more advanced state. For the objective of this report, General design guidelines contained in EUROCAE composite WAM-ADS-B document will be used as an input.

System Requisites defined in this document will be allocated to low level requirements that will be created in DEL D08 [9].

As different platforms will be created for the validation, a table is included in Appendix A provide implementers for each requisite.

3.1 Inputs from EUROCAE (WG51SG4)

The Composite (ADS-B and WAM) Surveillance system contains the necessary functions to measure the horizontal position and provide altitude and Identity of all targets transmitting on 1090 MHz in its intended coverage volume.

This document has taken into account the ED-129A & ED-142 specifications for its development. The future EUROCAE specifications ED-129B and ED-142A are expected to be published in the near future, in that moment will be included in this document.

3.1.1 Data Output Management

In a composite WAM - ADS-B surveillance sensor, the system outputs combined WAM and ADS-B target and status reports on multiple outputs, which are individually configurable.

The format of the Composite Surveillance System Output data channel would include system track data for:

Identifier	**REQ-15.04.02-D06-0010.0000**
Requirement	At least two mandatory output sources shall be provided from the Composite Surveillance Sensor, with an optional third output if required: • ADS-B Output Channel ASTERIX CAT 021 [7] • WAM Output Channel ASTERIX CAT 020 [8] Combined Output Channel (optional) could be provided to support legacy displays.
Title	System Outputs
Owner	INDRA
V&V Method	<Test>

Further consideration regarding which data items from which surveillance channel are used is required.

If the Confidence Containment Bound exceeds a minimum requirement then the ADS-B position data would be used for combined tracks. It´s expected that the composite MSDF Tracker will weight all contributing sensors.

3.1.2 Comparison of ADS-B and WAM positions.

3.1.2.1 General

When an ADS-B equipped aircraft is within the coverage of a sufficient number of WAM receivers, it is possible for the WAM system to determine a position independently from the position information in the ADS-B messages. Even when there are as few as two receivers, the time difference of arrival will define a hyperbola in space where the position of the aircraft should coincide (this is referred to generally below as a "partial position").

Identifier	**REQ-15.04.02-D06-0010.0010**
Requirement	The aircraft horizontal position transmitted by the ADS-B position messages and as decoded by the composite system shall be compared against the position, or partial position, determined by multilateration techniques in the system for the same aircraft where there is sufficient reception from multiple receivers.
Title	ADS-B position comparison
Owner	INDRA-DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0010.0020**
Requirement	The aircraft horizontal position transmitted by the ADS-B position messages and decoded by the composite system shall be compared against the position, or partial position, determined by ranging techniques in the system for the same aircraft.
Title	ADS-B position comparison 2
Owner	INDRA
V&V Method	<Test>

3.1.2.2 Same aircraft conditions

Identifier	**REQ-15.04.02-D06-0010.0030**
Requirement	The ICAO 24 bit address shall be used to determine that the ADS-B and WAM position information is for the same aircraft.
Title	Same aircraft condition 1
Owner	INDRA-DFS-NATS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0010.0040**
Requirement	If the composite system has detected that the ICAO 24 bit address is ambiguous (i.e. more than one aircraft with the same address), then comparison of ADS-B and WAM positions shall be used to identify targets and maintain different tracks.
Title	Same aircraft condition 2
Owner	INDRA
V&V Method	<Test>

3.1.2.3 Common time of applicability

Identifier	**REQ-15.04.02-D06-0010.0050**
Requirement	The ADS-B and WAM lateral position information shall be compared at the same time of applicability.
Title	Common time of applicability 1
Owner	INDRA-DFS-NATS
V&V Method	<Test>

Usually, it is expected that a WAM position will be formed from the receipt of the ADS-B messages, SSR replies and other squitters.

Time of creation in ADS-B is unknown, the timestamp in ADS-B denotes the time of message creation. A possible way to deal with it in the MSDF tracker is to enlarge the covariance in the “along trajectory” direction, thus putting time uncertainty into noise, and treating it with noise.

Due to this, it will not be possible to make a simultaneous WAM position measurement coinciding in time with the creation of the reported ADS-B position message. Then for the comparison data has to be properly temporal aligned within an MSDF system to make use of an earlier WAM reported position. Before comparison, the positions need to be time aligned to a common time using existing WAM track or ADS-B velocity information. However, to avoid too much extra position uncertainty being introduced, the allowable time difference between the original WAM and ADS-B measurements must be limited.

3.1.2.4 Uncertainties in positions – ADS-B uncompensated latency

The difference between ADS-B and WAM positions will be affected by the normal (no-fault) measurement uncertainties in each measurement. These uncertainties are to be expected and will include expected accuracies, biases, extrapolation errors and the effects of uncompensated latency.

Identifier	**REQ-15.04.02-D06-0010.0060**
Requirement	The comparison between ADS-B and WAM positions shall take into account the normally expected uncertainties in the position information from both ADS-B and WAM.
Title	Uncertainties in position 1
Owner	INDRA-DFS
V&V Method	<Test>

The normally expected uncertainties to be taken into account may include:

- Expected accuracy of ADS-B position source.
- Expected accuracy of WAM position measurement.
- Nominal bias limits in WAM position
- Uncertainties introduced by extrapolation of positions to a common time
- Effects of uncompensated latencies in the ADS-B position.

Example: For ADS-B, the nominal position accuracy may be determined from the accuracy quality indicator NACp (version 1 onwards) or NUCp (version 0). Alternatively, the nominal ADS-B accuracy may be preset by a configurable system parameter to a more realistic, yet conservative value, for a GPS source (conservative accuracy value 25m 95%)

The GEN-SUR standard gives direct recommendations which accuracy of the sensor is necessary for each application variant. Instead of verifying each application variant separately it appears to be suitable just to verify the provided accuracy of the sensor itself. For WAM the provided accuracy is given by I020/500 or I020/RE. Hence the suitability of a plot for specific applications, as described in 3.2.4, is indicated by the plot itself. The provided accuracy of the WAM system must not be better than the true accuracy for a specific plot. Otherwise the data must be considered as degenerated and separation can only be done with significant security margins.

It is expected that the WAM system will inherently calculate its expected accuracies from knowledge of the receiving geometry (i.e. GDOP) and its expected uncertainties in measurements of time of arrival. Nominal bias limits could also be assumed as WAM system parameters. Final accuracy of the WAM system will be expressed on the ASTERIX item I020/500, Position Accuracy.

Uncompensated latencies in ADS-B introduce additional along-track position errors proportional to aircraft ground speed. In ADS-B installations, the maximum allowable uncompensated latency depends upon the version of ADS-B.

Identifier	**REQ-15.04.02-D06-0010.0070**
Requirement	The maximum allowable uncompensated latency for ADS-B shall take account of the ADS-B version.
Title	Uncertainties in position 2
Owner	INDRA
V&V Method	<Test>

The expected uncompensated latency for ADS-B may be characterised by time bias and standard deviation parameters for each version of ADS-B.

In areas of good accuracy WAM, the difference between ADS-B and WAM positions in the along-track direction could be averaged over a number of successive measurements to form a dynamic estimate of the uncompensated latency time bias for the aircraft. By obtaining a better estimate of latency, a more accurate comparison could be made.

The system may dynamically refine the estimate of the ADS-B time bias value of each aircraft from the results of successive comparisons of WAM and ADS-B along-track positions.

3.1.2.5 Comparison with Partial Position Hyperbola

In the case of a partial position hyperbola, as determined by the TDOA from two receivers, the difference of concern is essentially the length of the normal (90°) line from the hyperbola to the ADS-B position. Consequently, the difference threshold will depend upon all the error uncertainties from each measurement resolved along this direction.

Identifier	**REQ-15.04.02-D06-0010.0080**
Requirement	To minimize the error component produced by the ADS-B in the case of a partial position hyperbola, the difference between the ADS-B position and the intersection of the normal line to the partial position hyperbola shall be compared against a threshold taking account of all the normally expected uncertainties in both measurements (as described above). This approach will provide the best case error for the comparison.
Title	Comparison with partial Position Hyperbola
Owner	INDRA
V&V Method	<Test>

3.1.2.6 Output of Comparison Information

Identifier	**REQ-15.04.02-D06-0010.0090**
Requirement	The composite surveillance system shall provide information about the result of the validation to accompany the output of each ADS-B position report.
Title	Output Comparison information 1
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0010.0100**
Requirement	Information shall be set to indicate one of the following comparison conditions: No WAM/ADS-B comparison was performed *[This may be due to lack of WAM coverage or other ill-conditioned solutions]* Comparison was made against a partial position solution. *[Reception by two WAM sensors will provide a position solution hyperbola].* Comparison was made against a full, unambiguous, WAM lateral position. Comparison was made against a Range from interrogation validation.
Title	Output Comparison information 2
Owner	INDRA
V&V Method	<Test>

3.1.3 Improving WAM Capabilities

3.1.3.1 Reducing Active WAM Interrogations

It is possible to substantially reduce the need for active interrogations by the WAM channel while still meeting the update requirements on non-horizontal position data (specifically for altitude and aircraft identity), i.e. by using the respective information contained within the ADS-B messages. However, certain safeguards are needed to validate that the ADS-B information can be used in this way and thereby mitigate against possible systematic integrity errors in the data.

Identifier	**REQ-15.04.02-D06-0010.0110**
Requirement	Use of ADS-B non-position data by the WAM channel shall be permissible only when all the following conditions are met: • The ADS-B and WAM channel tracks are associated and the WAM track has “full” 3D position. • The ADS-B track position data agrees with the WAM track position (i.e. the comparison flag is successful). • Validation of the ADS-B data item, depending upon certain ADS-B protocol versions, is successful.
Title	Use of ADS-B non position data
Owner	INDRA
V&V Method	<Test>

3.1.3.1.1 ADS-B Data Version Handling

There are currently three ADS-B 1090 MHz MOPS versions that are operational in the field. At the moment, the majority of the ADS-B transmitting aircraft are equipped with Version 0 transponders (ED-102 / DO-260). A small percentage of the transmitting aircraft are equipped with Version 1 transponders (DO-260A). Version 2 (ED-102 A/ DO-260B) is observed on an increasing number of aircraft that operate in Europe. It is Version 2 that is required under the European and American ADS-B Out mandates (mandate deadline: 2020).
Not all ADS-B transmitting aircraft are certified for ADS-B (i.e. as a minimum in compliance with EASA AMC 20-24), and a very few Version 0 aircraft are observed to consistently transmit incorrect ADS-B messages (also with respect to misleading measurement integrity NUCp values). Since ADS-B is only partially used operationally within European airspace, ADS-B certification before 2020 is not mandatory. As a consequence, no corrective actions are undertaken against Version 0 (and Version 1) aircraft that transmit incorrect ADS-B messages.

Note: aircraft that are not covered by the SPI IR mandate can be equipped with ADS-B version 2 that is not certified to the same level as SPI-IR compliant aircraft. In these cases the SDA will be less than 2. These aircraft should be treated with suspicion, in the same way as ADS-B version 0 & 1 aircraft.

As a consequence, Table 3 lists the combination of ADS-B Out version numbers and data items that require validation.

<table>
<tr><th>ADS-B Protocol Version</th><th>ADS-B Data Item</th></tr>
<tr><td rowspan="2">Version 0 & 1
Version 2, SDA<2</td><td>Aircraft Identification</td></tr>
<tr><td>Pressure Altitude</td></tr>
</table>

Table 3: ADS-B Data Item / Protocol Versions Requiring Validation

Table 4, in turn, lists the combination of ADS-B Out version numbers and data items that do not require validation.

<table>
<tr><th>ADS-B Protocol Version</th><th>ADS-B Data Item</th></tr>
<tr><td rowspan="2">Version 0 & 1,
Version 2, SDA=2</td><td>Special Position Identification (SPI)</td></tr>
<tr><td>Emergency Status / Indication</td></tr>
<tr><td rowspan="8">Version 2, SDA=2</td><td>Aircraft Identification</td></tr>
<tr><td>Mode A Code</td></tr>
<tr><td>Pressure Altitude</td></tr>
<tr><td>Selected Altitude</td></tr>
<tr><td>Barometric Pressure Setting</td></tr>
<tr><td>Ground Speed Vector</td></tr>
<tr><td>Vertical Rate</td></tr>
<tr><td>ACAS Resolution Advisory</td></tr>
</table>

Table 4: ADS-B Data Item / Protocol Versions Not Requiring Validation

3.1.3.1.2 ADS-B Data Validation Requirements

3.1.3.1.2.1 General

Before the ADS-B data item can be considered to be used in the WAM track, the WAM derived position of the ADS-B data message must associate with an existing WAM track.

Identifier	**REQ-15.04.02-D06-0010.0120**
Requirement	Before an ADS-B data item can be used in the WAM track, the WAM horizontal position determined on the data plot containing the data item shall be successfully associated with the WAM track.
Title	WAM-ADSB association 1
Owner	INDRA
V&V Method	<Test>

Depending upon the ADS-B version, as detailed in Table 4 above, the use of the applicable ADS-B data item by WAM is subject to validation. This is to be performed at different times, as follows:

1. Initial validation – WAM tracks initially obtain the data item by active interrogations. Subsequently, after the data item value has been initially established, it is then permissible to check that this data agrees with the same data obtained passively from ADS-B squitters. If agreement is successful, then the ADS-B data item can be used subsequently instead of making further WAM interrogations for the same data.

2. Periodic re-validation – at predetermined time intervals after successful initial validation, the WAM obtains the data item again by an active interrogation to check against the ADS-B data again. If successful, then the ADS-B data continues to be used or otherwise, the WAM channel reverts to obtaining the data item by active interrogations and any further use of the ADS-B data item will be subject to initial validation again.

Identifier	**REQ-15.04.02-D06-0010.0130**
Requirement	Validation of the applicable ADS-B data item (Pressure Altitude, Aircraft Identification) shall be done after initial validation conditions are met and periodically thereafter at pre-defined (parameter) time intervals.
Title	WAM-ADSB association 2
Owner	INDRA
V&V Method	<Test>

3.1.3.1.2.2 Pressure Altitude

Initial Validation Conditions for Pressure Altitude

Identifier	**REQ-15.04.02-D06-0010.0140**
Requirement	The WAM track shall have initialised the track Pressure Altitude information using at least 2 active interrogations.
Title	Initial Validation Conditions for Pressure Altitude
Owner	INDRA
V&V Method	<Test>

Validation Check for Pressure Altitude

The comparison of pressure altitude values from ADS-B and WAM needs a tolerance margin to allow for fluctuations in value due to quantisation and also to take account of possible changes in altitude between the times of applicability of the data item. *[Also to allow for uncompensated latency time in ADS-B].* Consequently, the altitude tolerance margin (ΔA) could be considered as:

$$\Delta A = P1 + P2*\Delta t$$

where P1 and P2 are system parameters and Δt is the time difference. [*Typical values would be P1=100ft, P2=100ft)].*

Identifier	**REQ-15.04.02-D06-0010.0150**
Requirement	The validation check of Pressure Altitude data shall require the values from WAM and ADS-B to be within a certain tolerance margin.
Title	Initial Validation Conditions for Pressure Altitude 2
Owner	INDRA-DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0010.0160**
Requirement	The tolerance margin between Pressure Altitude values from WAM and ADS-B shall take account of possible differences in altitude values due to uncertainties in quantisation and timing. See [3]
Title	Initial Validation Conditions for Pressure Altitude 3
Owner	INDRA-NATS
V&V Method	<Test>

However, the allowable time difference (Δt) needs to be within a reasonable limit for the altitude validation check to be appropriate.

Identifier	**REQ-15.04.02-D06-0010.0170**
Requirement	The validation check of Pressure Altitude shall require the time difference between the ADS-B and WAM values to be less than a parameter amount. (Otherwise the check is considered as unsuccessful)
Title	Initial Validation Conditions for Pressure Altitude 4
Owner	INDRA-NATS
V&V Method	<Test>

<u>Periodic re-validation check</u>

Identifier	**REQ-15.04.02-D06-0010.0180**
Requirement	After initialisation and successful validation, the WAM track shall actively interrogate for Pressure Altitude information at a periodic time interval determined by a system parameter and the ADS-B validation check repeated.
Title	Initial Validation Conditions for Pressure Altitude 5
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0010.0190**
Requirement	In case of unsuccessful comparison outcome, the WAM track shall re-initialise the Pressure Altitude information using active interrogations.
Title	Initial Validation Conditions for Pressure Altitude 6
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0010.0200**
Requirement	In case of a WAM track loss of Pressure Altitude for longer than a parameter time, the track shall complete its initial validation conditions before attempting ADS-B data validation.
Title	Initial Validation Conditions for Pressure Altitude 7
Owner	INDRA
V&V Method	<Test>

3.1.3.1.2.3 Aircraft Identification

Initial Validation Conditions for Aircraft Identification

Identifier	**REQ-15.04.02-D06-0010.0210**
Requirement	The WAM track shall have initialised the track Aircraft Identification information using at least 2 active interrogations giving the same Aircraft Identification.
Title	Initial Validation Conditions for Aircraft Identification 1
Owner	INDRA
V&V Method	<Test>

Validation Check for Aircraft Identification

Identifier	**REQ-15.04.02-D06-0010.0220**
Requirement	The validation check of Aircraft Identification data shall require the values from WAM and ADS-B to be the same.
Title	Validation Check for Aircraft Identification.
Owner	INDRA
V&V Method	<Test>

Periodic re-validation check

Identifier	**REQ-15.04.02-D06-0010.0230**
Requirement	After initialisation and successful validation, the WAM track shall actively interrogate for Aircraft Identity information at a periodic time interval determined by a system parameter and the ADS-B validation check repeated.
Title	Periodic re-validation check
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0010.0240**
Requirement	In case of unsuccessful comparison outcome, the WAM track shall re-initialise the Aircraft Identity information using active interrogations.
Title	Periodic re-validation check 2
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0010.0250**
Requirement	In case of a WAM track loss of Aircraft Identity information for longer than a parameter time, the track shall complete its initial validation conditions before attempting ADS-B data validation.
Title	Periodic re-validation check 3
Owner	INDRA
V&V Method	<Test>

3.1.3.2 Enabling WAM Passive Acquisition

On the premise that active WAM all-call interrogations will always be required to track any aircraft that do not broadcast ADS-B squitters and for which the ADS-B installation is faulty or not (fully) trustworthy (i.e. version 0 / 1 installations), the key question at hand is if the all-call rate could be lowered as a function of the ADS-B Out population.

Otherwise, the WAM track initiation outside the operational coverage volume based on "partial" WAM position fixes along with confirming ADS-B horizontal position information provides for the benefit of an early initiation of a "partial" WAM track.

Note: applicability to be assessed (as, formally, a WAM system is not allowed to use the all-call feature).

3.1.3.3 WAM Performance Monitoring

Although no specific requirements can be made here, it clearly is feasible to make use of ADS-B horizontal position (and geometric height) to monitor WAM system health and performance in various ways such as:

- Checking expected WAM receiver coverage of ADS-B equipped aircraft (e.g. for detection of poorly performing antennas/receivers)
- Comparison of ADS-B position with WAM position (e.g. for checking of time difference of arrival clock synchronization and expected measurement accuracy).
- To reduce the number of dedicated ground monitors (parrots) by the use ADS-B aircraft of opportunity.

Such considerations could provide substantial cost benefit gains to the overall WAM/ADS-B composite system.

Identifier	**REQ-15.04.02-D06-0010.0260**
Requirement	Candidate WAM/ADS-B composite installations should consider the potential use of ADS-B to assist with WAM system performance monitoring including possible cost benefits to the overall system deployment and maintenance.
Title	WAM performance Monitoring
Owner	INDRA
V&V Method	<Test>

3.2 Inputs from GEN – SUR

Latest version of GEN-SUR SPR v1.0 has been used as input for this document. The objective of the project is to evaluate the benefits of the use of a composite WAM – ADS-B system. To achieve this, the project will extract the performance requirements needed to provide separation on each of the environments defined and will analyze how they are meet with the standard WAM service and with the Composite WAM – ADS-B service.

3.2.1 Probability of Detection per Update Interval Requirements

The update interval at SUR-Sensor level for Surveillance Reports containing any new horizontal position associated with any single aircraft will be less than the [SUR sensor update interval] with a probability of [PoD for Horizontal Position] as expressed in the following table.
The update interval at SUR-Sensor level for Surveillance Reports containing any new pressure altitude associated with any single aircraft will be less than the [SUR sensor update interval] with a probability of [PoD for Pressure Altitude] as expressed in the following table
The update interval at SUR-Sensor level for Surveillance Reports containing any new identity (Mode A code or AC/ID), Emergency, and SPI/IDENT associated with any single aircraft will be less than the [SUR sensor update interval] with a probability of [PoD for Aircraft Identity, Emergency and SPI/IDENT] as expressed in the following table.

Note: the term “new” refers to a code change (i.e. different from the previous one)

ENVT	SUR sensor update interval	PoD for Horizontal Position		PoD for Pressure Altitude	PoD for Mode A code change	PoD for Aircraft Identification	PoD for Emergency	PoD for SPI
ER_5NM Low Density	8	96%		95%	86%	62%	77%	77%
ER_5NM Medium Density	8	97%		96%	97%	77%	94%	94%
ER_5NM High density	8	98%		98%	97%	77%	94%	94%
TMA_3NM Low Density	5	97%		96%	77%	53%	81%	81%
TMA_3NM Medium Density	5	98%		97%	77%	53%	81%	81%
TMA_3NM High Density	5	99%		98%	89%	65%	81%	81%
APP_2,5NM High Density	5	99%		99%	89%	65%	81%	81%
APP_2,0NM High Density	5	99%		99%	89%	65%	81%	81%

Table 5: Probability of detection per Update Interval requirements

3.2.2 Track Initiation

The track initiation delay at SUR-Sensor level associated with any single aircraft will be less than the [Track initiation delay] with a probability of [Pd] as expressed in the next table.

Data Item	ENV	Traffic	Track Initiation delay	Pd	Driving scenario
Track Initiation	TMA_3NM	High Density APP_2.5NM APP_2.0NM	16s	95%	Scenario 1: Departure Scenario - Track initiation Scenario 2: Independent Parallel Runways Departure – Track initiation Scenario 4: Transponder Switch – Track initiation
		Medium Density	16s	95%	Scenario 4: Transponder Switch – Track initiation
		Low Density	21s	95%	Scenario 1: Departure Scenario - Track initiation Scenario 4: Transponder Switch – Track initiation
	ER_5NM	High Density	10.5s	95%	Scenario 3: Entry to Enroute Airspace – Track initiation
		Medium Density	10.5s	95%	Scenario 3: Entry to Enroute Airspace – Track initiation
		Low Density	18.5s	95%	Scenario 3: Entry to Enroute Airspace – Track initiation

Table 6: Track initiation delay and probability requirements

3.2.3 Probability of Long Gaps

The overall probability of number of Long Horizontal Position Gaps that last for more than "n" times the maximum Display refresh Cycle, will be less than or equal to the values in the table below.

Environment	n = 2	n = 3	n = 4
ER_5NM Low Density	0,7%	0,2%	0,025%
ER_5NM Medium Density	0,2%	0,07%	0,008%
ER_5NM High density	0,1%	0,03%	0,004%
TMA_3NM Low Density	0,6%	0,2%	0,02%
TMA_3NM Medium Density	0,2%	0,07%	0,008%
TMA_3NM High Density	0,1%	0,03%	0,003%
APP_2.5NM (High Density only)	0,04%	0,02%	0,0005%
APP 2.0NM (High Density only)	0,04%	0,02%	0,0005%

Table 7: Probability of Long Gaps requirements

3.2.4 Horizontal Position

The horizontal position "core" accuracy, as applicable at the SUR Sensor interface, will be in compliance with the root-mean-square performance benchmarks as expressed as a function of the sensor measurement output period.

Environment	$\sigma_{rms,Sensor}$ [m] per Sensor Measurement Output Period				
	1s	2s	4s	5s	8s
ER_5NM Low Density	440	415	370	350	305
ER_5NM Medium Density	365	340	300	285	245
ER_5NM High density	290	270	235	220	190
TMA_3NM Low Density	190	180	150	140	
TMA_3NM Medium Density	150	135	115	110	
TMA_3NM High Density	115	100	90	85	
APP_2.5NM (High Density)	70	65	55	55	
APP_2.0NM (High Density)	60	55	45	45	

Table 8: GEN-SUR SUR Sensor Level Horizontal Position Measurement "core" Accuracy (RMS) Requirements

3.3 Requirements for NATS system

3.3.1 Validation SUT Requirements

The following validation requirements are placed on the NATS CRISTAL RAD HD WAM / ADS-B validation platform [*System Under Test*] to achieve the 15.04.02 WP2 validation objectives defined in D07 [10].

Identifier	**REQ-15.04.02-D06-0020.0000**
Requirement	The location of the Mode S interrogator shall support a comparative assessment of the multi-ranging (active) and passive WAM operation.
Title	Mode S interrogator location
Owner	NATS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0020.0010**
Requirement	The interrogator of the validation platform shall confirm to all licensing obligations and constraints placed on it by the UK NSA.
Title	Interrogator licensing
Owner	NATS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0020.0020**
Requirement	The validation platform shall provide sufficient low level coverage for the ADS-B separation performance assessment.
Title	Low level coverage
Owner	NATS
V&V Method	<Test>

3.3.2 Other Validation Requirements

The following validation requirements are placed on supplementary system to the NATS CRISTAL RAD HD WAM / ADS-B validation platform to achieve the 15.04.02 WP2 validation objectives described in D07 [10].

Identifier	**REQ-15.04.02-D06-0020.0030**
Requirement	NATS existing MRT data for the same defined coverage area of the CRISTAL RAD HD validation platform shall be recorded in ASTERIX CAT034 and CAT048 on the NATS RRRS
Title	MRT ASTERIX output
Owner	NATS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0020.0040**
Requirement	The WAM target data shall be recorded in ASTERIX CAT020 on the RRRS and WAM service messages in ASTERIX CAT 19.
Title	WAM ASTERIX output

Owner	NATS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0020.0050**
Requirement	The ADS-B target data shall be recorded in ASTERIX CAT021 on the RRRS and ADS-B service messages in ASTERIX CAT 23.
Title	ADS-B ASTERIX output
Owner	NATS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0020.0060**
Requirement	NATS non-operational development ARTAS MST shall take input of ASTERIX CAT020, CAT021, CAT034 and CAT048 from the NATS RRRS in various combinations (*to validate the integration of ADS-B and WAM in an MST*).
Title	ARTAS ASTERIX inputs
Owner	NATS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0020.0070**
Requirement	NATS RRRS shall be used to replay recorded CAT020, CAT 19, CAT021, CAT 23, CAT034 and CAT048 to NATS non-operational development ARTAS MST.
Title	Replay tools
Owner	NATS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0020.0080**
Requirement	The NATS Space Simulation facility shall be configured to accept CAT020, CAT021 and CAT062 inputs (for user acceptance validation by controllers).
Title	NATS space simulation input
Owner	NATS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0020.0090**
Requirement	The version of SASS-C used in the validation assessment shall be capable of providing the validation performance assessment metrics.
Title	SASS-C version
Owner	NATS
V&V Method	<Test>

3.4 Requirements for Indra - DFS system

The following requirements have been allocated to the Indra-DFS Composite Surveillance system.

3.4.1 System functional requirements

Identifier	**REQ-15.04.02-D06-0030.0000**
Requirement	The deployed system shall be used to evaluate the impact on the Identification performance values of the standard WAM service for Active and passive system operation
Title	Performance evaluation
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0010**
Requirement	The deployed system shall be used to evaluate the impact on the Identification performance values of the Composite WAM – ADS-B service for Active and passive system operation
Title	Performance evaluation
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0020**
Requirement	The composite surveillance sensor shall provide the following services simultaneously : - WAM service. - ADS-B service. - Composite WAM/ADS-B service.
Title	Services
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0030**
Requirement	The WAM and Composite service shall work as passive or active system using one or several Mode S interrogators.
Title	System Configuration
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0040**
Requirement	The next functionalities shall be evaluated ADS-B Positional validation In this area, different methods will be used to validate the ADS-B data transmitted by targets. The following methods will be used: • TDOA validation with at least 2 Receiver Stations Some guidance for TDOA validation is provided in [3] The result of the ADS-B data validation will be provided in specific ASTERIX CAT21 bits created for that purpose. See [7] Ranging information will be included in the SP bits of the ASTERIX CAT020.
Title	Evaluation of functions
Owner	INDRA-DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0050**
Requirement	The next functionalities shall be evaluated ADS-B Positional validation In this case will be used the following method to validate the ADS-B data transmitted by targets: • Range validation in Active WAM context, checking that the ADS-B reported position is located in inside the boundary limits of the ellipsoid produced by the replies of the target to an interrogation generated by the system. The result of the ADS-B data validation will be provided in specific ASTERIX CAT21 bits created for that purpose. See [7] Ranging information will be included in the SP bits of the ASTERIX CAT020.
Title	Evaluation of functions
Owner	INDRA-DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0060**
Requirement	The next functionalities shall be evaluated ADS-B Positional validation In this case will be used the following method to validate the ADS-B data transmitted by targets: • Full WAM validation, comparing the ADS-B reported position with the position calculated by the WAM system. The result of the ADS-B data validation will be provided in specific ASTERIX CAT21 bits created for that purpose. See [7] Ranging information will be included in the SP bits of the ASTERIX CAT020.
Title	Evaluation of functions
Owner	INDRA-DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0070**
Requirement	The next functionalities shall be evaluated • Barometric altitude provided by ADS-B with Barometric altitude provided by WAM system obtained from active interrogations. Checking the difference of the barometric altitude reported in ADS-B squitter with the barometric altitude obtained by the WAM system using the (DF4) replies.
Title	Evaluation of functions
Owner	INDRA-DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0080**
Requirement	Quality of the different tracks provided by the different services will be analyzed: • Individual accuracy (along, across, POD, RMS, sigma, max err) of ADS-B and WAM • Combined accuracy of ADS-B and WAM The quality of the track provided by the WAM sensor shall be analysed by individual accuracy evaluations (along, across, POD, RMS, sigma, max error).
Title	Evaluation of functions
Owner	INDRA-DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0090**
Requirement	The provided accuracy of the WAM data shall be analysed. Adding WAM plots to good ADS-B (e.g. NUC=8) would not necessarily enhance the track quality of the position result. Therefore it appears of more interest to evaluate the accuracy of the provided accuracy of the WAM sensor.
Title	Evaluation of functions
Owner	INDRA-DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0100**
Requirement	The provided track data ages shall be analysed. Track data ages are a pretty good methods to show the advantage of composite surveillance (besides the ability of cross validation).
Title	Evaluation of functions
Owner	INDRA-DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0110**
Requirement	The next functionalities shall be evaluated • Analysis of ADS-B figure of merit Statistics for the different quality parameters NUC (DO-260) and/or NIC/NAC/SIL (Do-260A/B) will be analyzed fort the different targets of opportunity and for the different transponder versions.
Title	Evaluation of functions
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0120**
Requirement	The next functionalities shall be evaluated • ADS-B uncompensated latency
Title	Evaluation of functions
Owner	INDRA
V&V Method	<Test>

3.4.2 System interface requirements

Identifier	**REQ-15.04.02-D06-0030.0130**
Requirement	The composite Surveillance Sensor shall provide target data in ASTERIX cat 20 v1.8 for WAM (standard and composite) and ASTERIX cat 21 v2.81 for ADS-B.
Title	Surveillance Sensor ASTERIX output
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0140**
Requirement	MSDF Tracker shall process as inputs ASTERIX CAT020 and CAT021
Title	Tracker Data Fusion ASTERIX input
Owner	DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0150**
Requirement	The composite Surveillance Sensor shall provide different SIC-SAC codes for the standard WAM service and for the Composite WAM service
Title	Surveillance Sensor ASTERIX output
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0160**
Requirement	MSDF tracker shall differentiate the WAM flow and Composite WAM flow with the SIC-SAC codes.
Title	Tracker Data Fusion ASTERIX input
Owner	DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0170**
Requirement	The composite Surveillance Sensor shall differentiate ADS-B dataflows with service or receiver indicator in ASTERIX CAT021.
Title	Surveillance Sensor ASTERIX output
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0180**
Requirement	MSDF Tracker shall differentiate ADS-B dataflows with service or receiver indicator in ASTERIX CAT021.
Title	Surveillance Sensor ASTERIX input
Owner	DFS
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0190**
Requirement	WAM, ADS-B and Composite WAM/ADS-B services shall be capable to be configured with a different update rate or to work in data driven mode.
Title	Update rate
Owner	INDRA
V&V Method	<Test>

Identifier	**REQ-15.04.02-D06-0030.0200**
Requirement	The different WAM, ADS-B and composite WAM/ADS-B streams shall be available in parallel.
Title	Update rate
Owner	INDRA
V&V Method	<Test>

4 References

[1] SESAR Requirements and V&V Guidelines Latest version

[2] SESAR Toolbox User Manual Latest version

[3] K. Pourvoyeur, R. Heidger: "Secure ADS-B Usage in ATC Tracking", Proc. Tyrrhenian International Workshop on Digital Communications / Enhanced Surveillance of Aircraft and Vehicles (TIWDC/ESAV) , Sept. 15–16, 2014, Rom, Italy.

[4] ED-142 Technical Specification for Wide Area Multilateration (WAM) Systems.

[5] ED-129A Technical Specification for a 1090 MHz Extended Squitter ADS-B Ground Station

[6] ADS-B / WAM "Composite" Provisions For Inclusion Within ED-129B & ED-142A (WG51-SG4 Working Paper 2 February 2015)

[7] EUROCONTROL STANDARD DOCUMENT FOR SURVEILLANCE DATA EXCHANGE Part 12: Category 021 ADS-B Reports v2.81. September 2012

[8] EUROCONTROL STANDARD DOCUMENT FOR SURVEILLANCE DATA EXCHANGE Part 14 : Category 020: Multilateration Target Reports v1.8 December 2010

[9] 15.04.02 D08 Technical report, composite cooperative surveillance prototype

[10] 15.04.02 D07 Verification Strategy, composite cooperative surveillance

[11] 15.4.5a D18 First iteration of ADS-B Surveillance System Specifications

[12] 15.4.5a D19 Second iteration of ADS-B Surveillance System Specifications

[13] 15.4.5a D20 Third iteration of ADS-B Surveillance System Specifications

Appendix A Requisite allocation

REQ	TEXT	REQ OWNER
REQ-15.04.02-D06-0010.0000	At least two mandatory output sources shall be provided from the Composite Surveillance Sensor, with an optional third output if required: • ADS-B Output Channel ASTERIX CAT 021 [7] • WAM Output Channel ASTERIX CAT 020 [8] • Combined Output Channel (optional) could be provided to support legacy displays.	INDRA
REQ-15.04.02-D06-0010.0010	The aircraft horizontal position transmitted by the ADS-B position messages and as decoded by the composite system shall be compared against the position, or partial position, determined by multilateration techniques in the system for the same aircraft where there is sufficient reception from multiple receivers.	INDRA-DFS
REQ-15.04.02-D06-0010.0020	The aircraft horizontal position transmitted by the ADS-B position messages and decoded by the composite system shall be compared against the position, or partial position, determined by ranging techniques in the system for the same aircraft.	INDRA
REQ-15.04.02-D06-0010.0030	The ICAO 24 bit address shall be used to determine that the ADS-B and WAM position information is for the same aircraft.	INDRA-DFS-NATS
REQ-15.04.02-D06-0010.0040	If the composite system has detected that the ICAO 24 bit address is ambiguous (i.e. more than one aircraft with the same address), then comparison of ADS-B and WAM positions shall be used to identify targets and maintain different tracks.	INDRA
REQ-15.04.02-D06-0010.0050	The ADS-B and WAM lateral position information shall be compared at the same time of applicability.	INDRA-DFS-NATS
REQ-15.04.02-D06-0010.0060	The comparison between ADS-B and WAM positions shall take into account the normally expected uncertainties in the position information from both ADS-B and WAM.	INDRA-DFS
REQ-15.04.02-D06-0010.0070	The maximum allowable uncompensated latency for ADS-B shall take account of the ADS-B version.	INDRA

REQ-15.04.02-D06-0010.0080	To minimize the error component produced by the ADS-B in the case of a partial position hyperbola, the difference between the ADS-B position and the intersection of the normal line to the partial position hyperbola shall be compared against a threshold taking account of all the normally expected uncertainties in both measurements (as described above). This approach will provide the best case error for the comparison.	INDRA
REQ-15.04.02-D06-0010.0090	The composite surveillance system shall provide information about the result of the validation to accompany the output of each ADS-B position report.	INDRA
REQ-15.04.02-D06-0010.0100	Information shall be set to indicate one of the following comparison conditions: No WAM/ADS-B comparison was performed [This may be due to lack of WAM coverage or other ill-conditioned solutions]. Comparison was made against a partial position solution. [Reception by two WAM sensors will provide a position solution hyperbola]. Comparison was made against a full, unambiguous, WAM lateral position. Comparison was made against a Range from interrogation validation.	INDRA
REQ-15.04.02-D06-0010.0110	Use of ADS-B non-position data by the WAM channel shall be permissible only when all the following conditions are met: • The ADS-B and WAM channel tracks are associated and the WAM track has “full” 3D position. • The ADS-B track position data agrees with the WAM track position (i.e. the comparison flag is successful). • Validation of the ADS-B data item, depending upon certain ADS-B protocol versions, is successful.	INDRA
REQ-15.04.02-D06-0010.0120	Before an ADS-B data item can be used in the WAM track, the WAM horizontal position determined on the data plot containing the data item shall be successfully associated with the WAM track.	INDRA

REQ-15.04.02-D06-0010.0130	Validation of the applicable ADS-B data item (Pressure Altitude, Aircraft Identification) shall be done after initial validation conditions are met and periodically thereafter at pre-defined (parameter) time intervals.	INDRA
REQ-15.04.02-D06-0010.0140	The WAM track shall have initialised the track Pressure Altitude information using at least 2 active interrogations.	INDRA
REQ-15.04.02-D06-0010.0150	The validation check of Pressure Altitude data shall require the values from WAM and ADS-B to be within a certain tolerance margin.	INDRA-DFS
REQ-15.04.02-D06-0010.0160	The tolerance margin between Pressure Altitude values from WAM and ADS-B shall take account of possible differences in altitude values due to uncertainties in quantisation and timing. See [3]	INDRA-NATS
REQ-15.04.02-D06-0010.0170	The validation check of Pressure Altitude shall require the time difference between the ADS-B and WAM values to be less than a parameter amount.	INDRA-NATS
REQ-15.04.02-D06-0010.0180	After initialisation and successful validation, the WAM track shall actively interrogate for Pressure Altitude information at a periodic time interval determined by a system parameter and the ADS-B validation check repeated.	INDRA
REQ-15.04.02-D06-0010.0190	In case of unsuccessful comparison outcome, the WAM track shall re-initialise the Pressure Altitude information using active interrogations.	INDRA
REQ-15.04.02-D06-0010.0200	In case of a WAM track loss of Pressure Altitude for longer than a parameter time, the track shall complete its initial validation conditions before attempting ADS-B data validation.	INDRA
REQ-15.04.02-D06-0010.0210	The WAM track shall have initialised the track Aircraft Identification information using at least 2 active interrogations giving the same Aircraft Identification.	INDRA
REQ-15.04.02-D06-0010.0220	The validation check of Aircraft Identification data shall require the values from WAM and ADS-B to be the same.	INDRA
REQ-15.04.02-D06-0010.0230	After initialisation and successful validation, the WAM track shall actively interrogate for Aircraft Identity information at a periodic time interval determined by a system parameter and the ADS-B validation check repeated.	INDRA
REQ-15.04.02-D06-0010.0240	In case of unsuccessful comparison outcome, the WAM track shall re-initialise the Aircraft Identity information using active interrogations.	INDRA
REQ-15.04.02-D06-0010.0250	In case of a WAM track loss of Aircraft Identity information for longer than a parameter time, the track shall complete its initial validation conditions before attempting ADS-B data validation.	INDRA
REQ-15.04.02-D06-0010.0260	Candidate WAM/ADS-B composite installations should consider the potential use of ADS-B to assist with WAM system performance monitoring including possible cost benefits to the overall system deployment and	INDRA

	maintenance.	
REQ-15.04.02-D06-0020.0000	The location of the Mode S interrogator shall support a comparative assessment of the multi-ranging (active) and passive WAM operation.	NATS
REQ-15.04.02-D06-0020.0010	The interrogator of the validation platform shall confirm to all licensing obligations and constraints placed on it by the UK NSA.	NATS
REQ-15.04.02-D06-0020.0020	The validation platform shall provide sufficient low level coverage for the ADS-B separation performance assessment.	NATS
REQ-15.04.02-D06-0020.0030	NATS existing MRT data for the same defined coverage area of the CRISTAL RAD HD validation platform shall be recorded in ASTERIX CAT034 and CAT048 on the NATS RRRS	NATS
REQ-15.04.02-D06-0020.0040	The WAM target data shall be recorded in ASTERIX CAT020 on the RRRS and WAM service messages in ASTERIX CAT 19..	NATS
REQ-15.04.02-D06-0020.0050	The ADS-B target data shall be recorded in ASTERIX CAT021 on the RRRS and ADS-B service messages in ASTERIX CAT 23.	NATS
REQ-15.04.02-D06-0020.0060	NATS non-operational development ARTAS MST shall take input of ASTERIX CAT020, CAT021, CAT034 and CAT048 from the NATS RRRS in various combinations (*to validate the integration of ADS-B and WAM in an MST*).	NATS
REQ-15.04.02-D06-0020.0070	NATS RRRS shall be used to replay recorded CAT020, CAT 19, CAT021, CAT 23, CAT034 and CAT048 to NATS non-operational development ARTAS MST.	NATS
REQ-15.04.02-D06-0020.0080	The NATS Space Simulation facility shall be configured to accept CAT020, CAT021 and CAT062 inputs (for shadow mode validation by controllers).	NATS
REQ-15.04.02-D06-0020.0090	The version of SASS-C used in the validation assessment shall be capable of providing the validation performance assessment metrics.	NATS
REQ-15.04.02-D06-0030.0000	The deployed system shall be used to evaluate the impact on the Identification performance values of the standard WAM service for Active and passive system operation	INDRA
REQ-15.04.02-D06-0030.0010	The deployed system shall be used to evaluate the increment on the Identification performance values of the Composite WAM – ADS-B service for Active and passive system operation	INDRA

REQ-15.04.02-D06-0030.0020	The composite surveillance sensor shall provide the following services simultaneously: - WAM service. - ADS-B service. - Composite WAM/ADS-B service.	INDRA
REQ-15.04.02-D06-0030.0030	The WAM and Composite service shall work as passive or active system using one or several Mode S interrogators.	INDRA
REQ-15.04.02-D06-0030.0040	The next functionalities shall be evaluated ADS-B Positional validation In this area, different methods will be used to validate the ADS-B data transmitted by targets. The following methods will be used: • TDOA validation with at least 2 Receiver Stations Some guidance for TDOA validation is provided in [6] The result of the ADS-B data validation will be provided in specific ASTERIX CAT21 bits created for that purpose. See [7] Ranging information will be included in the SP bits of the ASTERIX CAT020. See [8]	INDRA-DFS
REQ-15.04.02-D06-0030.0050	The next functionalities shall be evaluated ADS-B Positional validation In this case will be used the following method to validate the ADS-B data transmitted by targets: • Range validation in Active WAM context, checking that the ADS-B reported position is located in inside the boundary limits of the ellipsoid produced by the replies of the target to an interrogation generated by the system. The result of the ADS-B data validation will be provided in specific ASTERIX CAT21 bits created for that purpose. See [7] Ranging information will be included in the SP bits of the ASTERIX CAT020. See [8]	INDRA-DFS

REQ-15.04.02-D06-0030.0060	The next functionalities shall be evaluated ADS-B Positional validation In this case will be used the following method to validate the ADS-B data transmitted by targets: • Full WAM validation, comparing the ADS-B reported position with the position calculated by the WAM system.. The result of the ADS-B data validation will be provided in specific ASTERIX CAT21 bits created for that purpose. See [7] Ranging information will be included in the SP bits of the ASTERIX CAT020. See [8]	INDRA-DFS
REQ-15.04.02-D06-0030 .0070	The next functionalities shall be evaluated • Barometric altitude provided by ADS-B with Barometric altitude provided by WAM system obtained from active interrogations. Checking the difference of the barometric altitude reported in ADS-B squitter with the barometric altitude obtained by the WAM system using the (DF4) replies.	INDRA-DFS
REQ-15.04.02-D06-0030.0080	Quality of the different tracks provided by the different services will be analyzed: • Individual accuracy (along, across, POD, RMS, sigma, max err) of ADS-B and WAM • Combined accuracy of ADS-B and WAM The quality of the track provided by the WAM sensor shall be analysed by individual accuracy evaluations (along, across, POD, RMS, sigma, max error).	INDRA-DFS
REQ-15.04.02-D06-0030.0090	The provided accuracy of the WAM data shall be analysed. Adding WAM plots to good ADS-B (e.g. NUC=8) would not necessarily enhance the track quality of the position result. Therefore it appears of more interest to evaluate the accuracy of the provided accuracy of the WAM sensor.	INDRA-DFS
REQ-15.04.02-D06-0030.0100	The provided track data ages shall be analysed. Track data ages are a pretty good methods to show the advantage of composite surveillance (besides the ability of cross validation).	INDRA-DFS

REQ-15.04.02-D06-0030.0110	The next functionalities shall be evaluated • Analysis of ADS-B figure of merit Statistics for the different quality parameters NUC (DO-260) and/or NIC/NAC/SIL (Do-260A/B) will be analysed fort the different targets of opportunity and for the different transponder versions.	INDRA
REQ-15.04.02-D06-0030.0120	The next functionalities shall be evaluated • ADS-B uncompensated latency	INDRA
REQ-15.04.02-D06-0030.0130	The composite Surveillance Sensor shall provide target data in ASTERIX cat 20 v1.8 for WAM (standard and composite) and ASTERIX cat 21 v2.81 for ADS-B.	INDRA
REQ-15.04.02-D06-0030.0140	MSDF Tracker shall process as inputs ASTERIX CAT020 and CAT021	DFS
REQ-15.04.02-D06-0030.0150	The composite Surveillance Sensor shall provide different SIC-SAC codes for the standard WAM service and for the Composite WAM service	INDRA
REQ-15.04.02-D06-0030.0160	MSDF tracker shall differentiate the WAM flow and Composite WAM flow with the SIC-SAC codes.	DFS
REQ-15.04.02-D06-0030.0170	The composite Surveillance Sensor shall differentiate ADS-B dataflows with service or receiver indicator in ASTERIX CAT021.	INDRA
REQ-15.04.02-D06-0030.0180	MSDF Tracker shall differentiate ADS-B dataflows with service or receiver indicator in ASTERIX CAT021.	DFS
REQ-15.04.02-D06-0030.0190	WAM, ADS-B and Composite WAM/ADS-B services shall be capable to be configured with a different update rate or to work in data driven mode.	INDRA
REQ-15.04.02-D06-0030.0200	The different WAM, ADS-B and composite WAM/ADS-B streams shall be available in parallel.	INDRA

Appendix B Comparison of ADS-B and WAM lateral positions

A.1 Introduction

This Appendix describes the objectives and principles of the comparison of an aircraft's ADS-B lateral position against its independently determined WAM position, if available. It indicates the error characteristics that need to be taken into account in determining an appropriate difference threshold and containment bound. A simple method of doing this is described, but implementers are free to design their own method to better satisfy the same requirements for their system.

The objective of the ADS-B / WAM comparison is to determine whether or not the two positions agree, but within certain bounds and probability. In principle, the 2D position difference between ADS-B and WAM positions at the same time of applicability are tested against a threshold value, but what is an appropriate threshold value? Indeed, an appropriate threshold value needs to take account of the likely position errors on both ADS-B and WAM position measurements.

When both ADS-B and WAM systems are in their nominal (no fault) state and therefore working within their expected position measurement performance limits, there will generally be some difference between their positions because of normal measurement errors in each position. Consequently, in the nominal state, there will be some probability that the difference between the two positions will happen to exceed the threshold – this is referred to as a "false alert" (i.e. a significant difference is flagged, but there are no faults in either ADS-B or WAM systems). The probability of a false alert will depend upon the relative magnitudes of the threshold and the expected position errors distributions in each source. The expected probability of false alert is therefore a configurable system parameter that will control the position difference threshold.

If there is a fault in the ADS-B position source (either from an undetected GPS satellite fault or some other systematic aircraft installation fault), then there is likely to be some sustained bias error in the ADS-B position:- this is of course what we want to detect by comparison against the WAM position. However, because of the normal measurement errors, there will be some lower limit to the magnitude of the fault bias error that can be detected without excessive false alerts. Consequently, it is important to qualify the extent to which the comparison is able detect a fault bias and it is here that the notion of the containment bound is used. The containment bound defines the magnitude of a sustained position fault bias that can be detected (or not detected) with a certain required probability. Conventionally, this probability is expressed as a "missed alert" probability. Again, the containment bound will depend upon the magnitudes of normally expected position measurement errors an indeed, as shown in this Appendix, it can be simply derived from the position difference threshold.

A.2 Normal Measurement Errors

The difference threshold value that is needed for the comparison of positions must take into account the normally expected uncertainties in the position information from both ADS-B and WAM. The normal errors will include contributions from:

- Expected accuracy of ADS-B position source.
- Expected accuracy of WAM position measurement.
- Nominal bias limits in WAM position
- Uncertainties introduced by extrapolation of positions to a common time
- Effects of uncompensated latencies in the ADS-B position.

Each of these normal error contributions are described in more detail in the sub-sections below.

A.2.1 Expected Accuracy of ADS-B

ADS-B position accuracy is conventionally defined by the 95% error radius and this is qualified by NACp in ADS-B version 1 onwards. For version 0, there is no accuracy qualifier, but a worst case accuracy can be derived from the NUC integrity qualifier (i.e. accuracy = NUC/2).
However, for various reasons, the NACp (and NUCp) qualifier gives very conservative position accuracy values that are not truly representative of the real accuracy of the GPS source. Consequently, it may be better to use a configurable default parameter for a more realist, yet still conservative, accuracy value for ADS-B.
[Note the NACp accuracy qualifier is not sent in the same message as position, so an earlier value has to be maintained or an assumed default accuracy value used].
The 2D (radius) accuracy errors from the ADS-B GPS source are assumed to be Rayleigh distributed. There is no other information sent to describe the component errors in any finer detail, so it is simply assumed that the errors in each dimension (x,y) are the same and can be modelled as independent Gaussian distributions with the same standard deviations. From the statistical properties of Rayleigh and Gaussian distributions it can be shown that:

$$\text{ADS component errors } \sigma Ax = \sigma Ay = Ra / 2.45;$$

where Ra is the 95% accuracy radius.

A.2.2 Expected Accuracy of WAM

Inherently, the WAM system must be able calculate its expected accuracies from knowledge of the receiving geometry (i.e. GDOP) and its expected uncertainties in measurements of time of arrival. Indeed, the expected accuracies in each dimension and also the co-variance are values that are needed for output in WAM reports (in ASTERIX category 20 items).
In this Appendix, for simplicity and conservatively, we assume that the WAM errors are over-bounded by a circular error and so the errors in each dimension are the same (i.e. $\sigma Wx = \sigma Wy$). Furthermore, it is simply assumed that the errors in each dimension are independent Gaussian distributions (as assumed for ADS-B accuracy above).
Of course, the WAM manufacturer is free to take advantage of the better internal knowledge of the WAM accuracy components (including co-variances) and also may have a better knowledge of the expected accuracy error distribution in practice, in particular if it is significantly non-Gaussian.

A.2.3 Nominal bias limits in WAM

In practice, the WAM position may have some residual systematic bias that cannot be completely known or eliminated by the system itself. However, the possible extent of a bias is expected to be limited by the system design tolerances and capabilities of any self-calibration methods (such as using known transponders). The possible magnitude and direction of such biases is variable and is likely to depend upon the measurement geometry (i.e. GDOP).
Consequently, a potential bias limit for a WAM position measurement can be determined from internal knowledge of the WAM system.
Since the direction of the possible WAM position bias is unknown, it is simply added to the difference threshold (because the direction of the WAM bias could be opposite to the direction of the ADS-B position).

A.2.4 Uncertainties introduced by extrapolation of positions to a common time

When a WAM position has be determined from the ADS-B position message, the same time of applicability is assumed. However, when it has not been possible to make a simultaneous WAM measurement, extrapolation from an earlier measurement can be done, although the allowable time difference is limited to avoid excessive extrapolation errors.

Extrapolation errors in position are introduced from the inherent track uncertainty in velocity and, more significantly, unknown accelerations (particularly from turns) that may be occurring during the extrapolation period (Δt). As a result of an acceleration (f), the extra uncertainty in position will be ½ $f.\Delta t^2$. Consequently, a reasonable acceleration limit needs to be assumed (e.g. 5m/s/s).

Most conservatively, the potential extrapolation error is simply added to the difference threshold.

A.2.5 Effects of uncompensated latencies in the ADS-B position

Aircraft ADS-B installations are allowed a limited amount of uncompensated latency:

- Maximum 0.6s allowed in ED-161 & EASA CS-ACNS (version 2)
- Maximum 1.5s allowed in ED-126 & EASA AMC 20-24 (version 0/1)

Uncompensated latency means that the ADS-B position is old by an uncertain amount – this produces an aircraft-dependent along-track error proportional to speed.

Most conservatively, the worst case ADS-B latency could be assumed and latency × speed simply added to the position difference threshold. However, the worst-case latency with typical aircraft speeds produces relatively large position uncertainties (as compared to the typical ADS-B GPS source and WAM position accuracies). Consequently, it is advantageous for the fidelity of the position comparison to model the uncompensated latencies in ADS-B more realistically.

Practical measurements of compliant installations indicate that the uncompensated latency time error may be conservatively modelled as bias of 0.25s with a standard deviation of 0.15s.

The standard deviation × speed can be combined statistically with the ADS-B position source accuracy standard deviation to degrade overall ADS-B accuracy slightly (i.e. resultant sum of squares).

Although Bias × speed may be used to compensate the ADS-B position along track, it may be simplest and most conservative to add this margin to the difference threshold.

The assumed compensated latency time bias and standard deviation should be made ADS-B version dependent parameters.

Furthermore, in areas of good accuracy WAM, the difference between ADS-B and WAM positions in the along-track direction could be averaged over a number of successive measurements to form a dynamic estimate of the uncompensated latency time bias for the aircraft. Consequently, by obtaining a better estimate of uncompensated latency time bias, a more effective comparison could be made (i.e. a smaller comparison difference threshold could be used for the same false alert rate and this reduces the declared containment bound).

A.3 Nominal (no-fault) situation and determining the difference threshold

A.3.1 Taking account of normal random measurement errors

In the Figure and calculations below, the following terms are used:

- ADSx, ADSy are the x,y components of the ADS-B position.
- σAx, σAy are the standard deviations of the x,y components of ADS-B position.

- WAMx, WAMy are the x,y components of the WAM position.
- σWx, σWy are the standard deviations of the x,y components of WAM position.

Component and resultant differences:

- $\delta x = WAMx - ADSx$
- $\delta y = WAMy - ADSy$
- $\delta r = \sqrt{(\delta x^2 + \delta y^2)}$

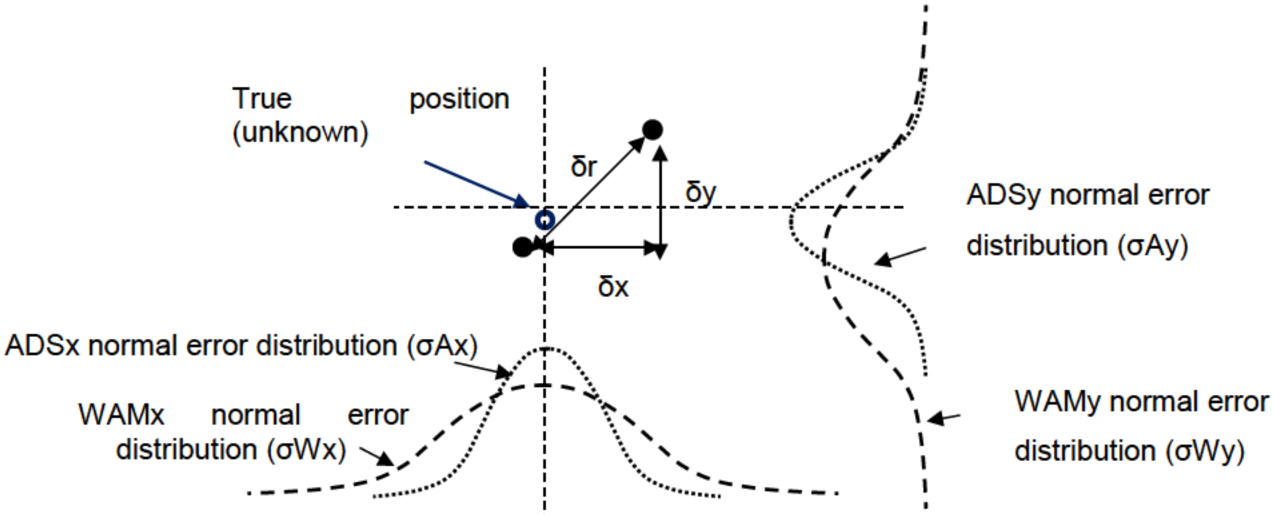

Figure 3: Illustrating nominal (no-fault) differences between ADS-B and WAM positions

In the Figure above, the ADS-B and WAM component errors (in x and y) are assumed to be normally distributed about the true position. [Possible bias errors are considered later].

Statistically, the distribution of a difference between two values with independent Gaussian error distributions is also Gaussian and so the resultant standard deviation of the difference components (δx and δy) is given by:

- $\sigma\delta x^2 = \sigma Wx^2 + \sigma Ax^2$; $\sigma\delta y^2 = \sigma Wy^2 + \sigma Ay^2$;

Given that the error distributions in x and y directions are the same magnitude, as was done by conservatively using the over-bounding circular errors from each source, then the two dimensional difference δr will have a Rayleigh distribution, with characteristic $\sigma = \sigma\delta x = \sigma\delta y$

From a Rayleigh distribution, the probability (Pfa) that the resultant difference (δr) is greater than a threshold D is calculated as: $Pfa = \exp(-D^2 / 2\sigma^2)$.

e.g. $D=4\sigma$,	Pfa = 3.4E-4
$D=4.5\sigma$,	Pfa = 4.0E-5
$D=5\sigma$,	Pfa = 3.7E-6

Consequently, the appropriate threshold value (D) can be determined to satisfy the required probability of false alert, as specified by a configurable system parameter.

A.3.2 Taking account of nominal bias errors

Most conservatively, it is pessimistically assumed that the nominal WAM bias, ADS-B bias from uncompensated latency and any time alignment bias could all be aligned in the same direction as the WAM to ADS-B position difference. Hence, the biases are simply added to the difference threshold (D) as initially determined above, i.e.

$$D \leftarrow D + BA + BW + BE;$$

Where BA = ADS-B uncompensated latency × speed.
BW = WAM nominal bias.
BE = Extrapolation bias in time alignment (from some sustained acceleration)

[It would indeed be possible to take account of the biases in a more sophisticated way, in particular by considering the known (along-track) direction of the ADS-B uncompensated latency bias with respect to the direction of the difference in positions].

The Figure below illustrates a fault situation where the originating ADS-B source has a sustained fault bias (Bf).

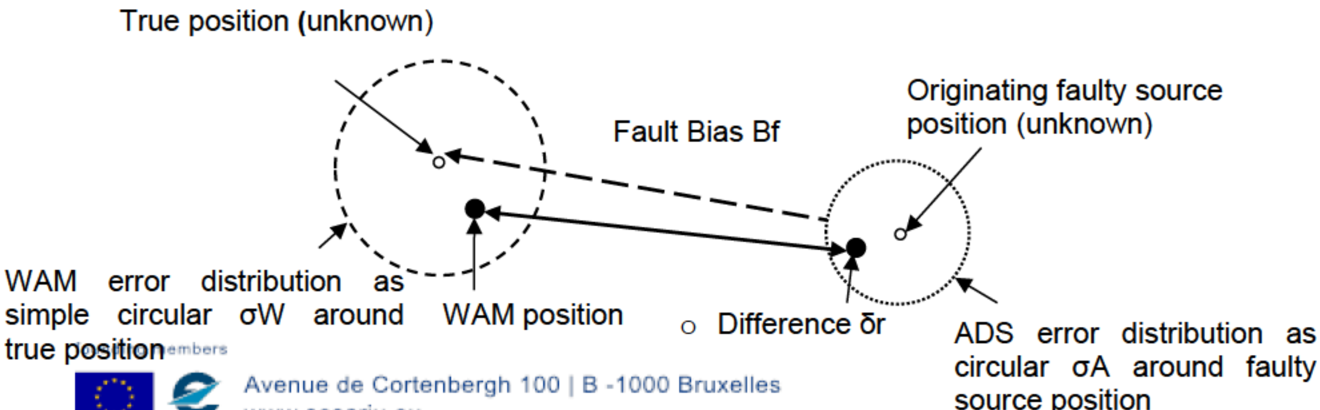

Figure 4: Illustrating fault situation with ADS-B position source bias

The difference (δr) between the WAM and ADS positions will be tested against the threshold value (D). However, even when the fault offset Bf is bigger than D, there is some probability that δr will be less than D (i.e. missed detection) because of the magnitudes and directions of random errors in the normal measurement errors of WAM and ADS.

It was seen earlier that D has to be set to give an acceptably low rate of false alerts in normal (no-fault) conditions and therefore D will need to be at least 4σ, where σ was the combined one directional ADS-B and WAM accuracy error standard deviations. Consequently, when Bf becomes somewhat bigger than D, the random accuracy errors that can most significantly cause δr to fall below D will be predominantly in the single direction along the line of the fault bias Bf. Consequently, one side of the joint σ distribution will predominantly determine the missed detection probability.

In particular, from the normal statistics of a Gaussian distribution (σ), a required missed detection probability of 1E-3 is achieved at approximately 3.1σ. Hence the containment bound (CB) is simply determined from the difference threshold (D) and the joint ADS-B and WAM accuracy error distributions (σ), i.e.

$$CB \approx D+3.1\sigma$$

[Note the 1E-3 missed detection probability is conventionally chosen to be the same requirement value as for the analogous GPS RAIM function, so that the declared containment bound (CB) is equivalent to the GPS horizontal protection limit (HPL) that is used in ADS-B to produce the integrity quality indicator (NIC)].

Comparison with Partial Position

In the case of only two WAM receivers of an ADS-B message, their time difference of arrival (TDOA) defines a hyperbola on which the ADS-B position should agree within the normally expected WAM and ADS-B uncertainties. In this case, the difference of concern is between the ADS-B position and its closest point on the hyperbola, as illustrated in the Figure below.

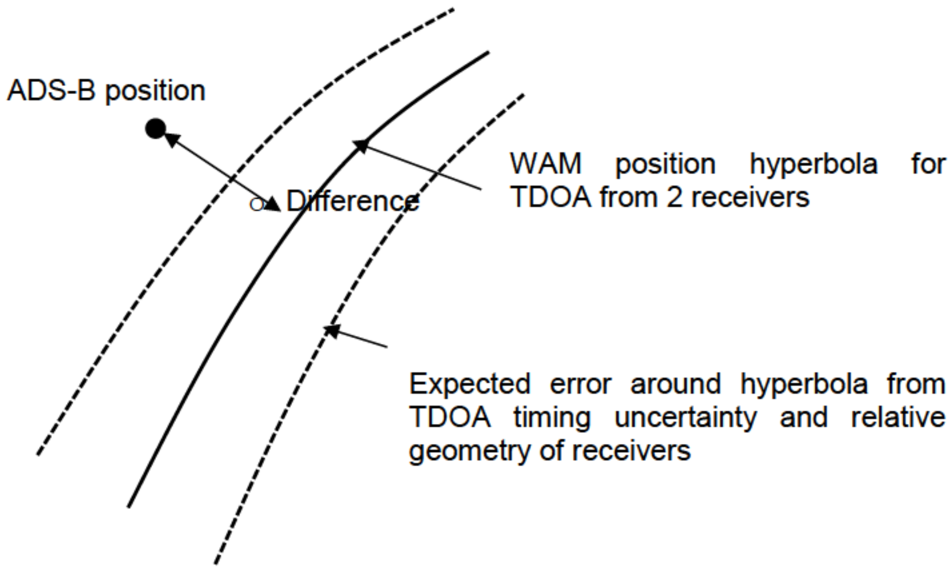

Figure 5: Illustrating TDOA hyperbola in the vicinity of the ADS-B position

A.3.3 Determining the difference threshold for the nominal (no-fault) situation

The difference threshold (D) is determined from the combination of the expected errors from ADS-B accuracy and the WAM errors in the direction normal (90°) to hyperbola at its closest point to the ADS-B position.

As before, the ADS-B accuracy is assumed to be circular and Rayleigh distributed, so the error in any one direction is assumed to be Gaussian (σA) where:

σA = Ra/2.45; and Ra is the 95% accuracy radius.

For WAM, the error in the direction normal to the hyperbola is determined from knowledge of the expected time measurement accuracy of TDOA and the geometry of the ADS-B position with respect to the receivers. It is assumed here that this error is represented by a Gaussian with standard deviation σW.

[Details of how to determine the WAM error from TDOA and geometry should not need to be given because it is in the domain of the WAM manufacturer].

Hence, in the nominal (no-fault) situation, the combined effect of the independent WAM and ADS-B Gaussian errors will produce a Gaussian difference distribution with standard deviation σd, where $\sigma d^2 = \sigma W^2 + \sigma A^2$.

Consequently, the probability of false alert (Pfa) for a difference threshold of D is given by the cumulative distribution function CDF(σd, D).

e.g. D=3.5σ,	Pfa = 4.6E-4
D=4σ,	Pfa = 6 E-5

However, a further margin needs to be added to the threshold to allow for the possible biases in WAM position and ADS-B uncompensated latency. As before, most conservatively, it is pessimistically assumed that the biases could all be aligned in the same direction as the WAM to ADS-B position difference. Hence, the biases are simply added to the difference threshold (D) as initially determined above, i.e.

$$D \leftarrow D + BA + BW + BE;$$

Where BA, BW and BE are biases as described previously.

A.3.4 Determining the containment bound for a position fault situation

Of course for the partial position hyperbola situation, only the component of an ADS-B faulty position in the direction at right angles to the hyperbola can be detected. Nevertheless, it is worthwhile to qualify the bounds to which the test applies and here again the concept of a containment bound is applicable.

As the fault bias in the direction at right angles to the hyperbola (Br) becomes somewhat bigger than the threshold D, then the random accuracy errors that can most significantly cause the difference to fall below D will be predominantly on one side of the joint σ distribution and so this will predominantly determine the missed detection probability.

As before, from the normal statistics of a Gaussian distribution (σ), a required missed detection probability of 1E-3 is achieved at approximately 3.1σ. Hence the containment bound (CB) is simply determined from the difference threshold (D) and the joint ADS-B and WAM accuracy error distributions (σ), i.e.

$$CB \approx D+3.1\sigma$$

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