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Preliminary Safety Case for Air Traffic Control Service in Radar Areas using ADS-B Surveillance

PSC ADS-B-RAD

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Preliminary Safety Case for Air Traffic Control Service in Radar Areas using ADS-B Surveillance

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Abstract

This Preliminary Safety Case documents the results of the EUROCAE ED-161/RTCA DO-318 “Safety Performance and Interoperability Requirements Document for ADS-B-RAD Application” (ADS-B surveillance in Radar Areas). This document aims at being an input to ANSPs to produce their own local Safety Case for the implementation of the ADS-B-RAD.

Keywords

Preliminary Safety Case	Safety Argument	Safety Evidence	ADS-B-RAD
CASCADE Programme	ATC Service	Separation Minima	Safety Targets
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EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
0.1	29/10/2008	First issue: Safety Argument structure.	All
0.2	31/10/2008	Preliminary Safety Case: intermediate version.	All
0.3	April 2009	Preliminary Safety Case: consolidated version.	All
0.4	June 2009	Preliminary Safety Case: change of the arguments structure to account for the distinction between specification and design.	All
0.5	July 2009	Preliminary Safety Case: consolidated version.	All
0.6	October 2009	Preliminary Safety Case: account for comments received by Eurocontrol CoE Safety	All
0.7	November 2009	Consolidation of the design arguments based on the released SPR.	All
0.8	December 2009	Update of the document.	All
0.9	March 2010	Update of the document following review of the CoE Safety on sections 1 to 7.	All
1.0	April 2010	Update prior first SRC Safety Regulatory Review.	All
1.1	June 2010	Update after first SRC Safety Regulatory Review.	All
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2.0	14 December 2010	Released issue that passed a Safety Regulatory Review Process conducted by representatives of National Supervisory Authorities/States within the SRC Coordination Group acting on behalf of the Safety Regulation Commission.	All

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EXECUTIVE SUMMARY

What is ADS-B-RAD about?

ADS-B (Automatic Dependent Surveillance – Broadcast) is a surveillance technique that relies on aircraft periodically broadcasting its parameters, such as identity, position and other onboard information. ADS-B is automatic in the sense that no Flight Crew or Air Traffic Controller action is required for the information to be transmitted. It is dependent surveillance in the sense that the surveillance-type information so obtained depends on the suitable position source and broadcast capability. This signal can be captured on the ground for surveillance purposes (ADS-B-out) or on board other aircraft for air traffic situational awareness (ADS-B-in) and airborne separation assistance.

EUROCONTROL Co-operative ATS through Surveillance and Communication Applications Deployed in ECAC (CASCADE) Programme coordinates the implementation of the ADS-B applications related to the Package I [Ref.2] of Ground and Airborne based Surveillance applications.

Part of the EUROCONTROL CASCADE Programme, the ADS-B-RAD application will support, and in some cases enhance, Air Traffic Services (ATC, FIS, Advisory and Alerting) through the addition of ADS-B surveillance in areas where radar surveillance also exists. This will provide enhancements to these services (compared to current capabilities) in a way similar to the introduction of an additional secondary surveillance radar (SSR) or Mode S radar. In a multi-radar environment, ADS-B may also replace one SSR or one Mode S radar that is intended to be decommissioned.

> *Note: the case where ADS-B is used as sole surveillance means to support ATS is addressed by another ADS-B application called ADS-B in Non Radar Areas – ADS-B-NRA. Another application, ADS-B APT, covers the case in which ADS-B is used to support ATS on the airport surface.*

The Claim

The purpose of this Preliminary Safety Case is to demonstrate that the ADS-B-RAD system, i.e. the use of ADS-B to provide surveillance information together with radar to support Air Traffic Control Service (ATC), will be *acceptably safe*.

Associated to the Claim, this PSC focuses on the replacement of one SSR or Mode S radar by ADS-B in areas where two SSR (or Mode S) radars exist.

ADS-B-RAD can in principle support all ATS services (excluding aerodrome service), but as detailed in the Claim, the ATC service was selected for defining the ADS-B-RAD requirements. This choice was done assuming that if the ADS-B-RAD system (encompassing procedures, people and equipment) can support ATC in the provision of area and approach control services, then these requirements will be sufficient to support the other less demanding services from a surveillance perspective.

From the system design perspective, ADS-B is considered here as the principal source of surveillance for the Air Traffic Controller, using radar information as back-up (i.e. no “fusion” assumed between ADS-B and radar information). A further Preliminary Safety Case is planned to account for the “fusion” case.

'Preliminary' standing for…

By definition a safety case is built on a set of arguments, i.e. statements set out hierarchically claiming that something is true, along with supporting evidence showing that the argument is valid. Goal Structuring Notation - GSN is often used, and it is the case here, for graphically representing this argument/evidence structure.

The high-level safety argument structure proposed in this safety case covers all the safety lifecycle steps, from the development of the ADS-B-RAD system, to bringing it into service and maintaining it throughout its operational life.

This current Safety Case is Preliminary in that it only addresses the Design stages of the ADS-B-RAD system development (identification of the related requirements) considering typical operating environment characteristics (as traffic density) and separation minima to be applied (see below). What this Preliminary Safety Case – PSC does not include are implementation, transition and in-service related issues. Security issues are also out of scope of this document.

At whom this PSC is aimed?

This Preliminary Safety Case for ADS-B-RAD passed a Safety Regulatory Review Process conducted by representatives of National Supervisory Authorities/States within the SRC Coordination Group acting on behalf of the Safety Regulation Commission. The SRC Position Paper [Ref.30] is the formal output of the review of the PSC. Implementers are encouraged to take account this document, and other guidance information, as support and input to Implementers and States when using this PSC as a basis to develop their Local Safety Case.

Accounting for all of that, the aim of this PSC is to be an input to the Air Navigation Service Providers (ANSPs) to produce their own full safety cases (in accordance with the requirements of the local regulator) for a local implementation of ADS-B-RAD.

ANSPs wishing to implement the ADS-B-RAD system in their own airspace should then consider the information and processes presented in this PSC. When the implementer would need to perform additional analysis for its particular case, then the information and processes used in this document may be re-applied to assist the development of the local ADS-B-RAD implementation and in particular the development of the Local Safety Case (LSC - see section 1.6).

In order to facilitate this ANSP's task, guidance material is included in this document for consideration at local implementation level, directly included in the corresponding sections of the document in form of *Guidance Material (GM) Boxes*. More than 80 Guidance Material elements are provided in this document.

Existing related and applicable Standards

As a means of supporting European Air Navigation Service Providers (ANSPs) in optimising their implementation of ADS-B-RAD system, several standards and procedures have been specifically developed.

In particular, the EUROCAE ED-161/RTCA DO-318 joint standard [Ref.1] provides the minimum operational, safety and performance requirements (SPR) and interoperability requirements (INTEROP) for the implementation of the ADS-B-RAD system. This joint standard (developed based on ED-78A [Ref.8] guidance and SAM [Ref.5]) has been developed by the Requirement Focus Group - RFG. This working group consists of members from FAA, EUROCONTROL, RTCA and EUROCAE with participation of AirServices Australia, NAV Canada and Japan, providing technical and operational expertise to RFG activities.

The Preliminary Safety Case document gathers all these results, as well as results from some other standards and related activities (ICAO annexes and documents, EASA reference documents, other EUROCONTROL work and standards, etc.), in order to provide appropriate and sufficient evidence to demonstrate the claim through the proposed arguments. The information presented in this PSC has been in some cases adapted and summarized from its original form in order to obtain a coherent and simplified document. But the PSC does not supersede all assumptions and results made in the reference documents, in particular those from ED-161/DO-318 [Ref.1].

"Acceptably safe" with respect to what?

The ADS-B-RAD system is defined here as all the elements (people, procedures and equipment) allowing to support Air Traffic Control (ATC) service in both En-route and TMA airspaces, using ADS-B to provide surveillance information together with radar. And the main purpose is to demonstrate that it is acceptably safe. But, what does "acceptably safe" mean?

The safety broader approach (as named in SAME Part 2 [Ref.22]) applied in the Safety Case addresses both the positive (success approach) and the negative (failure approach) contribution of the ADS-B-RAD system to the related ATM risk.

A safety criterion used to define "acceptably safe" is a comparative approach in which it is requested that the risk of an accident/incident for the ATC service supported by ADS-B-RAD system is no greater than when supported by a radar-only based system ("Reference system").

From baseline to proposed change: detailed considered scenarios

Multiple options exist for designing the ADS-B-RAD system: ADS-B combined with PSR, with SSR (or Mode S) and with PSR and SSR. Three (3) specific scenarios (assumed to be the most demanding ones), are used in the PSC for the derivation of the ADS-B-RAD system safety requirements satisfying the safety criteria mentioned above.

The strategy is then to assess ADS-B-RAD and the corresponding Reference systems in the same operational conditions through these scenarios, which encompass a specific surveillance system supporting ATC services in a specific Operational Environment (mainly characterised by the type of airspace and the separation minima applied). In all these scenarios, it is assumed that all aircraft are ADS-B and radar equipped and certified for ADS-B-RAD.

Both the ADS-B-RAD system (combining the use of ADS-B with other radar types) and the corresponding reference system (using only radars types) considered for each scenario are described here after:

Scenario 1 (RAD-1): ATC services in a TMA area with medium traffic density (i.e. an average of 6 flight hours controlled per sector hour and a maximum of 15 instantaneous aircraft count in a sector), applying 3 NM as separation minima. The surveillance systems considered here for supporting the ATC services are based on:

- ADS-B-RAD system: ADS-B and PSR surveillance means.
- Reference system: SSR and PSR surveillance means.

Scenario 2 (RAD-2): ATC services in En-route airspace with high traffic density (i.e. an average of 6 flight hours controlled per sector hour and a maximum of 20 instantaneous count aircraft in a sector), applying 5 NM as separation minima. Two sub-cases are used for the surveillance systems supporting the ATC services based on:

Case 2.a (RAD-2a):

- ADS-B-RAD system: ADS-B and SSR as surveillance means
- Reference system: two SSR as surveillance means

Case 2.b (RAD-2b):

- ADS-B-RAD system: ADS-B and Mode S (elementary surveillance) as surveillance means.
- Reference system: two Mode S as surveillance means

Scenario 3 (RAD-3): ATC services in TMA airspace with high traffic density (i.e. an average of 6 flight hours controlled per sector hour and a maximum of 15 instantaneous count aircraft in a sector), applying:

- 3 NM as separation minima in the wide area
- 2.5 NM separation minima for succeeding aircraft on the same final, and
- 2 NM separation minima for succeeding aircraft on adjacent ILS/MLS

The surveillance systems considered in this scenario for supporting the ATC services in this conditions are based on:

- ADS-B-RAD system: ADS-B and PSR and SSR as surveillance means
- Reference system: two SSR and PSR as surveillance means

Note that the most demanding ADS-B avionic safety requirements have been derived using these scenarios (which applies the most stringent separation minima). These ensure that the avionic safety requirements are not the limiting factor for the selection of a separation standard to be used in ADS-B-RAD system. This PSC recognises that the specification of the separation minima to be applied in ADS-B-RAD system rests with the responsibility of the implementer who may prescribe greater separation minima than those specified in this document.

The Arguments to be demonstrated …

The two principal Arguments that are addressed herein are the description of the ATC service supported by the ADS-B-RAD system (Argument 1) and the fact that the system is designed (Argument 2) to be acceptably safe.

For the Argument 1, the main purpose is to describe the ATC service supported by the ADS-B-RAD system and to state that there is no change when this service is supported by the Reference system (i.e. radar-only based) or by ADS-B-RAD system (i.e. ADS-B + radar) in the operating conditions mentioned before.

In Argument 2, Safety Targets are set for ADS-B-RAD system, in line with the safety criterion, presented before. In particular, to define the appropriate portion of the ESARR4 Target Level of Safety (TLS) to be allocated to ADS-B-RAD and the main purpose is to demonstrate that all necessary safety requirements are captured at system design level to safely provide the service described in previous argument. And that is to be done taking into account nominal conditions, abnormal conditions and also system failure cases. Corresponding safety requirements can be found from sections 7 to 10 of this document.

In nominal conditions, the strategy adopted to define the corresponding safety requirements is, in line with the safety criterion presented before, the one-by-one comparison between the Reference and the ADS-B-RAD system, in terms of operational procedures and tasks to be done, operational and technical data items used by the system, functions provided by each element of the system and their corresponding performances.

For the abnormal conditions, appropriate safety requirements are to be derived to ensure the robustness and resilience of the ADS-B-RAD system against failures or abnormal behaviour of external elements or events.

Finally, the integrity part of the ADS-B-RAD system design is to be done based on a risk assessment of potential failures of the ADS-B part of the system, providing the related safety requirements mitigating the associated risk and ensuring that the Safety Targets allocated from ESARR4 [Ref.6] and ED-125 [Ref.13] are satisfied.

At the end it is also necessary to show that all these safety requirements are realistic in the sense that they are verifiable and that they are capable of being satisfied in a typical implementation. Finally, it is to be shown that the evidences provided are trustworthy, i.e. can be relied upon, in terms of sound process, correctly applied by competent personnel to obtain them.

…and the Evidences provided.

In addressing these Arguments, the Evidence presented in the first part of the PSC (for argument 1) set out the concerned ATC service (unchanged for Reference and ADS-B-RAD scenarios) described as per PANS ATM Doc 4444 [Ref.3] and ICAO Annex 11 [Ref.17] and in the second part of the PSC (Argument 2), Evidence provided show that the system is designed to be acceptably safe.

For the Safety Targets, the apportionment from the ATM to the surveillance level has been done based on ESARR4 [Ref.6] and ED-125 [Ref.13] leading to acceptable risks related to ADS-B-RAD in the order of magnitude of:

- 9.0e-09 per sector hour (1.5e-09 per flight hour) for accidents
- 1.0e-06 per sector hour (2.0e-07 per flight hour) for serious incidents
- 2.0e-05 per sector hour (3.0e-06 per flight hour) for major incidents
- 7.0e-04 per sector hour (1.0e-04 per flight hour) for significant incidents

These figures are calculated based on the characteristics of the airspace considered in each scenario, in which 1 sector hour is considered to be equivalent to 6 flight hours. An ambition factor of 10 has been applied to the ESARR4 TLS in order to ensure that the system is “future-proofed” (against unknown environmental characteristics in the future) and that subjective expert judgement is given margin of error in the assessment done. These Safety Targets values are valid for all the ADS-B-RAD scenarios (detailed Safety Targets are in the same order of magnitude).

All necessary safety requirements are presented in the document: safety requirements on data items provided and display features for ATCo and FC interfaces (e.g. related to the horizontal position data and its related quality indicator for each aircraft), on new functions (e.g. ADS-B data processing at airborne and ground sides) and related performance (e.g. latency) as well as on other elements required for allowing ADS-B-RAD to be operated (e.g. VHF availability for Flight Crew/Air Traffic Controller voice communication). Safety requirements concerning the aircraft eligibility for separation minima considered in each scenario are also determined in terms of accuracy and integrity of the horizontal position data sent by each aircraft.

Finally, a certain number of assumptions have been made and validated, mainly concerning performances of external elements (e.g. GNSS integrity) and human actions (e.g. detection by Air Traffic Controller of incorrect information on the display).

All these results have been obtained based on the Requirement Focus Group (RFG) working approach: working groups including technical and operational experts formalising their activities as per ED78A [Ref.8] process and EUROCONTROL SAM methodology [Ref.5]. The large number of RFG participants, the variety of perspectives (US, Europe, etc), the involvement of operational people (ATCo & Pilots), the number of ANSPs including future European implementers, all these elements contribute to demonstrate that the RFG brought key competence to apply the mentioned methodologies and approaches and to shown that all the safety requirements are achievable in a generic implementation of the ADS-B-RAD system.

Safe? Yes, but taking account of…

This Preliminary Safety Case concludes that ADS-B-RAD system, i.e. the use of ADS-B to provide surveillance information together with radar to support Air Traffic Control Service (ATC) is *acceptably safe*, subject to the satisfaction of the safety requirements mentioned before but also to certain caveats highlighted here:

- The PSC is limited to generic aspects, i.e. to a typical ATC service and to the typical design of the ADS-B-RAD system in typical operational environments.
- The PSC only addresses the design stage of the application. It does not address implementation, transition and in-service stages of the safety lifecycle.
- The PSC defined a typical ATC service (including separation task) taking place in a typical operational environment supported by an ADS-B-RAD system, which is derived by comparison with a Reference radar-based situation.
- It is assumed for the purposes of the PSC that 100% of aircraft are equipped and certified for ADS-B-RAD.
- Human factors as they are closely related to the implementation are out of the scope of the PSC.
- The ICAO material (Circular) to support ADS-B for 3 NM has not been published at the time of edition of this PSC document.
- The ICAO material (Annex 10 and Doc 9871) update to support the removal of the current Mode A geographical filter has not been published at the time of edition of this PSC document.
- The case of “independent parallel runways with a spacing between centreline less than 1310 meters but not below 1035 meters has not been assessed in this PSC.
- No “fusion” is considered to take place between radar and ADS-B surveillance data at ground level. Another assessment is foreseen to be done in a short term to cover this case.
- Concerning the airborne part of the system, GNSS has been identified as the sole source of information for the horizontal position data and its corresponding quality indicator. Alternative positioning sources are not covered in this document.
- ADS-B data link version 0 (DO-242) does not satisfy ADS-B-RAD safety requirements.

1 INTRODUCTION

1.1 BACKGROUND

ADS-B (Automatic Dependent Surveillance – Broadcast) is a surveillance technique that relies on aircraft periodically broadcasting its parameters, such as identity, position and other onboard information. ADS-B is automatic in the sense that no Flight Crew or Air Traffic Controller action is required for the information to be transmitted. It is dependent surveillance in the sense that the surveillance-type information so obtained depends on the suitable position source and broadcast capability. This signal can be captured on the ground for surveillance purposes (ADS-B-out) or on board other aircraft for air traffic situational awareness (ADS-B-in) and airborne separation assistance.

The EUROCONTROL Co-operative ATS through Surveillance and Communication Applications Deployed in ECAC (CASCADE) Programme coordinates the implementation of the Automatic Dependent Surveillance-Broadcast (ADS-B) applications related to the Package I [Ref.2] of Ground and Airborne based Surveillance applications. A total of nine ADS-B applications have been dealt with by CASCADE so far. More details on these ADS-B applications can be found in §1.2.1 of EUROCAE ED-161/RTCA DO-318 joint standard [Ref.1].

Part of the EUROCONTROL CASCADE, the ADS-B-RAD system is defined as all the elements (people, procedures and equipment) allowing to support Air Traffic Services in both En-route and TMA airspaces, using ADS-B to provide surveillance information together with radar.

The introduction of ADS-B surveillance in areas where radar surveillance also exists will provide enhancements to these services (compared to current capabilities) in a way similar to the introduction of an additional secondary surveillance radar (SSR)

In a multi-radar environment, ADS-B may also replace one SSR or one Mode S radar that is intended to be decommissioned while maintaining at least the same level of ATC and *reducing installation and maintenance costs.*

1.2 AIM

The aim of this Preliminary Safety Case (PSC) is to demonstrate that the use of ADS-B to provide surveillance information together with radar (ADS-B-RAD system) to support ATC service has been designed to be acceptably safe (see section 2.3 for the corresponding safety criteria) through the identification of all the related safety requirements. This PSC particularly focuses on the Air Traffic Control separation task in both en-route and TMA airspace.

As a means of supporting European Air Navigation Service Providers (ANSPs) in optimising their implementation of ADS-B-RAD system, several standards and procedures have been developed. In particular, the EUROCAE ED-161/RTCA DO-318 joint standard [Ref.1] provides the minimum operational, safety and performance requirements (SPR) and interoperability requirements (INTEROP) for the implementation of the ADS-B-RAD system.

The purpose of this Preliminary Safety Case (PSC) is to document the results of this assessment, as well as results from some other standards and related activities, as input to the ANSPs to produce their own, local full safety cases in accordance with the requirements of the local regulator.

This PSC covers both the airborne and the ground elements. This PSC will derive the most demanding ADS-B avionic requirements through the consideration of the most stringent case, i.e. the ATC service (as defined in this document)

> *Note: This PSC recognises that the specification of the separation minima to be applied in (local) ADS-B-RAD system rests with the responsibility of the implementer who may prescribe greater separation minima than those specified in section 2.2.2 of this document.*

This document identifies all the airborne and ground safety requirements, using the following tag: “SAFxxx”. Safety requirements are mainly identified in the sections 7 to 10 of this document.

In addition, “Assumption”, “Issue” and “Limitation” identified throughout this document are labelled “Axxx”, “Ixxx” and “Lxxx” and the corresponding justification, implications or related actions required are identified in sections 13 (Assumptions, Issues and Limitations).

> *Note: The term “Limitation” used in this document refers to the limitation of the scope of the ADS-B-RAD system assessed (e.g. analysis limited to GNSS as sole positioning source, fusion technique being out of the scope of the document) and does not restrict the definition of local ADS-B-RAD systems for which additional analyses may have to be performed.*

This Preliminary Safety Case for ADS-B-RAD passed a Safety Regulatory Review Process conducted by representatives of National Supervisory Authorities/States within the SRC Coordination Group acting on behalf of the Safety Regulation Commission. The SRC Position Paper [Ref.30] is the formal output of the review of the PSC. Implementers are encouraged to take account this document, and other guidance information, as support and input to Implementers and States when using this PSC as a basis to develop their Local Safety Case.

1.3 INTENDED AUDIENCE

The intended audience for this document consists of the Stakeholders responsible for implementing the ADS-B-RAD system locally. It will help them to conduct their national and/or local safety assessments for ADS-B-RAD implementation. This will include ANSPs. NSAs are also concerned as they will need to ensure safety oversight of changes to functional systems (as per EC 1315/2007 [Ref.24]), based, amongst other things on the local implementation safety argument and evidence provided by ANSPs.

More specifically, it is proposed that the Safety Requirements, Assumptions, Limitations and Issues, together with the accompanying Guidance Material

(GM) derived in this Preliminary Safety Case will be considered by the various Stakeholders as follows:

- Aircraft domain Safety requirements and Assumptions (in line with the EUROCAE ED-161/RTCA DO-318 joint standard [Ref.1] airborne requirements) are used as input to the development of the certification material (ADS-B out Certification Specification (CS) [Ref.14] under development at the time of edition of this document). If the local implementation requires an amendment of these requirements, it requires the change to be justified through the Local Safety Case (LSC) activities. The National Regulator will also have to ensure that these requirements / assumptions have been implemented during Arg 3 (implementation phase).

- Ground domain Safety Requirements, Assumptions, Limitations and Issues, together with the accompanying Guidance Material (GM) derived in this Preliminary Safety Case should be considered by ANSPs when conducting their own Local Safety Case.

1.4 SCOPE

This PSC defines a service (Air Traffic Control for Area and Approach Control Services) taking place in a typical Operational Environment supported by an ADS-B-RAD system (use of ADS-B to provide surveillance information together with radar) which is derived by comparison with a “Reference system” (radar only based situation - see section 1.5).

The introduction of ADS-B in areas where radar surveillance does not exist is out of scope of this document but is covered by the ADS-B-NRA Preliminary Safety Case [Ref.23].

The introduction of ADS-B to enhance aerodrome operations is out of scope of this document and is planned to be covered by the ADS-B-APT Preliminary Safety Case (under development at the time of edition of this document)

This PSC only addresses the typical Operational Environment (traffic density, separation minima and more detailed characteristics) that are developed in section 2.2 and ESARR4 derived Safety Targets developed in section 5. Therefore local aspects of those characteristics (e.g. local OE with different traffic density/separation minima or different local Safety Targets) are not included in this document.

This PSC corresponds to a specific design in which ADS-B surveillance is the principal surveillance source presented to the Air Traffic Controllers with SSR/Mode-S radar as a back-up (i.e. no fusion of ADS-B and SSR/Mode-S data). The case of “fusion” of ADS-B and SSR/Mode-S data is therefore out of scope of this document and is planned to be addressed in a separate Preliminary Safety Case **I001**).

The ADS-B-RAD requirements have been derived from a typical radar-based Reference system supporting the same service (see section 3) in the same typical OE (see section 2.2), with in particular the same separation minima and the same traffic density. A situation corresponding to a change of OE between the Reference system and the ADS-B-RAD system is not covered in this PSC (see section 1.6).

Replacement by ADS-B of Non-Cooperative only surveillance (PSR) is out of scope of this document given the differences in sensor type and requirements associated with detection of aircraft that may not be equipped with a transponder.

This PSC corresponds to a specific airborne design in which ADS-B surveillance source is based on GNSS. Therefore other position determining methods (e.g. INS) are not included, as they are not capable of meeting the requirements defined in this PSC.

Although the global approach of this PSC is relatively data link technology independent, it contains some elements uniquely based on the characteristics of the1090 MHz link technology (e.g. notion of messages).

Regarding life cycle, this Safety Case is preliminary in that it addresses only a typical ATC service and the typical design of the ADS-B-RAD system in Typical Operational Environments (**I002**). Implementation, transition and in-service stages of the safety lifecycle (**I003**) are therefore not covered in this PSC.

> *Note: The mapping of the functional requirements expressed in this document onto the (local) physical architecture is out of scope of this document and will have to be covered as part of the implementation stage*.

Security issues are out of scope of this document.

1.5 DEFINITION OF GENERAL TERMS USED IN THIS DOCUMENT

The following terms are defined in order to better describe the context in which the claim is addressed and demonstrated in this PSC:

ADS-B-RAD system: These are all the elements (people, procedures and equipment) allowing to support Air Traffic Control Service in both En-route and TMA airspaces, using ADS-B to provide surveillance information together with radar.

Typical Operational Environment (OE): this is the Typical OE in which the service takes place, En-route and terminal areas. Section 2.2 provides the characteristics of Typical OE (traffic density, separation minima, and more detailed characteristics) considered for the design of the ADS-B-RAD system.

> *Note: in the rest of this document, the term “TMA” can be read as equivalent to any airspace that contains an Approach Control Service, and the term “En-Route” can be read as equivalent to any airspace that contains an Area Control Service.*

> *Note: in the rest of this document the term ATC refers either to the Area or Approach Control Services and excludes the Aerodrome Control Service which is not part of ADS-B-RAD (see ADS-B-APT)*

Reference system (**C001**)**:** similarly to the ADS-B-RAD system definition, this is all the elements (people, procedure, equipments) allowing to support ATC service through the use of radar-only in the Typical OE. The Reference system will be used as a reference for comparison when considering the ADS-B-RAD system.

Logical design: it contains the procedures, the human tasks, the functions, the surveillance data items and the related performances necessary to perform the ATC service in the Typical Operational Environments. It does not extend to the physical design which is performed at the local level (Arg3). The logical design is a view of the system that allows the definition of the requirements for the implementation.

Additional terms are defined below regarding the local implementation. These elements are out of scope of this PSC as they depend on the local implementation but will be referred to in the guidance material inserted throughout this document (see also section 1.6):

Local OE: this is the local OE in which the ATC service will take place, supported by the implemented local ADS-B-RAD system.

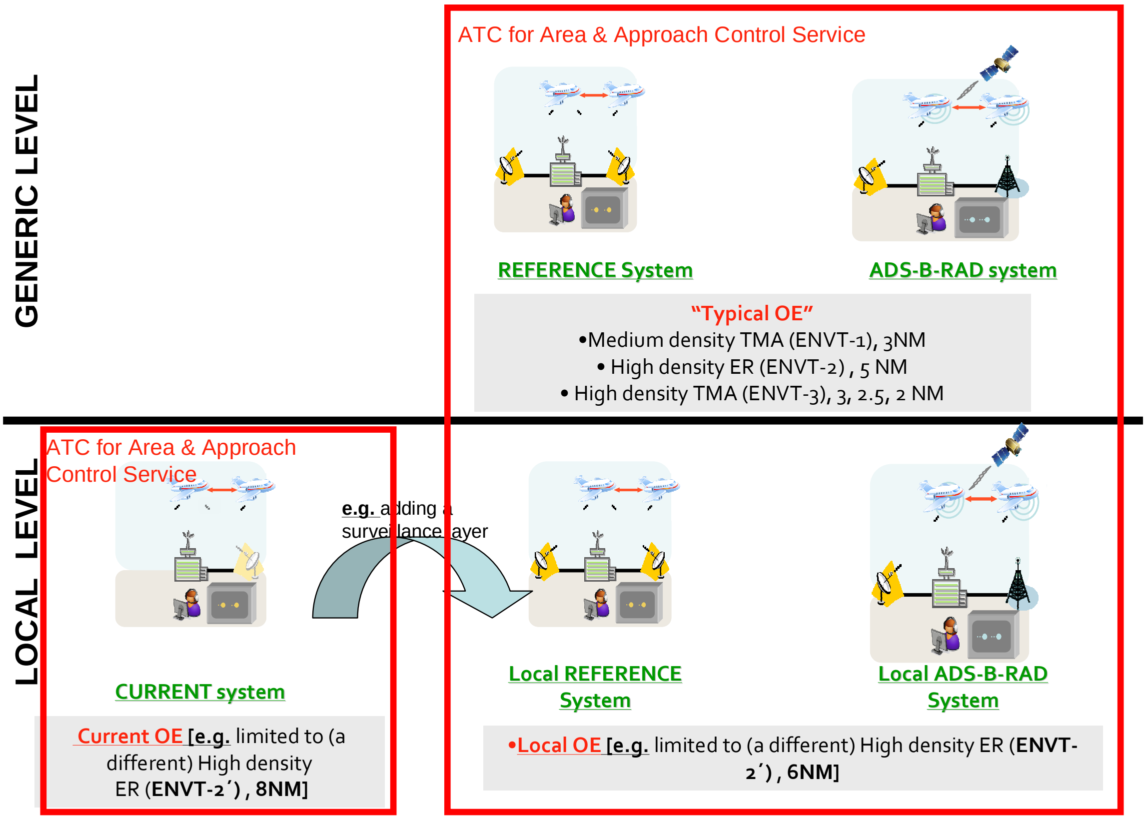
Local ADS-B-RAD system: this is the ADS-B-RAD system implemented at local level, in principle identical or relatively similar to the ADS-B-RAD system but with potentially some differing elements.

Local Reference system: this is the Reference system considered at local level, in principle identical or relatively similar to the Reference system but with potentially some differing elements (e.g. local reference radar differing from the Reference radar).

Current OE: this is the OE applied currently at local level (prior ADS-B deployment).

Current system: all the elements (people, procedures and equipment) allowing to support Air Traffic Control Service in the current OE.

The figure below illustrates these terms, using some characteristics of the Typical Operational Environments (as defined in section 2.2) versus local characteristics (fictitious) examples:



Red color illustrates the ATC service part and the definition of the Operational Environment versus the system design part (green)

Figure 1 Example of generic characteristics of the Typical Operational Environments (PSC) versus local characteristics

1.6 NEXT STEP TOWARDS LOCAL SAFETY CASE

ANSPs wishing to implement the ADS-B-RAD system in their own airspace should consider the information and processes presented in this PSC (including guidance provided throughout the document). When the implementer needs to perform additional analysis for their particular case, then the information and processes used in this document may be re-applied to assist the development of the local ADS-B-RAD implementation and in particular the development of the LSC.

I004 For the purposes of supporting their LSC, it is the responsibility of the implementer to perform a comparative analysis between:

- the typical Reference OE versus the local OE (e.g. avionics equipage, different traffic figures or separation minima)
- the Reference system versus the Local Reference System (radar based) situation (e.g. the characteristics of the Reference radar)

- the Local Reference System versus the Current system (e.g. dual radar 6 NM versus current single radar 10 NM)

With these comparisons the implementer will establish a position on the differences that exist. The larger the differences, the greater the amount of extra analysis and evidence that the implementer will be required to perform and collect to satisfy the arguments presented in this PSC.

For example the Current system may take place in an Operational Environment applying 10 NM separation in the Area Control Service for a particular group of sectors and, with the introduction of ADS-B adding to the current radar, the implementer may wish to reduce separation minima to 5NM.

In this case although the local reference system may allow 5NM (and hence may compare to the ADS-B-RAD system defined in this PSC), there may be other factors required to be changed in the Local OE to support the reduced separation minima apart from surveillance requirements (i.e. airspace design).

Note: the two first bullet points may have impact on the requirements defined in this document, whereas the third bullet point may impact the definition of the requirements related to transition from current situation into ADS-B-RAD situation.

Note: the satisfaction of the requirements will have to be addressed when considering Argument 3 (implementation) For example, the implementer will have to ensure that the RF conditions that may exist in the local operational environment do not adversely impact the satisfaction of the requirements expressed in this document.

Note: As this is introduced in section 9, during the implementation phase, a number of dependencies with other than surveillance infrastructure and systems are to be considered, such that the implementation of ADS-B must be regarded as a complex, multidiscipline program requiring a high level of coordination.

When relevant, these elements (typical Reference OE versus the local OE, Reference system versus the Local Reference System, Local Reference System versus the Current system) will have to be considered as part of the full local safety case covering the entire safety life cycle, including the service definition, the design, the implementation, the transition and the in-service stages.

In order to facilitate an ANSP´s task relating to local design, which is the other main objective of this PSC, proposed Guidance Material is directly included in the relevant sections of this document in the form of Guidance Material (GM) Boxes as shown here after:

GM000. Proposed Guidance to implementers is directly included in the corresponding sections of this document in the form of Guidance Material Boxes as this one.

Note: In the rest of the document, the term "implementer" corresponds to the authority responsible for development of the local safety case.

GM001. To develop these arguments and evidence at local level, it is suggested that the same decomposition, which is used at generic level in this PSC, should be used in general, and tailored to the local level situation. This could be done by focusing in particular on the differences between the elements presented in this PSC and those from the local level. Local Safety Case should include in addition to arguments presented in this PSC those relating to the implementation, transition and in-service phases.

GM002. To develop the evidence that will support arguments at a local level, the PSC methodology or other ESARR4 [Ref.6] compliant method should be used.

GM003. The validity/applicability of all the "Assumption", "Issue" and "Limitation" identified throughout this document should be considered at local level and their corresponding impact assessed in the local safety case.

1.7 REFERENCE AND APPLICABLE DOCUMENTS

This PSC refers largely to the Performance, Safety and Interoperability constituents from EUROCAE ED-161/RTCA DO-318 joint standard [Ref.1]. This document provides:

- A description of the ADS-B-RAD system on the basis of ICAO PANS ATM [Ref.3] including ADS-B procedures in chapter 8 ("Surveillance Services"),
- A description of the typical environments in which it will operate, which correspond to dense airspaces such as those that will be found in Europe and the USA;
- The corresponding safety and performance assessments and requirements together with interoperability and other related requirements.

This joint standard has been developed by the Requirement Focus Group - RFG. This working group consists of members from FAA, EUROCONTROL, RTCA and EUROCAE with participation of AirServices Australia, NAV Canada and Japan, providing technical and operational expertise to RFG activities.

The information presented in this PSC has been in some cases adapted and summarized from its original form in order to obtain a coherent and simplified document. The original text is available through the corresponding references (mainly from ED-161/DO-318 joint standard [Ref.1]).

Nevertheless, it has to be noted that this document does not supersede all the requirements and assumptions made in this reference document [Ref.1] (**I005**).

Other results from additional related activities (e.g. ICAO documents, EASA[1] reference documents, other standards, other EUROCONTROL work) have also been used and referred to in this Preliminary Safety Case.

Additionally, the applicable regulations considered in this document are the following:

- Commission Regulation (EC) 2096/2005 of 20 December 2005 laying down common requirements for the provision of air navigation service ([Ref.12])

- EUROCONTROL Document - Safety Regulatory Requirement 4 (ESARR4), “Risk Assessment and Mitigation in ATM” ([Ref.6])

Section 15 provides reference to all standards and documents considered in this Preliminary Safety Case.

1.8 DOCUMENT LAYOUT

Section 2 presents a complete, high-level Safety Argument (Arg0), covering the whole safety lifecycle, in order to provide a framework that can also be used for the development of a Local Safety Case by individual implementers.

The Safety Argument (Arg1), related to the description of the ATC service supported by the ADS-B-RAD system which is the same the one supported by the Reference system, is presented in **section 3.**

Section 4 presents the Safety Argument (Arg 2) related to the ADS-B-RAD system design and its lower-level Arguments from **section 5** to **section 12**.

Section 13 presents the caveats (i.e. assumptions, operational limitations, and outstanding safety issues) associated with the safety assessment on which this Preliminary Safety Case is based.

Section 14 then provides overall conclusions concerning the safety of the design in Typical Operational Environments of the ADS-B-RAD system, subject to the caveats presented in section 13.

Document references and a glossary are provided in **sections 15 and 16** respectively.

Annex A presents the hazard classification matrix used for sub-Argument presented in section 10 concerning the mitigation of internal failures.

[1] Under development at the time of the PSC edition.

Annex B lists the organisations involved in the design of the ADS-B-RAD system.

Annex C provides the Goal Structuring Notation (GSN) legend, i.e. the symbology used to represent Safety Arguments links and Preliminary Safety Case structure.

Annex D provides the full (one page) GSN structure detailed in the ADS-B-RAD PSC.

Annex E illustrates the scope of the service supported by the ADS-B-RAD system from an ICAO definition perspective.

Annex F provides some details on the derivation of the Safety Target ST002.

Annex G provides a summary of the Surveillance Separation Error (SSE) analysis that determines the horizontal position containment bound (Navigation Integrity Category or NIC) per the various separation minima scenarios considered in this document.

Annex H provides a discussion on Display Techniques for Primary Surveillance Radar (PSR) targets.

Annex I provides a discussion on Human Tasks in ADS-B-RAD.

Annex J analyses and compares the various methods of coordination and transfer between ADS-B-RAD and Reference systems.

Annex K ensures traceability between requirements of [Ref.1] and those of this PSC and provides some rationale when a difference is identified.

2 OVERALL SAFETY ARGUMENT (ARG 0)

A high-level view of the safety argument structure is presented, in the form of Goal-Structuring Notation (GSN)[2], in the following figure below:

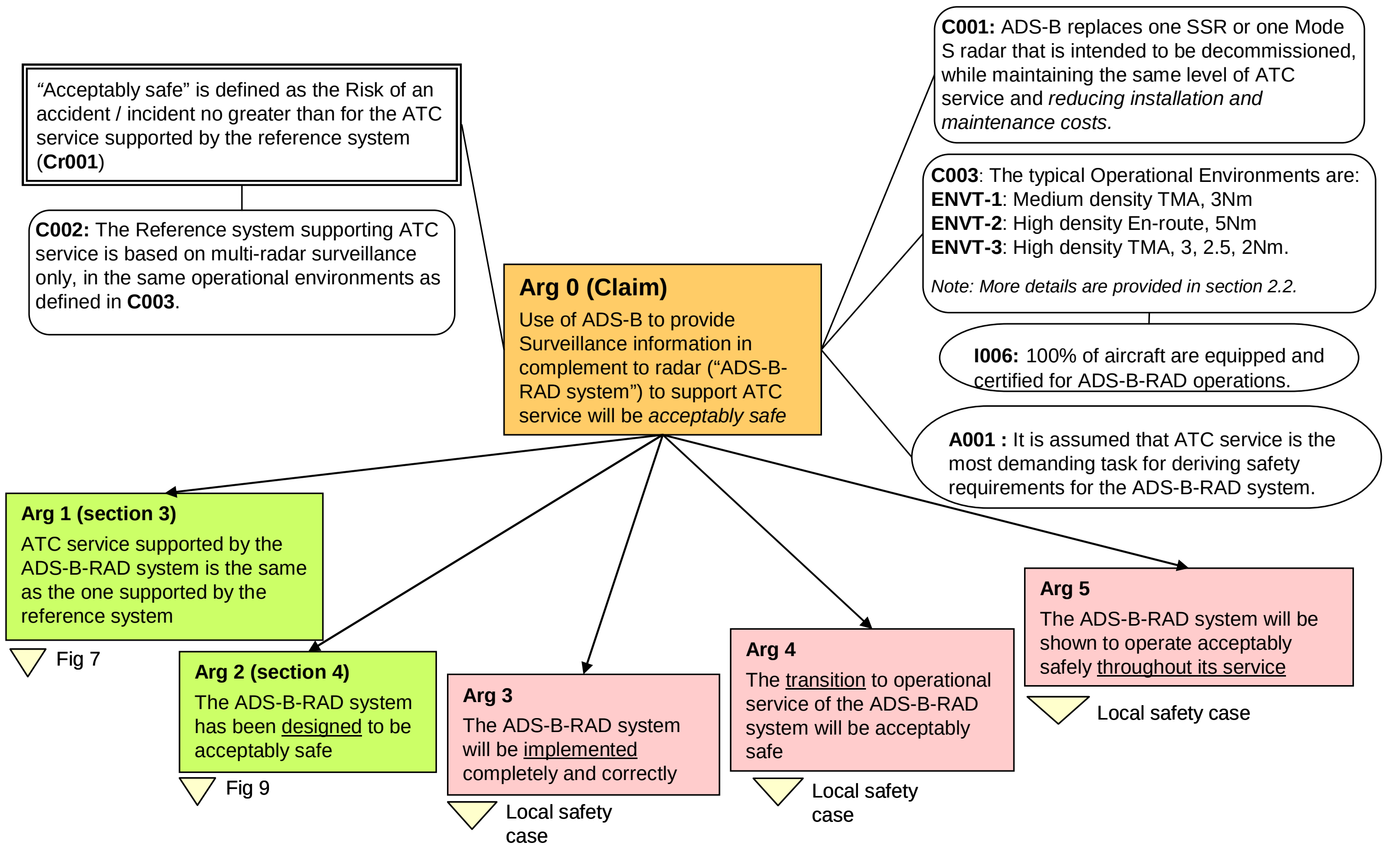


Figure 2: Decomposition of Argument 0 (Claim)

2.1 CLAIM

As indicated in section 1.4, this Safety Case is preliminary in that it addresses only the definition stage of the service supported by the ADS-B-RAD system and the design stage of the ADS-B-RAD system (**I003**) and does not cover the implementation, transition and in service stages. This is reflected by the green colour (in scope) versus the pink colour (out of scope) in the above figure.

Section 2.4 provides the strategy for decomposing the claim.

The Safety Argument starts with the top-level Claim (**Arg 0**) that the ADS-B-RAD system, i.e. the use of ADS-B to provide surveillance information together with radar to support Air Traffic Control Service (ATC) will be *acceptably safe.*

[2] A guide to GSN symbology is given in Annex C

Of the Air Traffic Services (ATS) that deal with airborne aircraft, the ATC service was selected as the main candidate for defining the ADS-B-RAD system requirements. The assumption is that if the ADS-B-RAD system can support ATC in the application of area and approach control services (excluding the Aerodrome Control Service), then the ADS-B-RAD system requirements will be sufficient to support the other less demanding services from a surveillance perspective.

Therefore, the ADS-B-RAD system has been designed to support the ATS Surveillance Service[3] within the confines of the ATC services of Area and Approach Control and the Annex D provides justification and detail of these considerations and how each ICAO services relate to each other from a hierarchical point of view.

This has been stated then as:

A001. It is assumed that the Area and Approach Control Services are the most demanding tasks for deriving safety requirements for the ADS-B-RAD system.

> *Note: The management of aircraft on the airport surface was not included in the ADS-B-RAD system as another EUROCONTROL CASCADE ADS-B application (ADS-B-APT) has been defined at standardisation level for this analysis and in particular this means that the ATC component related to the prevention of collisions on the manoeuvring area are not in the scope of the ADS-B-RAD system or this PSC*.

The selection of these demanding services for deriving ADS-B-RAD requirements was based on operational and technical RFG expertise.

C001 indicates the context in which the change will take place: introducing the ADS-B-RAD system in the typical Operational Environment (**C003**) in order to maintain the same level of Air Traffic Control Service (separation minima are unchanged). ADS-B is intended to replace one SSR or one Mode S radar that will be decommissioned, targeting at reducing installation and maintenance costs.

The safety criterion applied in the rest of this PSC document corresponds to the comparison to an existing Reference system, in line with context **C002**.

> *Note: Definition of the term Reference system is provided in the section 1.5.*

[3] Extract from PANS-ATM definitions: ATS surveillance service. A term used to indicate a service provided directly by means of an ATS surveillance system.

2.2 TYPICAL OPERATIONAL ENVIRONMENT DESCRIPTION

Three Typical Operational Environments have been considered for both the Reference and the ADS-B-RAD systems. The main characteristics that differentiate each of these environments are the traffic density, the type of airspace and the separation minima that is intended to be supported by the ADS-B-RAD and the Reference systems and are described in this section.

These 3 Typical Operational Environments are (**C003**):

ENVT-1: Medium density TMA, 3NM

ENVT-2: High density En-route, 5NM

ENVT-3: High density TMA, 3, 2.5, 2NM

ADS-B-RAD and the Reference systems operate in <u>identical</u> Typical Operational Environments as described in the following sub-sections. A detailed description of these typical Operational Environments can also be found in [Ref.1], Annex A.

> **GM004.** If the Local ADS-B-RAD Operational Environment is different to the one considered in this PSC, implementers should consider the deltas and the impact on the assessments.
>
> Note: in particular, differences in terms of traffic densities and separation minima impact the results of the safety assessment (e.g. GM070 in section 10.7 for traffic density and section 10.4.4 for separation minima).

2.2.1 Traffic Densities and Type of Airspace

The ADS-B-RAD and the Reference systems support the ATC Service in the following traffic densities:

- For a <u>medium density</u> <u>TMA</u> airspace (**ENVT-1**), an average of 6 flight hours controlled per sector hour and a maximum of 15 instantaneous aircraft count in a sector.

- For a <u>high density</u> <u>en-route</u> airspace (**ENVT-2**) , a maximum of 6 flight hours controlled per sector hour and a maximum of 20 instantaneous count aircraft in a sector.

- For a <u>high density</u> <u>TMA</u> airspace (**ENVT-3**), an average of 6 flight hours controlled per sector hour and a maximum of 15 instantaneous aircraft count in a sector.

Note: Assumptions made on the traffic densities are those from [Ref.1] §A.4.2.2).

*Note: For medium density TMA airspace, the figure is a result from combining a **<u>sector capacity</u>** with average flight time in sectors related to medium-density operations, e.g. 30 flights per hour sector capacity* *with an average 12 minute flight length in sector, or another example could be 36 flights per hour sector capacity with a 10 minute average flight length.*

Note: For high density en-route airspace, *the figure is a result from combining a sector capacity with average flight time* ***in sector*** *related to high-density operations, e.g. 60 flights per hour sector capacity with an average 6 minute flight length in sector, or another example could be 45 flights per hour sector capacity with an 8 minute average flight length.*

Note: High density TMA by its nature contains more and smaller sectors than in the medium density TMA albeit with the same sector traffic throughput (i.e. 6 flight hours per sector hour) and therefore is by definition more dense.

These provisions on the typical traffic densities have been developed mainly for consideration during the “failure approach” (section 10). They may also be used as input to define ground system processing requirements for capacity (“success approach”) – see 7.5.2. However it is recognised that these ground system requirements are local implementation specific and that the appropriate capacity requirements will have to be derived at a local level when considering the Local ADS-B-RAD Operational Environment.

2.2.2 Separation Minima

ADS-B-RAD and the Reference systems supporting ATC separation apply the following separation minima:

- 3 NM in ENVT-1 environment ([Ref.3], §8.7.3).

- 5 NM in ENVT-2 environment [Ref.3], §8.7.3).

- For ENVT-3 environment:

  - 3 NM separation minima in the wide area ([Ref.3], §8.7.3.2(a)).

  - 2.5 NM separation minima for succeeding aircraft on same final approach[4] ([Ref.3], §8.7.3.2(b)) (“in-trail” single runway or two independent parallel runway) – see illustration on Figure 3 and Figure 4.

  - 2 NM separation minima between successive aircraft on adjacent ILS

[4] As defined in PANS ATM 4444 [Ref.3], Chapter 1 - Definitions

localizer courses or MLS final approach tracks[5], in the case of dependent parallel runways [Ref.3], §6.7.3.4.3(b). – see illustration on Figure 5.

- Independent parallel approaches, where radar separation minima between aircraft on adjacent extended runway centre lines are not prescribed[4] (see illustration on Figure 4).

The following figures and table provide some illustrations and details on the scope of ADS-B-RAD system in ENVT-3 environment in approach:

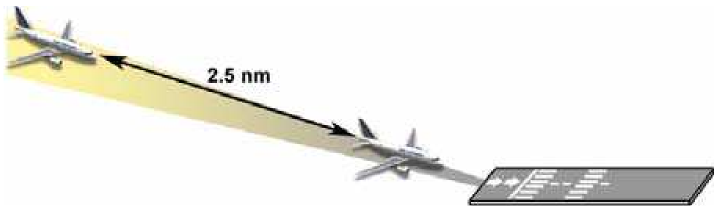


Figure 3: Separation Minima in single runway

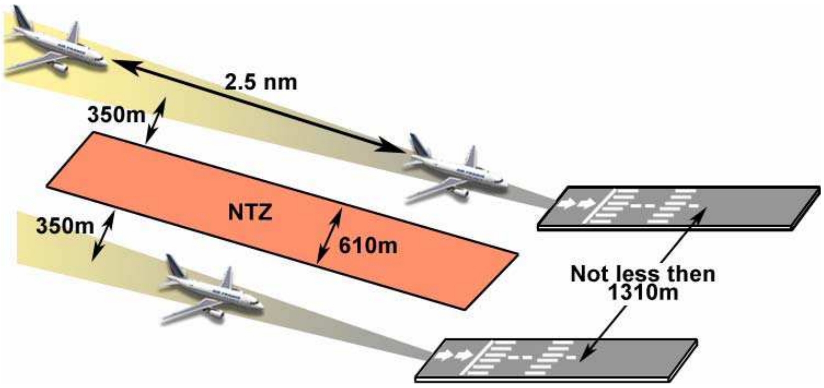


Figure 4: Separation Minima in two independent parallel runways

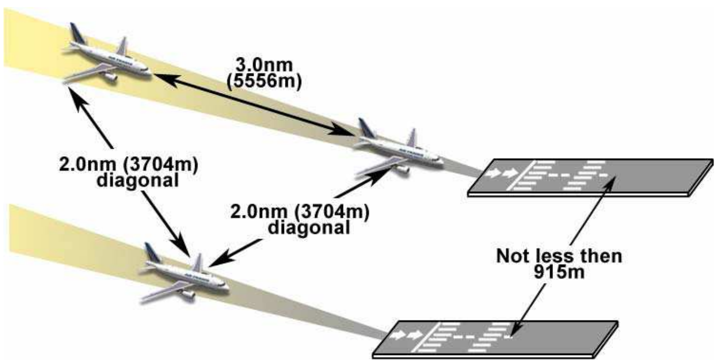


Figure 5: Separation Minima in two dependent parallel runways

[5] As defined in PANS ATM 4444 [Ref.3], §6.7.3.4.3

The following Table 1 has been extracted from [Ref.1], §A.5.7.3.2, which has sourced requirements from ICAO (as detailed in the first column). This provides guidance on the scope of the ADS-B-RAD system analysis with regards to parallel runways operations based on the distance between the runway centrelines (see Figure 4 and Figure 5).

Type of approach operation/Separation minima	Runway spacing between centreline requirements	In scope of ADS-B-RAD?
Independent parallel runways ([Ref.3] PANS-ATM 6.7.3.2). - ("in-trail") 2.5 NM separation minima for succeeding aircraft on same final	Greater than or equal to 1525 meters	Yes
	Less than 1525 meters but not less than 1310 meters	Yes
	Less than 1310 meters but not below 1035 meters between runway centre lines	No
Dependent parallel runways ([Ref.3]PANS-ATM 6.7.3.4) - 2 NM separation minima for succeeding aircraft on adjacent ILS/MLS	Not less than 915 meters	Yes

Table 1: Parallel Runway Operations & ADS-B-RAD Scope Summary

The above table was utilised in the definition of the ADS-B-RAD system to assist in determining which parallel runway operations were included and which were excluded from the scope of the analysis. One of the key driving indicators was the link between the runway centreline distances and the required design of technical performance of the radar in terms of azimuth accuracy (see ICAO reference in the first column of the above table). As ADS-B-RAD followed a comparative analysis (including technical aspects, see section 7.3.5.1), technical performance of the reference radar was an important factor in scoping the ADS-B-RAD system. More on the design factors surrounding this can be found at section 7.3.5.1.

This PSC has not assessed the case of *"Independent parallel runways with a spacing between centreline less than 1310 meters but not below 1035 meters"* **(L001**).

GM005. Implementers wishing to implement ADS-B-RAD in an environment with "Independent parallel runways with a spacing between centreline less than 1310 meters but not below 1035 meters" should perform their own local safety assessment (and addressing both the success and failure cases).

The latest edition of the PANS-ATM doc 4444 [Ref.3] contains separation minima of 5 NM when using ADS-B ([Ref.3]. At the time of the edition of the ADS-B-RAD Preliminary Safety Case, 3 NM and Approach[6] separation minima when using ADS-B are still under development at ICAO level (Circular) (**I007**).

GM006. Implementers wishing to implement in their Local ADS-B-RAD Operational Environment separation minima of less than 5 NM should check the status of ICAO documents in order to determine the separation minima to be locally applied.

Note: these separation minima applied in the Reference system are dependent on the surveillance technology (PSR, SSR and Mode S) in place in that airspace.

2.2.3 Airspace Classes and Airspace Structure

ADS-B-RAD and the Reference system are limited to the classes/sections of airspace where the provision of Air Traffic Control Services apply, and in particular to those in which the surveillance is used to separate aircraft.

Note: [Ref.1] contains reference to the limitation of the ADS-B-RAD system analysis to airspace classified as classed A to D. The main purpose of this was to avoid including other less 'surveillance' demanding Air Traffic Services (e.g. FIS) in the analysis (see section 2.1). The operational complications surrounding other classes of airspace (such E to G), the mix of services and usual variation in transponder equipage rates made these unattractive from a typical analysis point of view. Therefore, classes E to G have been excluded and although separation is provided to some aircraft (e.g. IFR to IFR in Class E) the inclusion of these classes in the scope would add no value to the determination of the ADS-B surveillance requirements.

A002. It is assumed that there is no change in design of airspace between the reference and ADS-B-RAD systems (OSED ENV-ASSUMP 6 in [Ref.1]).

[6] 2.5NM for succeeding aircraft on same final separation and 2NM for succeeding aircraft on adjacent ILS/MLS

2.2.4 Equipage Rate

The design of ADS-B-RAD system has been done assuming that:

I006: All aircraft in the ADS-B-RAD airspace are equipped with suitable certified ADS-B and radar transponder equipment and systems (§ASSUMP-12 [Ref.1]).

> *Note: in the rest of this document, the term "certified" means according to the EASA Certification Specification material (not published yet at the time of edition of this document) and in line with the avionic requirements part from section 7.5.1 of this document.*

GM007. The European Commission Surveillance Performance and Interoperability Implementing Rule (SPI-IR) specifies in particular the requirement for ADS-B out equipment carriage on certain aircraft. As explicitly stated in [Ref.1], section A.4.1.3.3, possible partial equipage issues are left open for decision and resolution at local implementation level (through e.g. mandating airborne equipage or segregating airspace between equipped and certified aircraft and the rest of the traffic, or permitting Air Traffic Controllers to tactically manage a mixed equipage environment). Implementers should assess the impact of their choice regarding the management of the mixed equipage environment when considering their Local Operational Environment.

2.3 SAFETY CRITERION

As previously explained, the ADS-B-RAD system supports ATC services, in particular Area and Approach Control Services[7] as defined in ICAO Annex 11 §2.3.1. ([Ref.17])

The main objectives of these services are (as per ICAO definition in Annex 11 §1) ([Ref.17]):

- preventing collision between aircraft

- expedite and maintain an orderly flow of air traffic

These services are part of the overall concept of Air Traffic Management, defined (as per ICAO definition in Doc.4444 - [Ref.3]) as the dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management - safely, economically and efficiently - through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions.

The relationship between the ATM system and the Air Traffic Services can be highlighted by means of the Barrier Model. The figure below presents the modelling of the ATM system, implicitly including ATS and then ATC services, for Conflict Management purposes (model based on ICAO doc 9854 "Global ATM Operation Concept" - [Ref.26]).

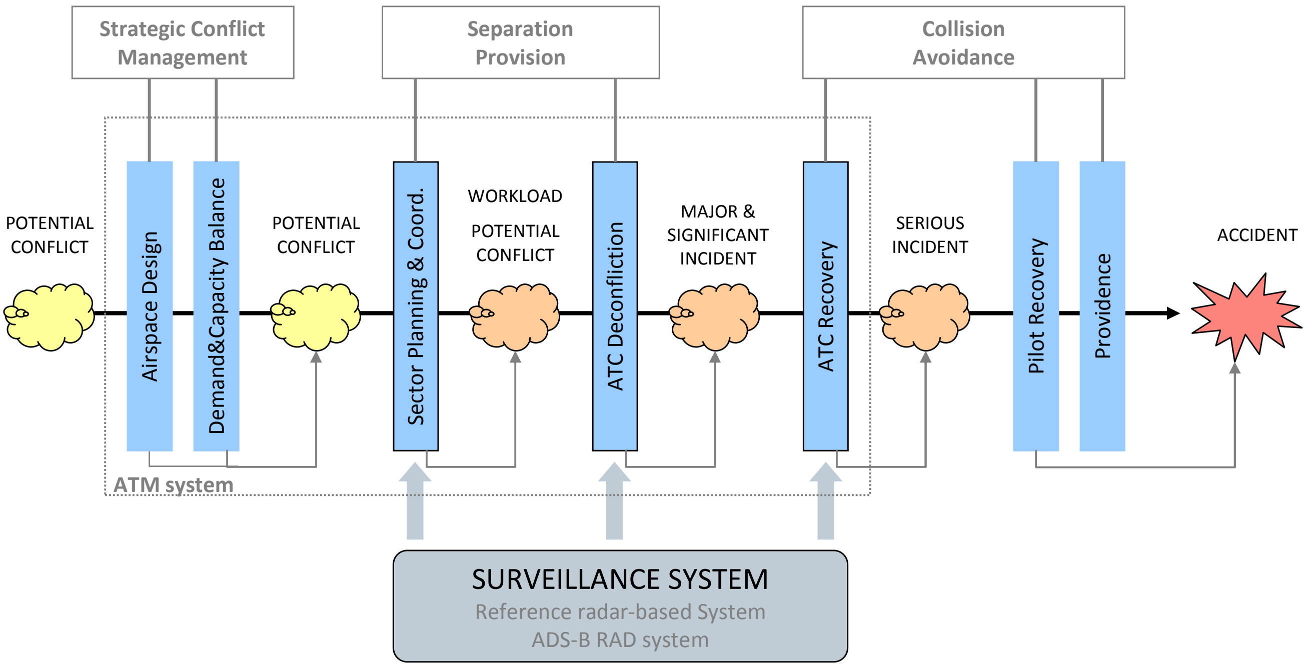


Figure 6: Barrier Model for ATM

[7] Aerodrome Control Service is normally included as an ATC Service but this is not supported by the ADS-B-RAD system

As per the above model the 'prevention of collision' objective in the ATC service primarily aims to mitigate, to an acceptably safe level, the potential risks inherent in aviation; they are represented in the highlighted cloud shapes (i.e. Excessive workload, Major and Significant Incident, Serious Incident and Accident); they are further detailed in Annex A under the form of severity classes. The maximum amount by which these types of aviation risk can be reduced by ATM, and in particular for this PSC by ADS-B RAD system (i.e. maximum positive contribution to aviation safety) depends on the corresponding functionality and performance properties of the ADS-B RAD system – i.e. on what the System does and how well it does it (addressed in the success approach).

Of course, the System can also fail (albeit infrequently), causing an increase in the risk of an accident due to:

- failure to prevent an accident that could reasonably have been expected to be prevented (failure by omission)
- causing an accident that would otherwise not have happened (failure by commission)

This negative contribution to the risk of an accident is determined by the integrity[8] of the ADS-B RAD System (addressed in the failure approach).

Hence, the following safety criterion is used to define the term "acceptably safe", expressing in this way the safety aspects expected with respect to using ADS-B-RAD to support ATC services and the related applicable regulatory requirements:

Cr001. The risk of accident or incident for the ATC service supported by the ADS-B-RAD system is no greater than when supported by the Reference system.

GM008. When developing local safety case, implementers need to define a local Reference system that would be accepted as acceptably safe by their national regulator when implemented in the Local ADS-B-RAD Operational Environment.

[8] Defined, in SAME Pt 2, as "The ability of a system, under all circumstances, to provide all the services (or functions) required by the users, with no unintended or un-commanded services (or functions)."

The details of the ATC service supported by the ADS-B-RAD and the Reference systems are described in section 3.2.

GM009. When developing LSC, an additional Safety Criterion should be included, relating to the AFARP[9] consideration, e.g. "the risk of accident or incident arising from the ADS-B-RAD system is reduced as far as reasonably practicable". This additional Safety Criterion is mainly to be addressed in Arg4 and Arg5 considering the following:

- SES CR 2096/2005 and ESARR 3 place a general obligation on implementers to "reduce risk as far as reasonably practicable".

- *Incident investigation and corrective action*, in relation to on-going operations, accordance with EC directive 42/2003 and ESARR 2 is a very important contributor to the achievement of the *AFARP* objective (extract from Eurocontrol SAME [Ref.21]).

2.4 STRATEGY FOR DECOMPOSING THE CLAIM

The Claim is decomposed into five principal Safety Arguments, which relate to the five main, contiguous stages of the lifecycle of the Change. Goal Structuring Notation (GSN) convention is used where an Argument can be considered to be true, if (and only if) each of its immediate 'offspring' can be shown to be true. The outcome of each stage is argued to be acceptably safe.

These five Arguments provide a potential framework for the development of a full Safety Case, which will have to be produced prior to bring the ADS-B-RAD system into operational service in Radar Areas[10]. However, for the purposes of this Preliminary Safety Case only the parts of Arg1 and Arg 2 are covered in any detail as indicated in section 2.1 and illustrated in Figure 2.

Arg 1 asserts that the ATC service supported by the ADS-B-RAD system is the same as the one supported by the Reference system[11]. This Argument is discussed further in section 3 below.

Arg 2 asserts that the ADS-B-RAD system has been designed to be *acceptably safe.* Corresponding Evidence is also largely based on ED-161/RTCA DO-318 joint standard [Ref.1]. Additional elements from ICAO and EUROCONTROL are considered as well as Evidence in support to Arg 2. In

[9] This is also a general obligation placed on ANSPs by ESARR 3 [Ref.7].

[10] The sub-arguments of Arg.5 have to be defined before turning ADS-B-RAD into operational service, and the evidence will be provided once it will be in service.

[11] Therefore the "*specification*" phase (at service level – see SAME) is not modified and is not described in this document.

case of different design, local evidence will have to be added to complement all the evidence provided in this PSC as a result of a local Functional Hazard Assessment (FHA)[12] / Preliminary System Safety Assessment (PSSA) and when considering success approach and failure approach cases. This Argument is discussed further in section 4 below.

Arg 3 asserts that the ADS-B-RAD system will be implemented in accordance with the logical design (derived under Arg 2). The implementation phase covers all the preparation needed in order to bring the physical system into operational service. Clearly, it will be necessary to show that the physical design satisfies the logical design of Arg 2 and then to show that the system - as built - satisfies the safety requirements derived for the physical design. This Argument would be supported by the results of a full System Safety Assessment (SSA), to be carried out by the responsible implementer in the local safety case.

Arg 4 asserts that the transition to operational service of the ADS-B-RAD system will be *acceptably safe.* This Argument requires Evidence that all final preparations for operational service have been completed. Again this Argument would be supported by the results of a full System Safety Assessment (SSA) in the local safety case, and it is also the responsibility of the relevant implementer.

Arg 5 asserts that the ADS-B-RAD system will continue to be shown to be acceptably safe in operational service. It is important for the relevant implementer to monitor operational safety, for two reasons: firstly, to validate the conclusions of the *a priori* safety assessment (Arg 1 and Arg 2); and, secondly, to ensure that any problems that might arise in operational service are properly investigated and the appropriate corrective action taken. As in two previous arguments, this one also would be supported by the results of a full System Safety Assessment (SSA) in the local safety case.

Note that for Arg 2 presented above the Success and Failure approaches have been processed through the safety assessment as defined in the EUROCONTROL ANS Safety Assessment Methodology [Ref.5] (SAM)[13] /SAME [Ref.21].

[12] Depending on the level at which hazards are identified, the FHA can be conducted either in Arg1 or in Arg 2. For this application, FHA has been conducted as part of Arg 2 (see section 10 for more detail).

[13] In practice, the distinction between the *success* and *failure* approaches, and which sub-Argument belongs to which approach is not important – what is crucial is ensuring overall that everything required by the seven sub-Arguments is covered.

3 ATC SERVICE DEFINITION (ARG 1)

3.1 STRATEGY FOR DEMONSTRATING ARG 1

The purpose of this section is to demonstrate that the ATC service is the same as the one supported by the Reference system. For that perspective the definition of the ATC service as per ICAO Annex 11 and PANS ATM 4444 is referred to and a more detailed description of the service is provided as well.

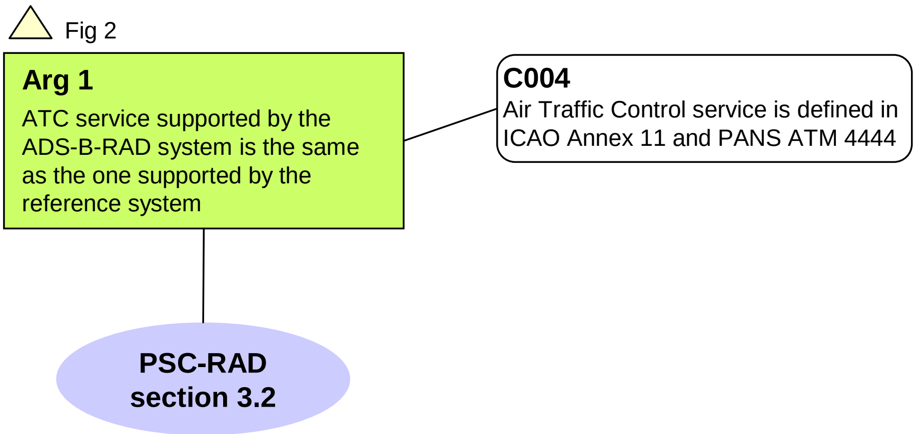


Figure 7: Decomposition of Argument 1

3.2 ATC SERVICE DESCRIPTION (ARG 1)

As already mentioned before, the objective of the ADS-B-RAD system is to support the same service as the Reference system. A summary of the relationship between ATS, ATC and the Surveillance Services is provided in Annex E together with a number of relevant definitions.

The definition of this service (**C004**) is described below[14]:

As mentioned before, the Area and Approach Control Services are mainly provided for the purpose of:

- Preventing collisions between aircraft
- Expediting and maintaining an orderly flow of air traffic

In order to perform this service (and as per ICAO Annex 11 [Ref.17] §3.3.1), the corresponding area, approach or aerodrome[15] traffic control unit should:

a) be provided with information on the intended movement of each aircraft, or variations therefrom, and with current information on the actual progress of each aircraft;

[14] See also Annex D that includes in particular a number of relevant definitions

[15] Ouside the scope of ADS-B-RAD as previously indicated

b) determine from the information received, the relative positions of known aircraft to each other;

c) issue clearances and information for the purpose of preventing collision between aircraft under its control and of expediting and maintaining an orderly flow of traffic;

d) coordinate clearances as necessary with other units:

- whenever an aircraft might otherwise conflict with traffic operated under the control of such other units;
- before transferring control of an aircraft to such other units.

The surveillance system, directly related to previous points a) and b), permit the controller to issue and coordinate clearances to maintain an efficient flow of air traffic with the required separation between aircraft - points c) and d).

From a service user point of view, the ATC service can be described in 4 main phases, which is applicable to both the ADS-B-RAD and the Reference systems (note: references included hereafter refer to ICAO PANS ATM) as illustrated in the following figure and that are further detailed after it:

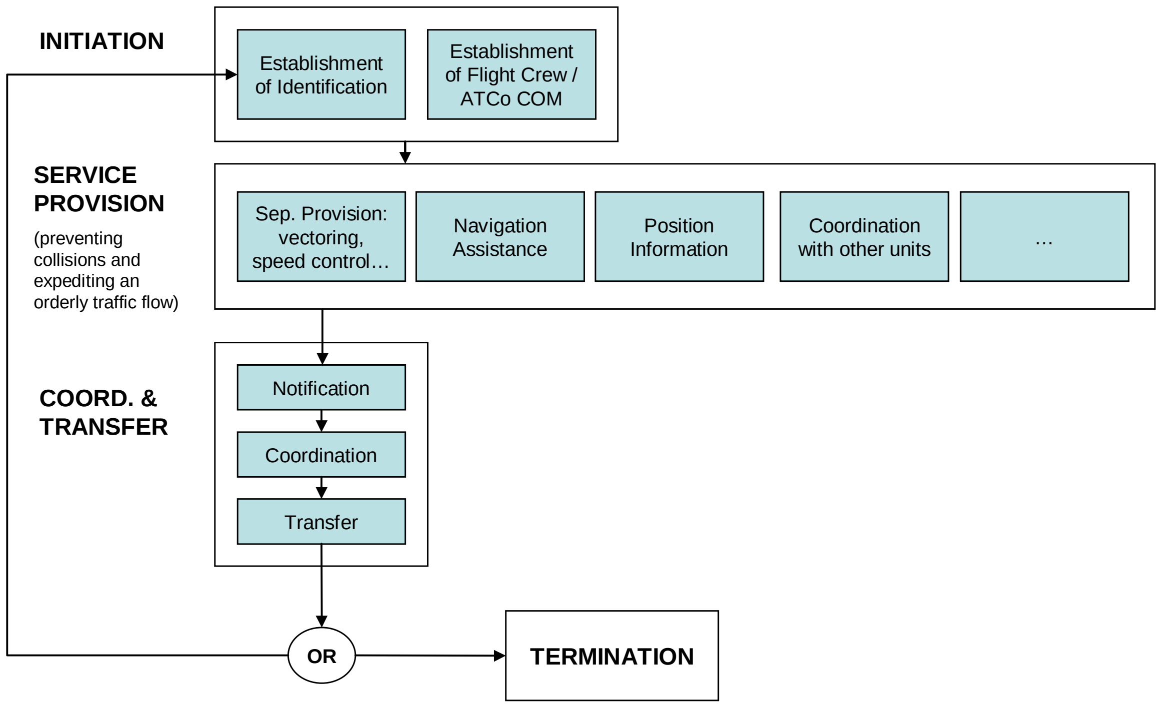


Figure 8: Definition of Phases composing ATC service

Initiation: This phase includes:

- establishment of identification of aircraft entering in the controllers area of responsibility (§8.6.2);

- establishment of direct pilot-controller communication (§8.3).

Provision of Service: This phase includes:

- application of appropriate separation minima between aircraft (§8.7.2) using specific control methods as vectoring (§8.6.5) and speed control (§8.7.5);

- provision of other particular services as position information (§8.6.4) and navigation assistance.

Examples are provided in ICAO PANS ATM §8.7.1 for Area Control services, and in §8.9.2 for specific Approach Control services.

Coordination and Transfer: This phase ensures an uninterrupted provision of Air Traffic Services from an aircrafts point of view (see more detail in §10). It is performed in 4 stages:

- notification of the flight to the next ATC unit in order to prepare for coordination, as necessary;

- coordination of conditions of transfer of control between the transferring ATC unit and the accepting ATC unit, and acceptance of conditions by the latter; and

- the transfer of control (§8.7.4) to the accepting ATC unit or control sector, including the transfer of identification (§8.6.3) and the transfer of communication (§10.1.2.4).

Termination (§10.1.2.5): This corresponds to the case when a flight ceases to be operated as a controlled flight, i.e. where the aircraft arrives at its destination, by leaving controlled airspace or by cancelling its IFR status and proceeding VFR in airspace where VFR flights are not controlled.

GM010. See guidance material developed in Annex D in relation to the scope of the service supported by the ADS-B-RAD system.

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4 ADS-B-RAD DESIGN (ARG 2)

Arg 2 aims at ensuring that ADS-B-RAD system has been designed to be *acceptably* safe.

Arg 2 includes guidance material relating to design issues that should facilitate implementer´s task relating to the design of the local ADS-B-RAD system (see section 4.1).

The decomposition of Arg 2 is shown in the Figure 9 below:

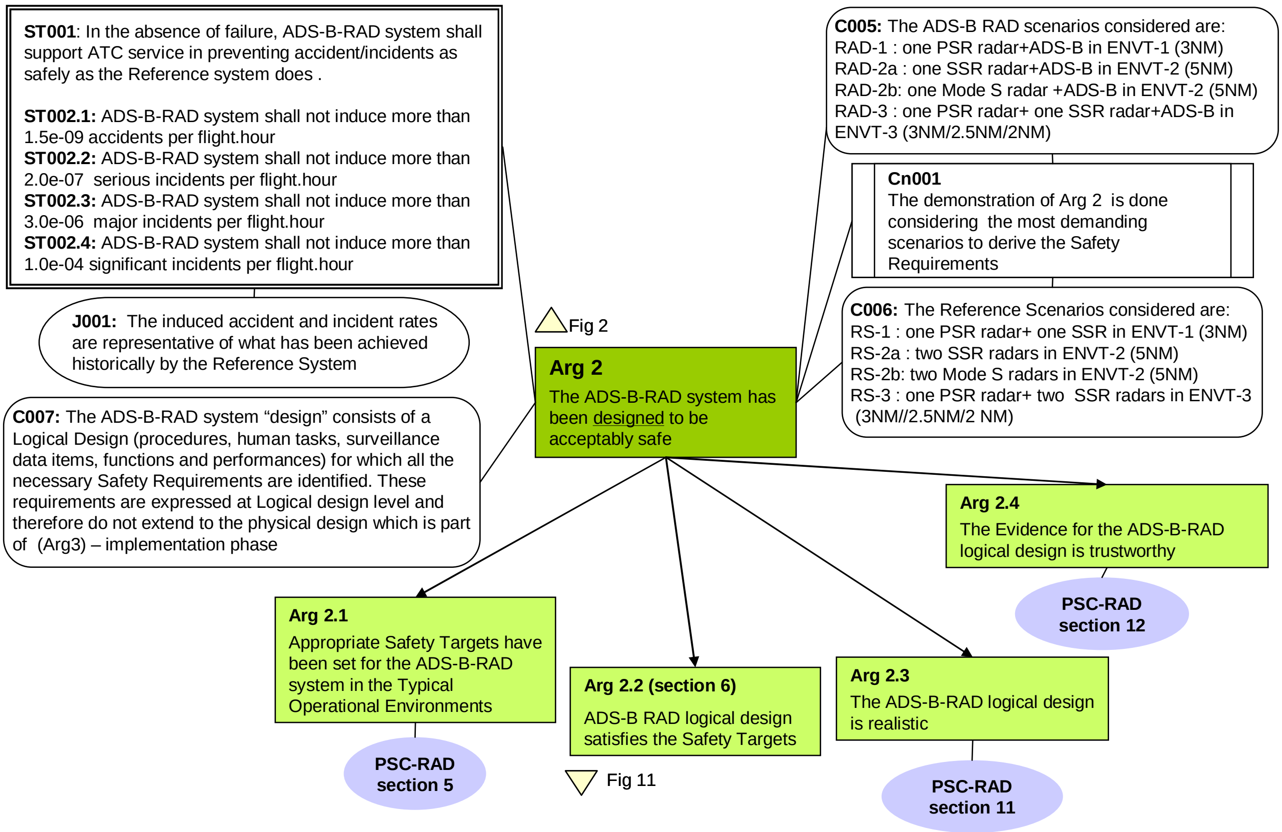

Figure 9: Decomposition of Argument 2

As defined above in section 1.5, ADS-B-RAD system encompasses all the elements (procedures, human tasks, surveillance data items, functions and performances) allowing to support the ATC service described in section 3.

These requirements are expressed at Logical design level (functional) and therefore do not extend to the physical design which is part of Arg 3 – implementation phase (local level).

The ADS-B-RAD system "design" consists of a Logical Design[16] that describes the main attributes of and interactions between these several system elements in terms of safety functionality and performance. This is performed in the Typical Operational Environments. All the necessary Safety functionality and performance attributes are defined as Safety Requirements and are expressed at Logical design level. In order to support the derivation of these Safety Requirements an architectural representation of the system design (called Logical Model -LM) is used. This LM is entirely independent of the eventual physical implementation of that design (i.e. physical elements as hardware, software, training, etc., are not shown in the model) but are to be covered in Arg 3 (**C007**), the implementation phase (local level), for the Ground Domain, which is out of scope of this document.

4.1 STRATEGY FOR DEMONSTRATING ARG 2

Due to the fact that there are multiple variations of radar types (PSR, SSR, Mode S) and consequently multiple combinations of radar plus ADS-B (e.g. PSR + SSR, SSR + Mode S, etc.), the same approach as per [Ref.1], §A.4.1.1, has been adopted by constraining the number of logical designs representing the ADS-B-RAD system to be considered in this document.

For this purpose, the strategy adopted in this PSC for demonstrating Arg 2 (**Cn001**) is to only consider the most demanding scenarios (as defined in next box) to derive the functional safety requirements.

The term **scenario** used in this document is defined as the combination of a particular "*ATS Surveillance system*" [17] supporting a logical design of the considered system for the provision of ATC services (as described in section 3) in one Typical Operational Environment (as defined in section 2.2).

The reasoning for that strategy is that if the ADS-B-RAD logical design is derived from the most demanding scenarios, then this logical design can be assumed to also be valid in less demanding scenarios. In addition, and as already indicated in section 1.2, this also allow to ensure that avionic requirements are not the limiting factor for the selection of a separation standard to be used in the service supported by the ADS-B-RAD system, as the most demanding ADS-B avionic requirements will also be derived.

[16] See definition in section 1.5

[17] ***ATS surveillance system**. A generic term meaning variously, ADS-B, PSR, SSR, a combination of them or any comparable ground-based system that enables the identification of aircraft* – see Annex D

Therefore, four **ADS-B-RAD scenarios** (**C005**) are considered in this section, covering the three different radar technologies with which ADS-B is combined: PSR, SSR and Mode S in the corresponding Typical Operational Environments described in the section 2.2. These scenarios are presented in Table 2 below.

	ATS surveillance system supporting ADS-B-RAD system	Typical Operational Environment
RAD-1:	Single Primary Surveillance Radar (***PSR***) with ***ADS-B*** surveillance.	*ENVT-1:* medium traffic density in TMA airspace, supporting 3NM separation minima.
RAD-2a:	Single mono-pulse Secondary Surveillance Radar (***SSR***) with ***ADS-B*** surveillance.	*ENVT-2*: high traffic density in En-route airspace, supporting 5NM separation minima.
RAD-2b:	Single ***Mode-S*** radar with ***ADS-B*** surveillance.	*ENVT-2*: high traffic density in En-route airspace, supporting 5NM separation minima.
RAD-3:	Single Primary Surveillance Radar (***PSR***) with a collocated single Secondary Surveillance Radar *(**SSR**)* together with ***ADS-B*** surveillance.	*ENVT-3*: high traffic density in TMA airspace, supporting: ▪ 3NM separation minima in the wide area, ▪ 2.5NM separation minima for succeeding aircraft on same final, ▪ 2 NM separation minima for succeeding aircraft on adjacent ILS/MLS.

Table 2: ADS-B-RAD Scenarios

As per Cr001, corresponding Reference scenarios (**C006**) are also to be considered in order to be able to apply the comparative approach. In these Reference scenarios, presented in Table 3, ADS-B in each “ATS surveillance system” is replaced by a particular radar type (SSR or Mode S). Note that the operational environment considered for each of these Reference scenarios is the same as for the corresponding ADS-B-RAD scenario.

	ATS surveillance system supporting Reference system	Typical Operational Environment
RS-1:	Primary Surveillance Radar (***PSR***) with a co-mounted Secondary Surveillance Radar (***SSR***)	*ENVT-1:* medium traffic density in TMA airspace, supporting 3NM separation minima
RS-2a:	Two Secondary Surveillance Radar (***SSR***)	*ENVT-2*: high traffic density in En-route airspace, supporting 5NM separation minima
RS-2b:	Two ***Mode-S*** radars	*ENVT-2*: high traffic density in En-route airspace, supporting 5NM separation minima
RS-3:	Single Primary Surveillance Radar (***PSR***) with dual Secondary Surveillance Radar (***SSR****)* (one of them co-mounted)	*ENVT-3*: high traffic density in TMA airspace, supporting: ▪ 3NM separation minima in the wide area ▪ 2.5NM separation minima for succeeding aircraft on same final ▪ 2 NM separation minima for succeeding aircraft on adjacent ILS/MLS

Table 3: Reference Scenarios

In the rest of the document the term **“Reference radar”** refers to these specific radars that are replaced by ADS-B in the ADS-B-RAD scenarios. Reference radar will be developed in detail in the following sections and in particular in section 7.3.5.1 for the performance aspects.

GM011. When developing the local safety case, the utilisation at local level of a Reference logical design supported by a Reference scenario is a two-step process:

Step1: Define a local Reference logical design (and scenario) that will be used for comparison with the ADS-B-RAD logical design (and scenario):

Implementers need to define a local Reference design that would be accepted as acceptably safe by their national regulator when implemented in the Local ADS-B-RAD Operational Environment.

Step2: If the local ADS-B-RAD design and the Reference logical design from step 1 equates to the ADS-B-RAD logical design, then the content of this PSC would directly be applicable provided all assumptions are met (in particular the characteristics of the local Reference radar supporting the local Reference scenario). If not, the implementer should derive their local ADS-B-RAD requirements. They may re-apply the PSC process (arguments and local evidence) and this does not prevent the implementer from using other methods approved by their State National Regulatory Authority.

It is the responsibility of any ATS provider using this PSC and wishing to implement a local ADS-B-RAD system, to ensure that the various conditions or assumptions mentioned in this document are applicable for their local ADS-B-RAD system or otherwise the corresponding impact should have to be assessed. This is in particular true for the:

a) Local Operational Environments characteristics.

b) Characterisation of the local Reference radar(s) in the local Reference scenario supporting local Operational Environments characteristics.

c) Identification of local hazards and their severity class in the local Operational Environments and the assessment of the corresponding impact in these Local Operational Environments (see section 10 relating to the failure approach case).

The figure below illustrates the distinction between the design addressed in this PSC and the local design, using some characteristics of the Typical Design (as defined in section 2.2) versus local characteristics (e.g. local reference radar different from the typical case) examples:

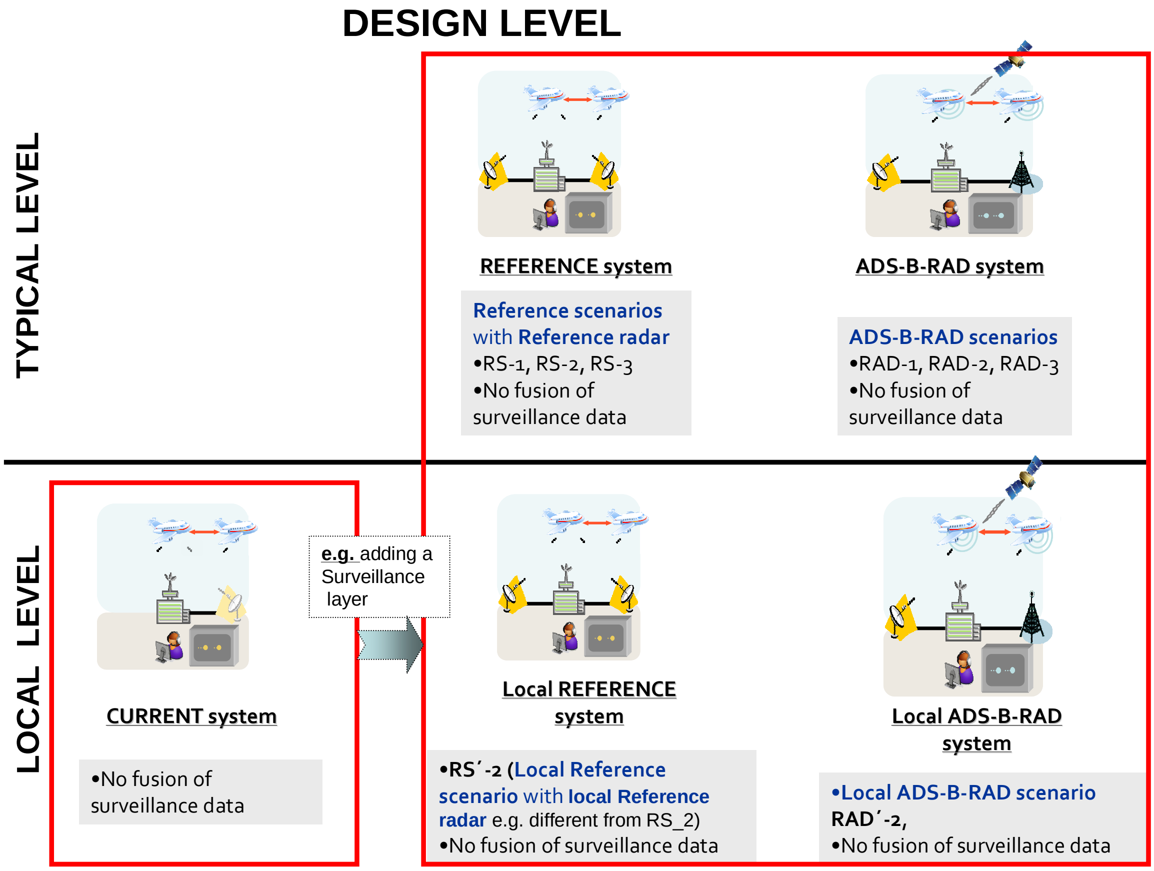

Figure 10: Example of design versus local design

4.2 STRATEGY FOR DECOMPOSING ARG 2

The main strategy for demonstrating that the ADS-B-RAD system has been designed to be acceptably safe is firstly to define appropriate safety targets for the ADS-B-RAD system and then to describe the logical design in terms of Safety functionality and performance attributes (Safety Requirements) ensuring that this logical design satisfies those Safety Targets.

Once it is done, two more topics need to be addressed in order to complete the argument:

- To show that the logical design is realistic – i.e. would be capable of being implemented in a physical system of people, equipment and procedures.
- To show that all the evidence under Arg 2.1 is trustworthy.

This is reflected in the decomposition of Arg 2 shown in Figure 9, presenting the following sub-arguments:

Arg 2.1: Appropriate Safety Targets have been set for the ADS-B-RAD system in the corresponding Typical Operational Environments.

Arg 2.2: The Logical design satisfies the safety targets defined in previous Arg 2.1.

Arg 2.3: The ADS-B-RAD Logical design is realistic.

Arg 2.4: The Evidence for the ADS-B-RAD Logical Design is trustworthy.

These sub-arguments are further described in section 5 for Arg 2.1, in sections 6 to 10 for Arg 2.2, in section 11 for Arg 2.3 and in section 12 for Arg 2.4.

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5 APPROPRIATE SAFETY TARGETS DERIVATION (ARG 2.1)

The objective of this section is to show that appropriate safety targets have been derived to the ADS-B-RAD system based on the safety criterion provided in section 2.3:

Cr001 The risk of accident or incident for the ATC service supported by the ADS-B-RAD system is no greater than when supported by the Reference system.

Following the explanations provided in section 2.3, the satisfaction of this safety criterion can be demonstrated by showing that:

1. the risk of an accident in the absence of failure is no higher than for the Reference System; and
2. the risk of an accident in the event of failure is no higher than for the Reference System.

These two objectives are achieved, respectively, through two Safety Targets, ST001 and ST002, detailed in next sections 5.1 and 5.2.

GM012. This PSC is covering both the airborne and the ground elements (see Figure 14 that presents the corresponding elements of each domain). The Safety Targets have been set in this section to ensure the end-to-end (airborne and ground) safety. As such, these Safety Targets are distinct from an airborne airworthiness approach as they have been set from an overall ATM perspective. Implementers should consider as part of their Local Safety Case the implication of their own Safety Targets on the resulting requirements.

5.1 SAFETY TARGET 1

The first Safety Target (**ST001**) is mainly used in the nominal mode of operation of ADS-B RAD system:

ST001 In the absence of failure, ADS-B-RAD system shall support the ATC service in preventing accidents/incidents as safely as the Reference system does.

This Safety Target clearly comes directly from the first of the above two objectives. It is a relative, qualitative target, and it is intended that it will be satisfied (under Arg 2.2.1 below) by showing that ADS-B RAD system provides the same (or improved) properties (in terms of Operational surveillance procedures, human tasks, surveillance data items, functions and performances) than the Reference system does.

Note that for each of the ADS-B-RAD scenario, this Safety Target considers the corresponding Reference System, as described in section 4.1. In this way, **ST001** is the appropriate Safety Target for each considered environment.

5.2 SAFETY TARGET 2

This Safety Target **ST002** comes indirectly from the second of the above two objectives. It is a relative, quantitative target presented as a Risk Classification Scheme (RCS) for the ADS-B RAD system (i.e. providing a safety target for each severity from 1 to 4).

This RCS, as derived from [Ref.1], is based on ATM Safety Targets obtained from ESARR 4 (value for severity class 1) and from ED-125 [Ref.13] (values for severity classes 2, 3 and 4). These ATM Safety Targets specify the overall (i.e. ATM) maximum quantitative frequency at which an operational effect for a given severity class can be tolerated to occur.

A certain percentage of these ATM Safety Targets has been then allocated for ADS-B-RAD as indicated in **Table 4** (the way in which these percentages have been determined is detailed in Annex F). It is intended that these ADS-B-RAD Safety Targets will be satisfied (under Arg 2.2.4 below) by showing that the occurrence of effects in case of ADS-B-RAD system failure do not exceed these allocated maximum frequencies.

Severity (Effects)	ATM Safety Targets [flight.h]	% of ATM Safety Targets	RAD Safety Targets [flight.h]
Severity 1 (accidents)	1e-08	15%	1.5e-09
Severity 2 (serious incidents)	1e-05	2%	2.0e-07
Severity 3 (major incidents)	1e-04	3%	3.0e-06
Severity 4 (significant incidents)	1e-02	1%	1.0e-04

Table 4: Safety Targets for ADS-B RAD System

These Safety Targets values are valid in the three considered typical Operational Environments (**ENVT-1, ENVT-2, ENVT-3**). The detailed Safety Targets for each environment are provided in Annex F and are in the same order of magnitude.

GM013. When considering their local environment, the implementer should check whether the ADS-B-RAD Safety Targets are appropriate ones or otherwise assess the corresponding impact.

The following safety targets are then derived for the ADS-B-RAD system to be used in case a failure occurs:

ST002.1: ADS-B-RAD system shall not induce more than 1.5e-09 accidents per flight.hour.

ST002.2: ADS-B-RAD system shall not induce more than 2.0e-07 serious incidents per flight.hour.

ST002.3: ADS-B-RAD system shall not induce more than 3.0e-06 major incidents per flight.hour.

ST002.4: ADS-B-RAD system shall not induce more than 1.0e-04 significant incidents per flight.hour.

The following Table 5 provides the past safety achievement of (radar-based) surveillance (**J001**), i.e. the Reference System for En-Route in ECAC. These Safety Targets of radar-based surveillance have been obtained from the Integrated Risk Picture (IRP) [Ref.29]:

Effects	Radar-based surveillance Safety Targets [flight.hour]
Fatal mid air collision	3.9e-09[18]
Imminent collision	4.8e-06
Separation infringement	5.5e-06

Table 5: Contribution of radar-based surveillance to accidents / incidents based on IRP Model (for En-Route)

Figures hereabove presented correspond to specific events in the IRP model, which have been considered to be equivalent to the indicated severities on the RAD RCS:

- fatal mid air collision corresponds to severity 1,
- imminent collision corresponds to severity 2 and
- separation infringement corresponds to severity 3.

No figure is provided for Severity 4 events because the elements related to this severity (e.g. the controller or pilot workload) are not explicitly represented in the IRP model, but implicitly addressed as influencing factors in the model.

[18] Initial IRP value for Fatal mid air collision is 5.5e-10/fh. This includes the airborne recovery mitigation. In the frame of ADS-B-RAD, this mitigation has not been taken into account and IRP initial value has therefore been adapted based on that, leading to the value of 3.9e-09/fh.

Comparing **ST002** with the figures shown in Table 5**,** it is shown that **ST002** reflects (i.e. same order of magnitude) the past safety achievement of (radar-based) surveillance for En-Route.

GM014. In airspaces where ADS-B is intended to replace a SSR radar (no change in the separation minima), implementers could use historical data, to derive or validate the local Safety Targets for the local ADS-B-RAD system.

Concluding, since **ST001** and **ST002** are both set relative to the Reference System, and cover both the failure-free and failure cases, then together they can be considered to be sufficient to satisfy Safety Criterion **Cr001**.

6 DESIGN SATISFACTION OF SAFETY TARGETS (ARG 2.2)

This section intends to demonstrate that the ADS-B-RAD system has been designed to be acceptably safe – i.e. satisfies the corresponding ST defined in section 5.

The decomposition of Arg 2.2 is shown in Figure 11 below:

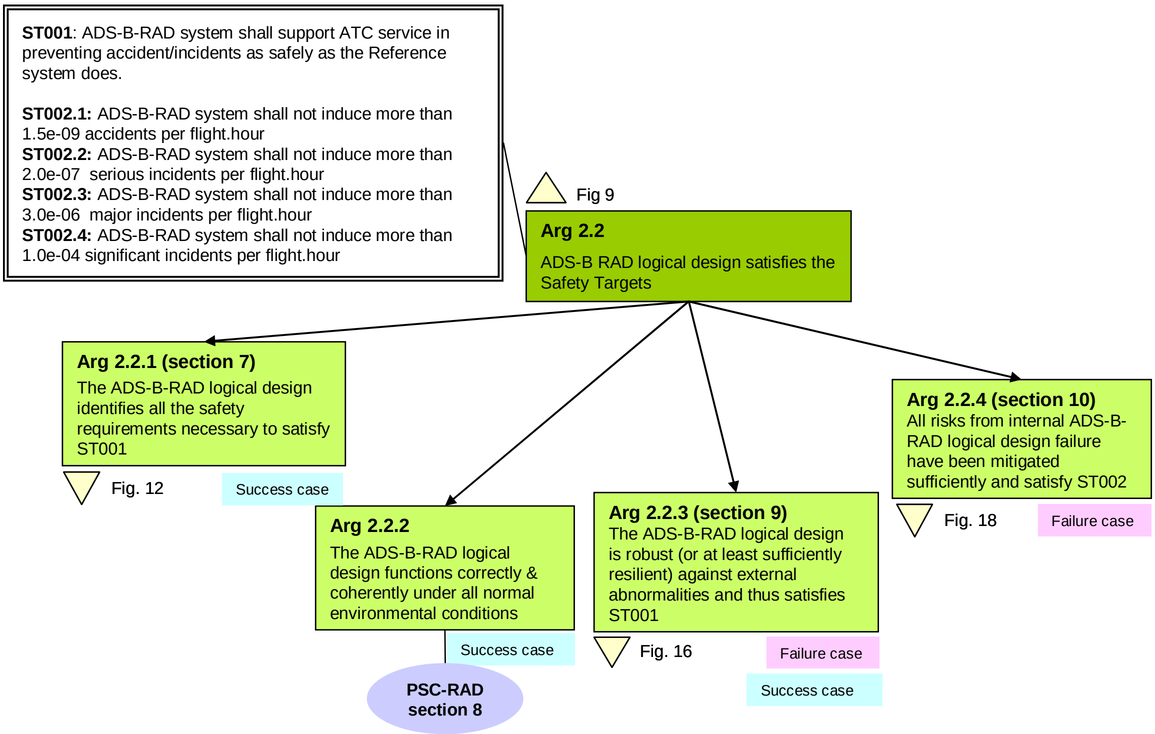

Figure 11: Decomposition of Argument 2.2

6.1 STRATEGY FOR DECOMPOSING ARG 2.2

The decomposition of **Arg 2.2,** as shown in Figure 11 above, comprises the following sub-Arguments, which reflect the Success and Failure approaches to safety assessment defined in the EUROCONTROL ANS Safety Assessment Methodology (SAM) [Ref.5]/SAME [Ref.21] corresponding to the logical design.

The strategy for decomposing Arg 2.2 covers the following sub-arguments:

Arg 2.2.1 – Logical Design Description

This argument asserts that the ADS-B-RAD logical design exhibits all the necessary Safety functionality and performance attributes (Safety Requirements) to satisfy the Safety Target **ST001** in the “success approach” – i.e. in the absence of failure.

Arg 2.2.2– Logical Design Correctness

Arg 2.2.2 asserts that the ADS-B-RAD logical design functions correctly and coherently under all normal environmental conditions. The main issues here are the internal coherency of the system, and the dynamic behaviour of the system, over the full range of conditions to which the system is expected to be subjected in its operational environment.

Arg 2.2.3 – Logical Design Robustness

This argument asserts that the ADS-B-RAD logical design is robust against external abnormalities in the operational environment, from two perspectives: can the system continue to operate effectively; and could such conditions cause the system to behave in a way that introduces additional risk.

Arg 2.2.4 - Mitigation of Internal Failures

Arg.2.2.4 asserts that all risks from the ADS-B-RAD logical design failure have been mitigated sufficiently (**ST002**). Here, the internal behaviour of the system is assessed from the perspective of how anomalous behaviour of the system could induce a risk that would otherwise not have arisen (“failure approach”).

The further decomposition of, and Evidence to support, Arg 2.2.1 to Arg 2.2.4 are presented below in sections 7 to 10 respectively.

7 LOGICAL DESIGN DESCRIPTION (ARG 2.2.1)

As mentioned in previous section, this argument aims at demonstrating that the ADS-B-RAD logical design provides the functionality and performance attributes (Safety Requirements) that are necessary to satisfy the corresponding safety target.

The decomposition of Arg 2.2.1, as shown in Figure 12 below, addresses the nominal mode of operation of the ADS-B-RAD and the Reference logical designs (success approach).

Each of these logical designs is to be considered in the various scenarios defined in the previous Table 2: ADS-B-RAD Scenarios and Table 3: Reference Scenarios.

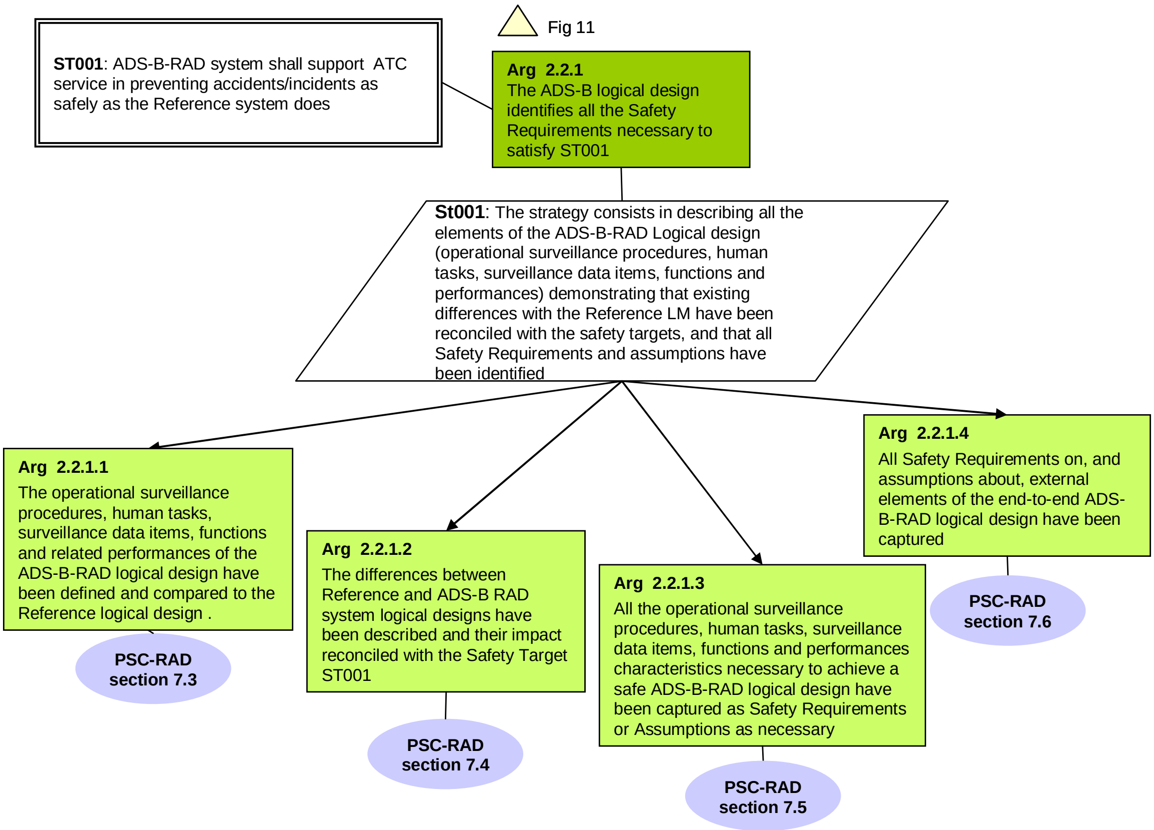

Figure 12: Decomposition of Argument 2.2.1

7.1 SAFETY TARGET

The Safety Target considered for this argument Arg.2.2.1, as for all the sub-arguments related to the success approach, is the following one**:**

ST001: ADS-B-RAD system shall support ATC service in preventing accident/incidents as safely as the Reference system does.

7.2 STRATEGY FOR DECOMPOSING ARG 2.2.1

The purpose here is to demonstrate that the ADS-B-RAD logical design exhibits all the necessary properties to safely support the ATC service.

As per ST001, ADS-B-RAD system shall support ATC services in preventing accidents/incidents as safely as the Reference system does.

For that it is intended to compare the logical design of ADS-B-RAD system against the Reference logical design, for all related scenarios previously presented (**C005** and **C006**), to finally obtain the set of safety requirements designing the ADS-B-RAD system.

The strategy (**St001**) consists in demonstrating that the ADS-B-RAD logical design is mainly the same as the Reference one, and that ADS-B technology performances are equivalent to those of the corresponding Reference radars (SSR or mode S).

If differences in any element attributes of the logical design are identified during the comparison, they will have to be described and reconciled with the safety target ST001 (as defined in section 7.1).

Based on that, the following lower-level arguments have been developed in order to satisfy Arg 2.2.1:

a) **Arg.2.2.1.1**. The operational surveillance procedures, human tasks, surveillance data items, functions and related performances of the ADS-B-RAD logical design have been defined and compared to the Reference logical design.

b) **Arg 2.2.1.2**. The differences between Reference and ADS-B-RAD system logical designs have been described and their impact reconciled with the Safety Target **ST001**.

c) **Arg 2.2.1.3** All the operational surveillance procedures, human tasks, surveillance data items, functions and related performances necessary to achieve a safe ADS-B-RAD logical design (including equipment[19], people, procedures) have been captured as Safety Requirements or Assumptions as necessary.

d) **Arg 2.2.1.4** All Safety Requirements on, and assumptions about, external elements of the end-to-end ADS-B-RAD logical design have been captured.

These arguments are addressed in turn, in sections 7.3 to 7.6. Conclusions regarding Arg 2.2.1 are then drawn in section 7.7.

[19] For generic aspects of ADS-B-RAD, “equipment” has been specified at functional level only. Local full Safety Case will have to address the physical architecture supporting the local implementation. See section 7 and the Guidance Material Box GM033.

As defined in section 1.5, the ADS-B-RAD system encompasses procedures, people and equipment elements. The strategy for the design of the system is then to describe, in Arg 2.2.1.1, each of these elements, their attributes and their interactions (using the Reference system as input when necessary). That means (as represented in Figure 13):

(1) To describe the operational **surveillance procedures** used by Air Traffic Controllers and Flight Crews, in order to provide Air Traffic Control Service to aircraft.

(2) To detail the interactions between human actors (Air Traffic Controller and Flight Crew) and the corresponding ground and airborne equipments (and external elements when necessary), in terms of **operational data items** and **human tasks** necessary to support these operational **surveillance procedures**.

(3) For the technical part, to describe the **technical data items** between the ground and airborne equipments (and external elements when necessary) relating to the provision of the **operational data items** mentioned above.

(4) To detail the functions performed by each element of the logical model as presented in Figure 14, including external elements for the handling of the **technical and operational data items**.

(5) Finally, to define the **performance** characteristics of the equipment elements. As ADS-B is intended to be equivalent to an SSR or a Mode S in all the scenarios under assessment, performance characteristics of both technologies will be compared as far as practical.

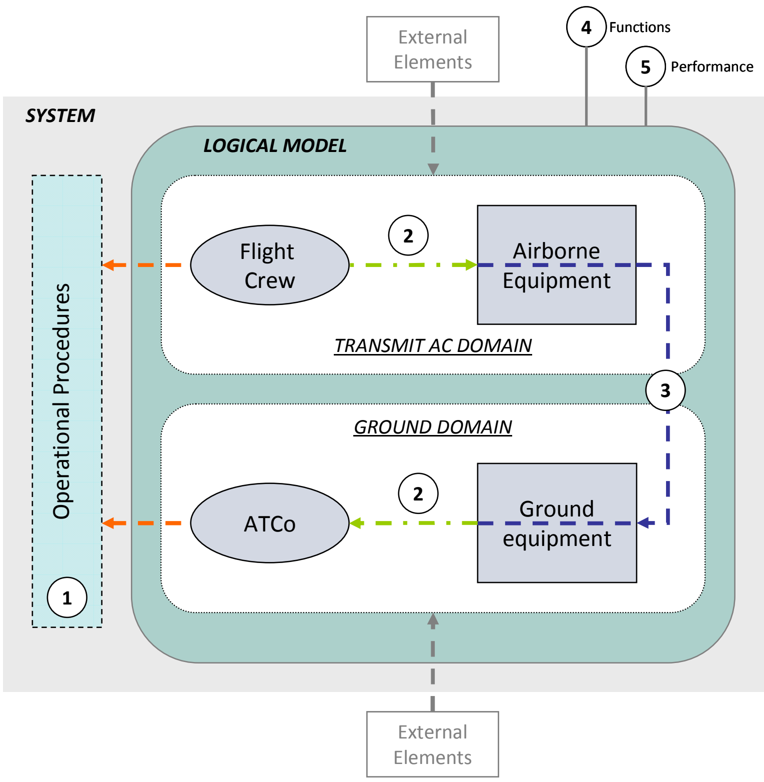

Figure 13: Strategy for addressing Arg 2.2.1

Note that the previous scheme only provides an overview of the ADS-B-RAD Logical Design. More detailed information is provided in the ADS-B-RAD Logical Model presented in Figure 14 and described in section 7.3.

7.3 DESCRIPTION OF THE ADS-B-RAD LOGICAL DESIGN (ARG 2.2.1.1)

The Logical Model in Figure 14 is a high level, architectural representation of the system presenting the different elements of the ADS-B-RAD logical design, which has been adapted from [Ref.1] in terms of distinction of interfaces between radar data flow ($X_{PR\ or\ SR}$) and ADS-B data flow (X_A). Interactions with external systems have also been added in this figure.

This section aims at describing these elements and their attributes, expressed in terms of operational surveillance procedures, related human tasks, surveillance data items, functions performed and performance characteristics. The Reference logical model, to be used as needed for the description of the differences between the ADS-B-RAD and the Reference logical models, is presented in Figure 15.

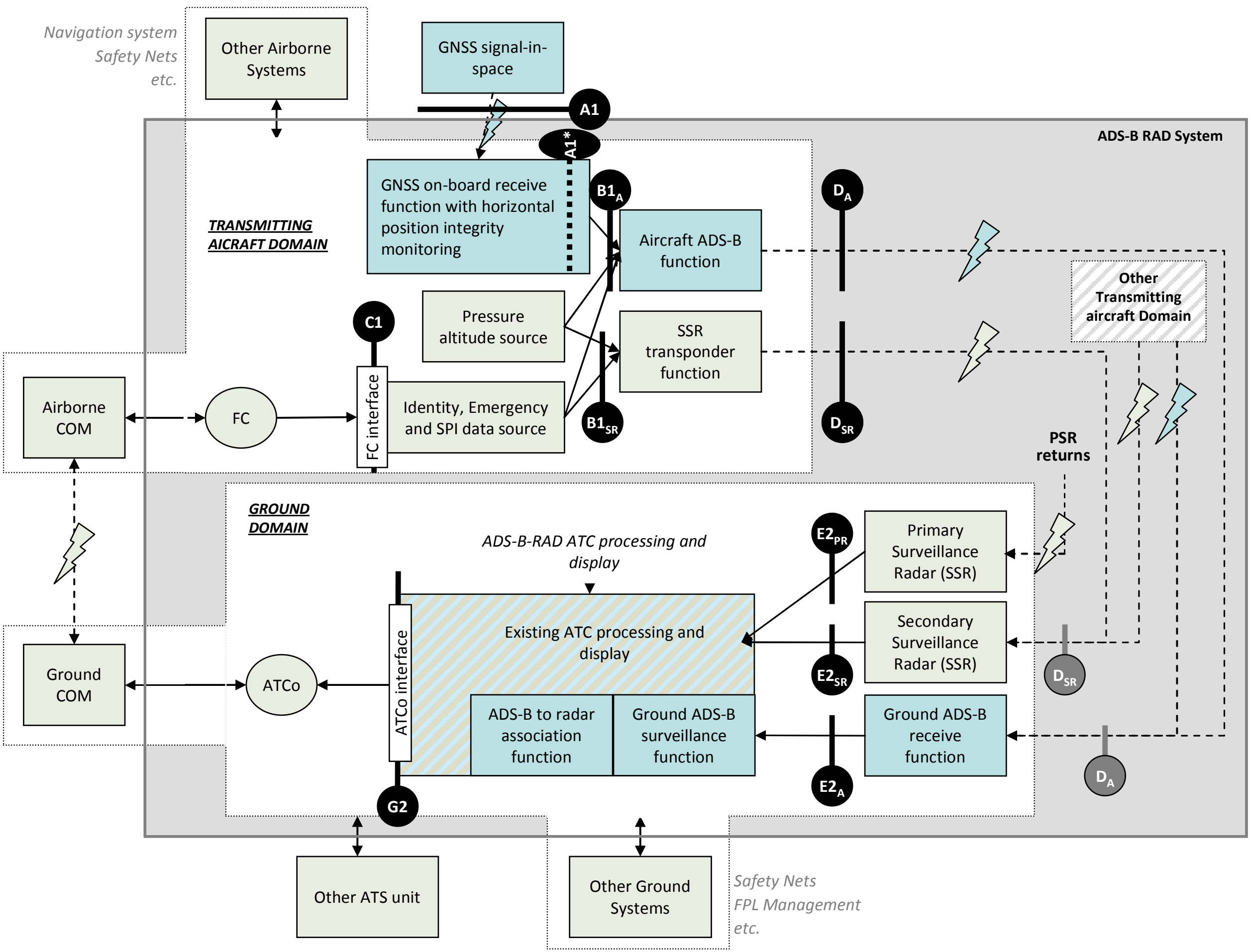

Figure 14: ADS-B-RAD Logical Model

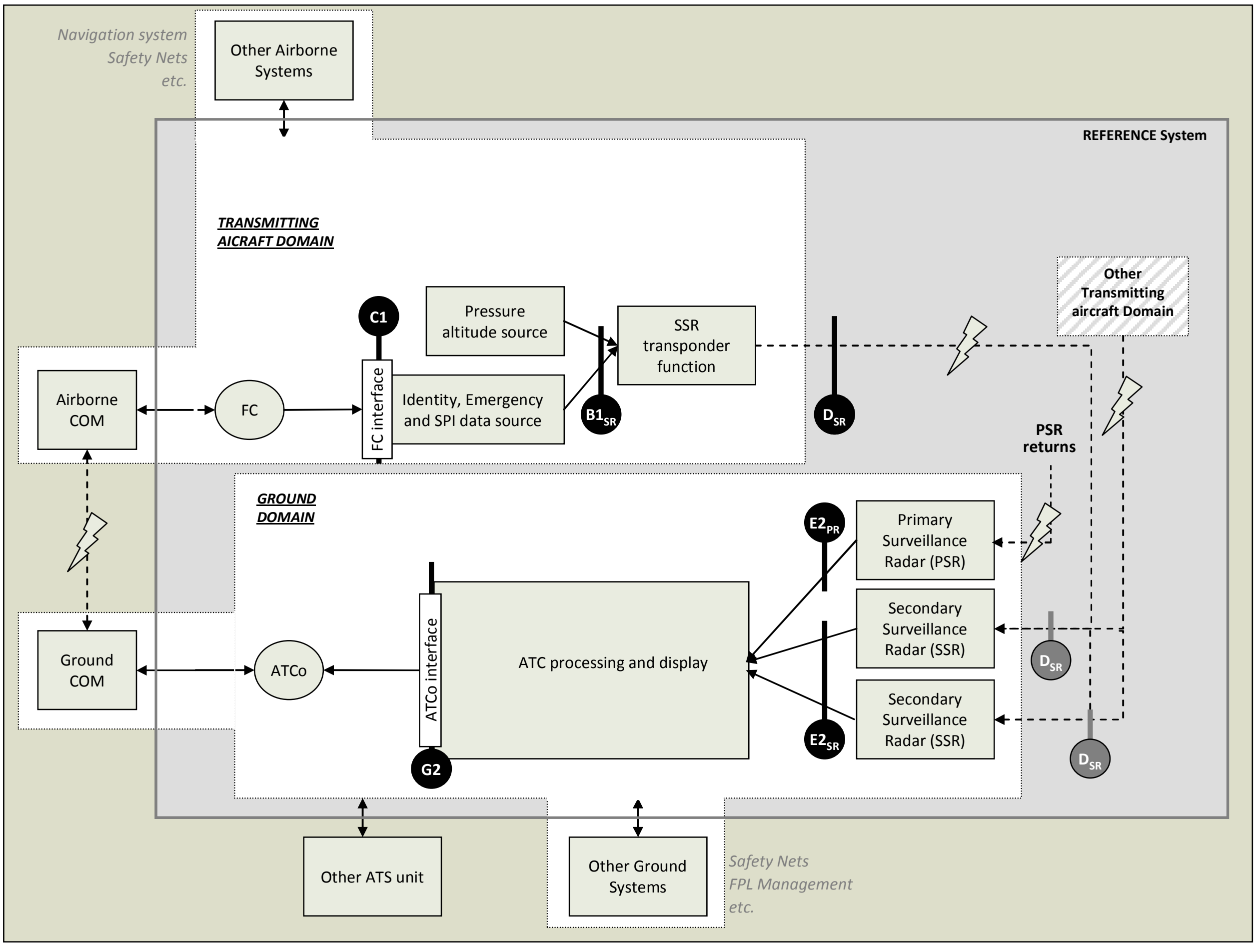

Figure 15: Reference Logical Model

All the considered scenarios defined in section 4.1 are represented in these two logical models above (in both ADS-B-RAD and Reference LM). When focusing on a specific scenario, the LM is to be slightly adapted (i.e. some elements and/or links are not to be considered). This adaptation is to be done case by case throughout the next sections.

Note that "SSR Transponder Function" covers both SSR and Mode-S. In the same line, the "Secondary Surveillance Radar (SSR)" also covers Mode-S in the corresponding scenarios and in the following sections.

The various elements in the ADS-B-RAD Logical Model which are new with respect to the Reference Logical Model are depicted in blue in Figure 14. Those elements that already exist in the Reference Logical Design but that are modified in someway in the ADS-B-RAD Logical Design are depicted in grey/blue.

The various "points of measurement" indicated in these two figures above (e.g. $A1$, D_A, $E2_{SR}$, $G2$) will be used throughout this section in order to clearly indicate to which part of the Logical Design the different results apply (e.g. performance values, requirements, etc.).

The "ADS-B-RAD ATC Processing and Display" function encompasses a part of the Reference system where only slight changes have been introduced (this is called the “Existing ATC Processing and Display” function) and two new functions: the “ADS-B to Radar Association” function and the “Ground ADS-B Surveillance Processing” function.

The interface A1* has been introduced for the specific case of latency introduced by the GNSS on-board receive function.

In the rest of this document, the following **terminology** is used with respect to some elements in the Logical Design:

“Aircraft Identity” information covers, as defined by ICAO, both Aircraft Identification (ACID) and Mode A code.

“Message” relates to the ADS-B transmission at interface D_A. It corresponds to a packet of information broadcast by an aircraft/vehicle. Each ADS-B message contains a defined set of aircraft/vehicle parameters. Message formats are link specific.

“Report” relates to the transmission at interface E2. An “ADS-B Report” is one of the data reports specifically defined in the ADS-B Minimum Aviation System Performance Specifications (MASPS) (RTCA DO- 242A [Ref.25]). A report can contain information from multiple messages. Similarly, a “Radar Report” is one of the data reports that include a set of radar data provided by the Primary Surveillance Radar and the Secondary Surveillance Radar.

“Target” relates to the display of surveillance information at interface G2.

“ADS-B Transmitting Aircraft Domain” corresponds to the blue parts of the “Transmitting Aircraft Domain” (A1/A1* to D_A), i.e. “GNSS on-board receive function with horizontal position integrity monitoring” and “Aircraft ADS-B function”.

“ADS-B Ground Domain” corresponds to the blue parts of the “Ground Domain”, i.e. “Ground ADS-B receive function”, “Ground ADS-B surveillance processing” function and “ADS-B to radar association function”.

Then, based on the logical model structure presented in the strategy in section 7.2, the operational surveillance procedures supporting the provision of ATC services are addressed in section 7.3.1, the interactions between operators and equipments (both operational data items and associated human tasks) in section 7.3.2, the technical data items are described in section 7.3.3, the functionalities of each element in section 7.3.4, and finally the respective performances characteristics in section 7.3.5.

7.3.1 Operational Surveillance Procedures to Support the Provision of the ATC Services

As described in [Ref.1], Annex A, §A.5.7.6, there is no change in the roles and responsibilities of the aircrew or controllers with regard to the provision of an Air Traffic Control service. The controller remains responsible for the provision of separation and expediting an orderly flow of air traffic. The flight Crew, apart from their clear and important responsibilities for safe conduct of the aircraft, is responsible for acting upon ATC instructions and providing information to ATC.

Operational surveillance procedures for the ADS-B-RAD logical design supporting the service and the Typical Operational Environments described in section 2.2 are introduced in this section and further developed in the next sections 7.3.1.1 (ATCo) and 7.3.1.2 (Flight Crew) as reference to PANS-ATM Doc 4444 [Ref.3] and as described in [Ref.1].

For each of the scenarii, there are no changes in phraseology between the ADS-B-RAD and the Reference logical designs.

7.3.1.1 Air traffic Controllers related Operational Surveillance Procedures

PANS-ATM Doc 4444 [Ref.3] includes the use of ADS-B to support Air Traffic Services. Although this ICAO document contains a complete description of all procedures relevant for ATS, only a sub-set was chosen for analysis within the ADS-B-RAD logical design and Annex D presents the set of ATS procedures that support ATS Surveillance Services. This annex focuses only on those operational surveillance procedures that relate to Area and Approach Control Services as opposed to those used for Flight Information Services or Aerodrome Control Services, which are out of scope for ADS-B-RAD.

GM015. Any difference in terms of operational surveillance procedure between the local ADS-B-RAD logical design procedures and the Reference logical design will have to be identified and the impact assessed – see section 1.6).

Of all the operational surveillance procedures provided in Annex D identification procedures are the only ones where the Reference and ADS-B-RAD may differ as a number of options are allowed for. The implementer may choose to use their Reference procedure and in that case there are no differences between the two. However, the implementer may choose to use different identification procedures as compared to the Reference logical design. The various options are presented below.

<u>Identification procedures options:</u>

The operational procedures used by Air Traffic Controllers to identify aircraft have been described in the [Ref.1] (in section A.5.6). There is a range of options regarding identification procedures as defined in PANS-ATM Doc 4444 [Ref.3] (e.g. recognition of the aircraft identification on the ATCo interface, recognition of an assigned discrete code, direct recognition of the aircraft identification, transfer of identification…), and this PSC does not prescribe one particular option. However, the identification procedures for ADS-B-RAD LM are assumed to be identical to the ones of the Reference LM.

Note: Some procedures are only applicable to an individual surveillance type (Mode S – direct recognition versus SSR identification procedures as defined in section 8.6.2.3 of the PANS ATM) whereas others are used across multiple surveillance types.

Note: In the [Ref.1] analysis, no assumption has been made on the flight plan correlation process.

The analysis performed in this PSC is based on Mode A code-based identification procedures for all RAD scenarios except for RAD-2b scenario where it is based on aircraft identification with Mode A code used as an alternate identification procedure (e.g. due for transfer of identification see §A.5.6.5 of [Ref.1]).

The ADS-B-RAD logical design supports either Mode A code[20] or aircraft identification[21] procedures in order to provide to the implementer, the option for the local ADS-B-RAD system to either maintain their legacy procedures (i.e. Mode A-based if applicable) or move to aircraft identification-based procedures if they are not already applied. It should be noted that current ICAO identification procedures allowed for ADS-B surveillance may be interpreted as excluding the use of Mode A codes and local authorities should include an assessment if mode A code procedure are applied using ADS-B surveillance[22].

The ICAO material (Annex 10 and Doc 9871) update to support the removal of the current Mode A geographical filter has not been published at the time of edition of this PSC document (**I008**).

GM016. Implementers wishing to utilise Mode A code-based procedures where ADS-B is the prime surveillance source should determine the availability and applicability of PANS-ATM identification procedure based on this information and in particular any update of ICAO material (Annex 10 and Doc 9871).

[20] This procedure implicitly refers to the ground system correlation of the Mode A code transmitted by the aircraft with the aircraft identification included in the item 7 of the Flight Plan, which is filled in by the flight crew/operator (see more information of the flight plan form in appendix 2 of [Ref.3]). The aircraft identification is then displayed to the controllers. This procedure requires a system of code assignment which ensures that each aircraft in a given portion of airspace is assigned a discrete code.

[21] This procedure implicitly refers to the direct downlink by the aircraft of the aircraft identification, which is then displayed to the controllers.

[22] This exclusion applies at the time of edition of this PSC and may change in the future with update to PANS-ATM.

GM017. Implementers wishing to implement aircraft identification-based procedure and for which the local logical designs differ from the logical designs above should assess the corresponding impact.

GM018. If local authorities wish to implement the method based on aircraft identification as a single source of identity information (i.e. without Mode A code as a back-up, e.g. airspace where Mode A code ceases to be transmitted), then a safety analysis is to be completed by the implementer to ensure the end-to-end system is safe and operationally acceptable [Ref.1] §A.5.6.2.6.

L001 The replacement of the use of the Mode A Code by Aircraft Identification as a single source of identity information in order to support identification method is not covered by the analysis in this document ([Ref.1] A.5.6.2.6).

7.3.1.2 Flight Crew related Operational Surveillance Procedures

Flight crew operational surveillance procedures for the ADS-B-RAD logical design are identical to those proposed in PANS-OPS Doc 8168 [Ref.9] for SSR (or Mode S) operations.

The same functions that are provided for the aircrew in relation to their interaction with radar transponder data will be provided from the ADS-B equipment ([Ref.1] paragraph A.5.5.1). This relates in particular to the interaction with mode A code and aircraft identification [call sign or aircraft registration], such as where radar transponders provide for a Mode A Code, Flight Crews are required to set the code that has been assigned by ATC, the airborne ADS-B equipment will also provide for similar “identity” data entry functionality.

Guidance material has been developed in support of flight crews operating within the environments described in this PSC (see Eurocontrol CASCADE [Ref.11]). This material provides a breakdown of specific operational surveillance procedures, which are in effect today across the variety of surveillance types.

These operational surveillance procedures are not new to flight crews, although they may be new to the particular airspace or region. This manual provides support to chief flight crews, management flight crews, flight operations and flight crew training staff, in highlighting those operational surveillance procedures that should be reviewed as part of the preparation of standard operating procedures, flight crew manuals and training material required by operators of ADS-B equipped aircraft that will fly in the ADS-B-RAD airspace.

As described in section 7.3.1.1, implementers have various options regarding the choice of identification procedures. Where the ADS-B-RAD identification procedure differs from the ADS-B-RAD logical design, there may be a corresponding impact on the flight crew procedures, for example they may have to change from entering Mode A code to entering aircraft identification.

GM019. Implementers wishing to implement aircraft identification-based procedure and for which the local Reference logical design differs from the Reference logical design above should assess the corresponding impact on the flight crew procedure and make appropriate arrangement for informing aircraft operators.

7.3.2 Interactions Between Human Actors and Interfacing Equipments

This section describes the interactions between the human actors (ATCo and FC) and the different equipment elements. Two aspects are to be addressed here:

- from one side, the **operational surveillance data items** required from these interfaces to support the operational surveillance procedures described in the previous section in order to provide the ATC service,
- and from the other side, the **human tasks** associated to these data and interfaces.

With respect to the latter, as developed in Annex I the ADS-B-RAD logical design has been defined such that the controller tasks remain identical to those of the Reference system, in particular the surveillance related human machine interfaces are the same:

A003. At the level of the PSC, it has been assumed that there is no major change regarding ATCo actions for ADS-B-RAD logical design compared to those performed in the Reference logical design.

Similarly, as developed in Annex I the ADS-B-RAD logical design has been defined such that most of the flight crew tasks remain identical to those of the Reference system, in particular the surveillance related human machine interfaces are the same except for the aircraft identification, which might differ depending on the environment:

A004. With the exception of the aircraft identification (see RAD Flight Crew manual [Ref.11] section §6.2), it is assumed that there are no change regarding Flight Crew actions for ADS-B-RAD and the same functionalities are applied regarding emergency situation, Mode A code change, SPI or deselecting of the Pressure-Altitude.

In addition human factors, as they are closely related to the physical implementation of these interfaces, are not covered in this PSC. These human factors are to be addressed at local safety case.

I009: Pilots and ATCo Human factors aspects are out of the scope of this PSC.

Note: However, some assumptions have been placed in section 10 on ATCo regarding hazard detection and recovery – see Table 38.

GM020. Implementers should conduct a human factor analysis on the ATCo interface and associated actions by controllers, to ensure that these are the same as in the Reference System, or perform an appropriate impact assessment otherwise.

Concerning the Operational **surveillance data,** two sets of items are identified: one at the level of the Air Traffic Controller and another at the level of the Flight Crew, both presented in following sections.

7.3.2.1 Operational Data Items on the Air Traffic Controllers Interface

This paragraph describes the operational surveillance data items to be provided at the level of the ATCo interface for the ADS-B-RAD logical design, i.e. at the point of measurement G2 in Figure 14.

For each ATS surveillance system of RAD-1, RAD-2 and RAD-3 scenarios, it is assumed that Advanced fusion techniques between ADS-B and SSR/Mode S data are not used and that ADS-B will be used as the principal surveillance source with radar providing a backup surveillance source in case of loss or degradation of ADS-B data[23] (**I001**).

Note: Data fusion was not assumed in [Ref.1] in order to ensure that the safety requirements derived remain in principle valid for a large variety of ground configurations. Assuming that ADS-B as prime surveillance source could sustain the service on its own, it would therefore derive the most stringent requirements.

Note: Radar backup surveillance source is automatically provided in case of loss or degradation of ADS-B data; this has been assessed in section 10 (in the failure approach).

In this regards, controller is presented with either one of the sources and not both simultaneously as individual tracks on the display (see Annex A of [Ref.1]).

[23] The case of fusion of ADS-B and Radar surveillance will be dealt with in a subsequent version of the PSC

Thus, the main surveillance data items and information (i.e. from ADS-B source) per aircraft that have to be available on the ATCo interface are:

Operational Data items at G2	Description
Aircraft Identity: - AC ID	Aircraft registration or call sign used in flight (alphanumeric digits)
-Mode A code	4 digits number
Horizontal Position	Latitude, Longitude position of aircraft through the use of symbols
Vertical Position	Pressure-Altitude[24] derived level information - Digit number
Emergency Indication	Emergency codes or equivalent (see note below) (Alphanumeric digits).
Special Position Indicator (SPI)	SPI
Indication of the ADS-B eligibility of the aircraft to apply applicable separation minima	[The controller interface provide an indication (through the use of symbols or by other means) on whether the surveillance data quality, combined or otherwise, is acceptable for the ATC service as indicated in [Ref.1], in Annex A.5.3.5.]
Ground Speed	Digit number in knots

Table 6: Data Items Required on the ATCo Interface

Note: In some cases the emergency indication is presented using the Mode A representation or an equivalent representation (e.g. EMG in place of 7700).

Note: Urgency codes are not the minimum required for ADS-B-RAD.

These surveillance data items are identical amongst the RAD-1, RAD-2 and RAD-3 scenarios.

In the Reference system, the same data items are available on the ATCo interface per aircraft and comparable position symbology is assumed[25].

In scenarios RAD-1 and RAD-3, it is possible to display the PSR data independently or as a combined symbol with ADS-B position data. See Annex

[24] As per PANS-ATM Doc4444 [Ref.3] Chapter 1: Definitions: “Pressure-Altitude” is an atmospheric pressure expressed in terms of altitude which corresponds to that pressure in the Standard Atmosphere.

[25] The design of symbology is out of scope.

H that provides details and guidance related to display techniques for PSR targets.

Note that apart from this surveillance related data, any other information and features that is/are available on the ATCo interface in the reference system (e.g. maps, alerts, etc.) is to be provided in a same way on the ATCo interface of the ADS-B-RAD system.

GM021. As per §A.5.3.2 in [Ref.1], ICAO (PANS-ATM) allows for individual position symbols for different surveillance sources to be presented to the controller during nominal operations. However this has not been foreseen in ADS-B-RAD in regards to ADS-B and SSR/Mode S position data as the ADS-B data has been assumed to be displayed as the principal source (§A.4.2.6 in [Ref.1]). Some allowances however have been made for PSR data in terms of display techniques (see Annex H).

7.3.2.2 Data Items at Flight Crew Interface

The Flight Crew interface for ADS-B-RAD has to provide the option to set, check and modify the following operational surveillance data items (i.e. at the point of measurement C1 in Figure 14) for all the RAD scenarios considered:

Data items at C1	Description
Aircraft Identity	ACID based on aircraft registration or call sign used in flight (alphanumeric digits)
	Mode A Code (four-digits number)
Emergency Indication	Emergency Codes: - emergency; - communication-failure; - unlawful-interference;
Special Position Indicator (SPI)	SPI

Table 7: Data Items Required on the Flight Crew Interface

Note: Urgency codes (for minimal fuel and medical) are not the minimum required for ADS-B-RAD.

Independent of the identification options described in 7.3.2.1, the Flight Crew will have to set/modify both Mode A code and Aircraft Identification throughout all phases of flight if instructed by ATC (even in the case of aircraft identification procedure, mode A code will be needed as back-up –see section 7.3.1.1 – (cf. [Ref.1] section A.5.6.5).

With respect to the Reference system scenarios, Mode A, Emergency Modes and SPI information are provided in the same way as requested for ADS-B-RAD.

This is not the case for AC ID information, which is not set in reference scenarios RS-1, RS-2a and RS-3 but, as explained above, is required to be set in the interface in the corresponding RAD-1, RAD-2a and RAD-3 scenarios (see more detail in section 7.4.2).

Note that apart from this surveillance related data, any other information and features that is/are available on the FC interface in the reference system (e.g. transponder on /off) is to be provided in a same way on the FC interface of the ADS-B-RAD system.

The same emergency conditions are expected to occur for the ADS-B-RAD and the Reference logical designs: the Emergency indications provided by the ADS-B-RAD logical design include in comparison to the Reference logical design two optional more elements for the Urgency mode[26]: Minimum fuel and Medical (see Table 7 above). Depending on the emergency, the pilot may be requested to select the reserved emergency codes including 7500, 7600 and 7700.

[26] *This is not an emergency situation but merely indicates that an emergency situation is possible,*

7.3.3 Technical Surveillance Data Items

This section describes the required technical surveillance data items for ADS-B-RAD logical model to be used by the different elements of the logical design in order to finally ensure the availability of the operational surveillance data presented in previous section 7.3.2.

These technical surveillance data items are presented in the next table at the level of all points of measurement indicated in Figure 14 for each data item required ultimately at the controller interface G2 (table partially derived from §Table B-1 of the OPA of [Ref.1]):

A1	*C1*	$B1_A$	$B1_R$	D_A	D_{SR}	$E2_A$	$E2_{SR}$	$E2_{PR}$	*G2*
	ACID ModeA	ACID ModeA	[ACID] ModeA	ACID ModeA 24bit@	[ACID] ModeA [24bit@]	ACID ModeA 24bit@	[ACID] ModeA [24bit@]		*Aircraft Identity (ACID; ModeA)*
Pseudo -range		Lat Long		Lat Long		Lat Long	Range Azimuth	Range Azimuth	*Horiz. Position (Lat Long)*
		Press-altitude	Press-altitude	Press-altitude	Press-altitude	Press-altitude	Press-altitude		*Vertical position (Press-altitude derived FL)*
	Emerg. Codes	Emerg. Modes and Codes	Emerg. Codes	Emerg. Modes and Codes	Emerg. Codes	Emerg. Modes and Codes	Emerg. Codes		*Emerg. Indication*
	SPI	SPI	SPI	SPI	SPI	SPI	SPI		*SPI*
		QI per aircraft position (HFOM , HPL)		QI per aircraft position (NAC, NIC, SIL, SDA) and version number- see notes below		QI per aircraft position	Global radar status		*Indication of the eligibility of the aircraft to receive ATC Service*
									Ground Speed

Table 8: Required Technical Surveillance Data Items for ADS-B-RAD LM

Note: To facilitate the link with the operational data items as described in Table 6 and in Table 7, columns C1 (Fligh Crew) and G2 (ATCo) are also presented in this Table 8.

At interface D_A, ADS-B data are transmitted through the form of ADS-B messages in accordance with the version number of the data link protocol in use (e.g. RTCA DO-242A).

At interface $E2_{A,}$ ADS-B data are under the form of reports that comply with ASTERIX category 21.

The eligibility of the aircraft to receive ADS-B-RAD service is based on the quality indicators processed and transmitted by the aircraft to the ground. They include indicators on position accuracy (Navigation Accuracy Category for Position, NACp), and integrity of the reported position (Navigation Integrity Category, NIC), combined with Source or Surveillance Integrity Level (SIL).

The type of quality indicators transmitted by ADS-B depends upon the version number of the data link protocol in use (version 1 or 2) as specified in SAF066 (in section 8.2) and associated note.

More details on these values required for ADS-B-RAD are defined in Table 14 and text below.

Moreover, in version 2 (see SAF066), an additional quality indicator is defined: the System Design Assurance – SDA. It provides the likelihood of the system integrity failure of the ADS-B function leading to the corruption of the aircraft horizontal position, ACID or altitude. The required SDA value for ADS-B-RAD is defined in the failure case, section 10, through SAF095.

As clarified in the Logical Model, the radar related elements cover both SSR and Mode-S types. It is to be noted that there no major difference between Mode S and SSR radar in terms of technical data required to be received on the ground. The only differences rely on:

- The use of 24 bit ICAO aircraft address for the dialogues between the Mode S and the aircraft (Note that the unique ICAO 24-bit aircraft address is not accessible or modifiable by the flight crew (see §4.4.1.1 of [Ref.1]) and,
- The direct transmission of the Aircraft Identification transmitted by the Mode S.

This difference has been indicated in the previous table using square brackets "[ ]" for Mode-S related data in data sets $B1_{R}$, D_{SR} and $E2_{SR}$.

The ICAO 24 bit address contained in each ADS-B message is only used in the construction of ADS-B reports.

Note that Ground Speed is not mentioned in the list of the technical data items of Table 8 above even if it is to be provided to Air Traffic Controller (as it is part of the operational data set G2 described in section 7.3.2.1). This is due to the fact that in the ADS-B-RAD logical design, this data item is to be reconstructed by the ground ATC processing system (by derivation from position information) as it is done in the Reference logical design case (see more information in section 7.3.4.2).

GM022. Implementers may consider the provision of Velocity and its associated quality indicator at the input of the ATC Processing System (for example, to assist the ground automation in the time registering of ADS-B targets on the ATC display ([Ref.1]). Implementers wishing to display the ADS-B reported velocity should conduct the appropriate analysis and derive the corresponding requirements.

Although there is a potential for geometric altitude to be sent by ADS-B, which may be used by the ground system (such as for cross-checking barometric altitude data) this parameter is outside the scope of ADS-B-RAD ([Ref.1], section A.7).

GM023. Implementers wishing to use the ADS-B reported geometric altitude should conduct the appropriate analysis and derive the corresponding requirements.

The new set of data introduced in ADS-B-RAD logical design with respect to the Reference one is indicated in blue in Table 8. They are applicable for all the RAD scenarios considered, in combination with the operational data sets presented in previous section 7.3.2 (i.e. C1 and G2), and other data sets existing in the Reference Logical Design as indicated here-after per scenario:

RAD-1: $E2_{PR}$

RAD-2a: $B1_R$, D_R, $E2_{SR}$ (all based on SSR only)

RAD-2b: $B1_R$, D_R, $E2_{SR}$ (all based on Mode S)

RAD-3: $B1_R$, D_R, $E2_{SR}$ (all in SSR), and $E2_{PR}$

The ADS-B-RAD Logical Model includes the Reference Logical Model points of measurements plus the following ones:

A1: this is the interface with the external positioning source (see more detail on this positioning source in section 7.6).

$B1_A$: this is ADS-B interface between the GNSS on-board Receive function and the Aircraft ADS-B function.

D_A: this is the ADS-B interface between the Aircraft ADS-B function and the Ground ADS-B receive function.

$E2_A$: this is the ADS-B interface between the Ground ADS-B Receive function and the Ground ADS-B Surveillance Processing function.

The differences between the ADS-B-RAD and the Reference Logical Models are explained in section 7.4.3.

7.3.4 Surveillance Functions

This section describes the ADS-B-RAD functions in the different RAD scenarios considered, and compares them with the corresponding Reference logical design functions as necessary.

In section 7.3.4.1 the functions of each element of the Transmitting Aircraft Domain are detailed. These elements, as identified in Figure 14, are:

- GNSS on-board receive function with Horizontal position integrity monitoring,
- Pressure altitude source,
- Identity, Emergency and SPI data sources through the flight crew interface,
- Aircraft ADS-B function,
- SSR transponder function.

In section 7.3.4.2 the functions of each element of the Ground Domain are detailed. These elements, as identified in Figure 14, are:

- Ground ADS-B receive function,
- Primary Surveillance Radar (PSR),
- Secondary Surveillance Radar (SSR),
- ADS-B-RAD ATC Processing and Display function.

The following tables provide the following information:

- *Receives*: corresponds to the input information in the concerned element.
- *Provides*: corresponds to the output information at the concerned element.
- *Functions*: describes the functions associated to the concerned element.
- *RAD-x*: identifies the scenarios (RAD-1, RAD-2a or RAD-2, RAD-3) applicable to the concerned element.
- *RS-x*: identifies the differences if they exist with the Reference logical model.

7.3.4.1 ADS-B-RAD Functions in the Transmitting Aircraft Domain

GPS on-board receive function with Horizontal position integrity monitoring

Receives	All (A1) data	**Provides**	($B1_A$) Horizontal Position data and Quality indicator
Functions	‣ Receives information from External Positioning Source ‣ Provides Outputs to the Aircraft ADS-B function		
RAD-x	Applicable to all RAD scenarios		
RS-x	New element in the ADS-B-RAD logical design. See more detail in section 7.4.4		

Pressure altitude source

Receives	n/a (direct data source)	**Provides**	($B1_A$) Pressure altitude
Functions	‣ Directly measures/captures pressure-altitude information ‣ Provides the same output to the Aircraft ADS-B function and SSR Transponder Function		
RAD-x	Applicable to all RAD scenarios		
RS-x	No change with respect to reference logical design		

Identity, Emergency and SPI data sources

Receives	All (C1) data	**Provides**	($B1_A$) Aircraft Identity data (Mode A and ACID), Emergency codes, SPI
Functions	‣ Through the FC interface, it enables the flight crew to select the emergency code and the SPI and to enter the Mode A code and the ACID. ‣ Provides the same output data to the Aircraft ADS-B function and SSR/Mode-S transponder function		
RAD-x	Applicable to all RAD scenarios.		
RS-x	As explained in section 7.3.1.1, ACID information is not set in reference scenarios RS-1, RS-2a and RS-3 but is set in RS2-b (see detail in section 7.4.4		

Aircraft ADS-B function

Receives	All ($B1_A$) data	**Provides**	All (D_A) data
Functions	‣ Receives the data from various sources ‣ Processes the received data.		

	‣ Outputs this data in ADS-B messages in accordance with the appropriate data link specifications		
RAD-x	Applicable to all RAD scenarios.		
RS-x	New element in the ADS-B-RAD logical design. See more detail in section 7.4.4		

SSR transponder function

Receives	All ($B1_R$) data	**Provides**	All (D_R) data
Functions	‣ Receives the data from various sources ‣ Processes received data ‣ Provides output data to ground domain (when requested by ground)		
RAD-x	Applicable to all RAD scenarios except for RAD-1 in which the SSR functions are not used. Note that this function is to be understood as Mode S function for scenario RAD-2b		
RS-x	As indicated here after, this function is needed in RS-1 but not in RAD-1. Note that this function is to be understood as Mode S function for scenario RS-2b.		

Table 9: Transmitting Aircraft Surveillance Functions

7.3.4.2 ADS-B-RAD Functions in the Ground Domain

Ground ADS-B receive function

Receives	All (D_A) data	**Provides**	All ($E2_A$) data
Functions	‣ Receives ADS-B messages from Transmitting Aircraft Domain ‣ Decodes the ADS-B messages and packages and time-stamps the ADS-B reports (based on 24-bit address) ‣ Provides the ADS-B reports to the Ground ADS-B Surveillance Processing function This function covers the ADS-B signal in space and the ground receiver (see table C-7 in Annex C [Ref.1])		
RAD-x	This element is applicable to all RAD scenarios.		
RS-x	New element in the ADS-B-RAD logical design. See more detail in section 7.4.4		

Primary SurveillanceRadar (PSR)

Receives	n/a (direct data source)	**Provides**	All ($E2_{PR}$) data
Functions	‣ Provides received own processed data in form of radar reports to the Existing ATC Processing and Display function		
RAD-x	This element is applicable to RAD-1 and RAD-3 scenarios.		
RS-x	No change with respect to reference logical design		

Secondary SurveillanceRadar (SSR)

Receives	All (D_R) data, SSR and Mode S as applicable	**Provides**	All ($E2_{SR}$) data, SSR and Mode S as applicable
Functions	‣ Receives radar data from Transmitting Aircraft Domain ‣ Provides received information and own processed data in form of radar reports to Existing ATC Processing and Display function (see table C-7 in Annex C [Ref.1])		
RAD-x	This element is applicable to scenarios RAD-2a (as SSR), RAD-2b (as Mode S) and RAD-3 (as SSR).		
RS-x	No change with respect to reference logical design		

ADS-B-RAD ATC Processing and Display function

<table>
<tr><td>Receives</td><td>All ($E2_{PR}$, $E2_{SR}$, $E2_{A}$) data</td><td>Provides</td><td>All (G2) data</td></tr>
<tr><td>Functions</td><td colspan="3">Ground ADS-B Surveillance Processing function
• Receives the ADS-B reports provided by the Ground ADS-B Receive function (see table C-7 in Annex C [Ref.1])
• Checks the ADS-B position Quality indicators and determines the ADS-B aircraft eligibility(see OR-4 [Ref.1])
• Transforms the ADS-B data into a common reference system (e.g. coordinate system) with radar data (e.g. time synchronisation with radar, co-ordinate conversion) (see table C-7 in Annex C [Ref.1])
• Sends the ADS-B reports to the ADS-B-to-radar Association function

Note: the term “common reference system “item does not mean the fusion of ADS-B with radar but the necessity that both data use the same system of reference.
ADS-B-to-Radar Association function
• Assesses whether ADS-B reports and radar data sufficiently match to support display of a single ADS-B target given multiple surveillance sources.
Existing ATC Processing and Display function
• Maintains the track data, including correlation with flight plan information (e.g. using Mode A code - see Environ.Assump-17, [Ref.1]).

Note: the association of ADS-B reports to internal flight plan information does not use 24 bit address provided in the ADS-B messages.
• Reconstructs ground velocity from position information received from surveillance sources (ADS-B and radar) (§A.5.3.1 of [Ref.1])
• Supports procedures that enable the use of automated transfer of identification between ATS units
• Updated system track information is sent to the ATCo interface, using ADS-B as the principal source of information and radar as a back-up source with a synchronous refresh cycle
• Displays surveillance ADS-B information to the controller presented in section 7.3.2.1 (see OR-1, [Ref.1])
• Displays position targets with a constant refresh rate (see Environ.Assump-18, [Ref.1])
• Presents clearly information so that the ATCo is able to determine which ‘part’ of the position symbol is to be used for applying separation standards (see Environ.Assump-29, [Ref.1])</td></tr>
<tr><td>RAD-x</td><td colspan="3">Ground ADS-B Surveillance Processing function: applicable to all RAD scenarios,
ADS-B to Radar Association function: applicable to all RAD scenarios, except in principle for RAD-1 where this</td></tr>
</table>

	function is not applicable depending on the display technique (see Annex H). *ADS-B-RAD ATC Processing and Display function:* applicable to all RAD scenarios with the exception that in RAD-1 scenario, the PSR position is presented in combination with the ADS-B information.
RS-x	*Ground ADS-B Surveillance Processing function:* this function does not exist in the Reference System. *ADS-B to Radar Association function:* depending on the Reference radar processing system, an equivalent of the "ADS-B-to-radar association function" may exist for radar-to-radar association. *ADS-B-RAD ATC Processing and Display function:* exists in the Reference system but without the processing and display of ADS-B data.

Table 10: Ground Surveillance Functions

7.3.5 Performance Characteristics

This section focuses on the performance aspects of the ADS-B-RAD system when considering the related ADS-B-RAD scenarios.

Section 7.3.3 includes the technical data items identified at the level of the ADS-B-RAD ATC Processing and Display function, where the performances are identified (see section 7.3.5.1). These performances are then propagated at airborne level (see section 7.3.5.2).

7.3.5.1 Performances at ADS-B-RAD ATC Processing and Display Function Input

As mentioned in the introduction of section 7.2, the comparison between the ADS-B-RAD and the Reference logical designs is translated at technical level into a direct comparison between the ADS-B technology performances and the corresponding Reference radars (SSR or mode S), therefore, i.e. a direct comparison of performance between interface $E2_A$ for ADS-B and interface $E2_{SR}$ for the reference SSR radar (see Figure 14).

One important element relates to the derivation of ADS-B required position accuracy. Therefore, the ADS-B-RAD system has, in its comparison to radar, selected what is known as a range of applicability value. This value is a distance from the radar head at which the azimuth based radar cross range error has been used to compare to the 95% ADS-B accuracy performance. This in turn was used to determine the ADS-B position accuracy requirements. There is a fundamental difference in the characteristics of the position accuracy between radar and ADS-B, i.e. ADS-B is not dependent on range.

Section B.2.3.1.5 §Annex B of [Ref.1] contains a justification for the selection of the various reference ranges used in the comparison. Additionally Appendix B-6 of [Ref.1] contains an alternate analysis for other reference ranges.

Specific Reference-radar performance values are thus needed in order to derive the equivalent ADS-B requirements, in compliance with Safety Target **ST001**.

These Reference-radar performance values are documented in §Annex B of [Ref.1] for each of the data items listed in Table 8 above at $E2_{SR}$, and are summarized in Table 11 below.

These performance values are addressed first in the radar case (see Table 11 below) and are then derived for the ADS-B case (see Table 13 below) at $E2_A$.

Reference logical design performance:

In the various Reference scenarios (as described in Table 3), the performance characteristics of the data items at a point of measurement $E2_{SR}$ (see Figure 14), are expressed in [Ref.1] for both En-route and TMA (including final approach), in terms of update interval and update probability (in §B.4.1 Tables B-2), accuracy (in §B.4.2 Table B-4), and other parameters such as latency and time stamp accuracy (in §B.4.5 Table B-13). The performance characteristics of the data items at the point of measurement D_{SR} (airborne level) are also considered for the vertical position.

The following Table 11 and Table 12 present the summary of the Reference-radar performance values (at ground level - $E2_{SR}$ and at airborne level – D_{SR}) to be considered for the specification of the ADS-B-RAD logical design performance values:

Reference Radar Performance $E2_{SR}$		**En-route [RAD-2a, RAD-2b]**	**TMA [RAD-1, RAD-3]**	**Final Approach. [RAD-3]**
Update interval (at $E2_{SR}$)	Update interval (radar scan period)	≤ 8s	≤ 5s	≤ 5s
Update probability (at $E2_{SR}$)	Position report	≥ 0.97	≥ 0.97	≥ 0.97
	Mode A code validation (per target report)	≥ 0.98	≥ 0.98	≥ 0.98
	Equivalent Mode A code validation (per scan)	0.95	0.95	0.95
	Mode C code validation (per target report)	≥ 0.96	≥ 0.96	≥ 0.96
	Equivalent Mode C code validation (per scan)	0.93	0.93	0.93
	Emergency/SPI code validation	≥ 0.98	≥ 0.98	≥ 0.98
Accuracy Horizontal Position (at $E2_{SR}$)	Core accuracy:			
	(Monopulse[27]) SSR model 95% azimuth accuracy – [Ref.1] appendix B- 3.2	0.127 °	0.127 °	0.127 °
	(Monopulse) SSR Range Of Applicability [Ref.1]B – 2.3.1.5.	60Nm	33Nm	15Nm
	(Monopulse) SSR model 95% cross range position accuracy	246m	137m	62m
	(Monopulse) SSR model 95% along range position accuracy	137m	137m	137m
Accuracy Vertical Position	Accuracy[28] Note: this is the same accuracy as available at D_R,	38.1m (125ft)[29]	38.1m (125ft)	38.1m (125ft)

[27] Given the high-density environments, the reference radar for accuracy comparisons is assumed to be Monopulse SSR rather than the lower performing sliding window radar, as the desire is to have ADS-B performance comparable with more modern radar ([Ref.1]OPA ASSUMP.15).

Reference Radar Performance $E2_{SR}$		En-route [RAD-2a, RAD-2b]	TMA [RAD-1, RAD-3]	Final Approach. [RAD-3]
at $E2_{SR)}$	see Table 12			
Vertical Position Resolution at $E2_{SR)}$	Resolution in Mode C Note: this is the same resolution as at D_{SR} level, see Table 12	≤ 100ft[30]	≤ 100ft	≤ 100ft
Latency at $E2_{SR)}$	Maximum age for position, Mode A Code, Emergency and SPI in radar report (at the input to the ADS-B-RAD ATC Processing and Display function)	2s	2s	2s
Time Stamp at $E2_{SR)}$	Maximum time stamp inaccuracy of radar reports is determined by the ground system	0.1s	0.1s	0.1s

Table 11: Reference Radar Performance Parameters for the Reference Logical Design at Interface $E2_{SR}$

Reference Radar Performance D_R		En-route [RAD-2a, RAD-2b]	TMA [RAD-1, RAD-3]	Final Approach [RAD-3]
Accuracy Vertical Position	Altimeter accuracy[31]	38.1m (125ft)[32]	38.1m (125ft)	38.1m (125ft)
Vertical Position Resolution	Resolution in Mode C	≤ 100ft[33]	≤ 100ft	≤ 100ft

Table 12: Reference Radar Performance Parameters for the Reference Logical Design at Interface D_{SR}

[28] This is minimum accuracy requirement for altimeter, and is dependent on the type of airspace. Many airspace regions, such as RVSM, will require better altimeter performance than specified here.

[29] As per Mode C provision in ICAO Annex 10

[30] As per Annex 10, Vol. IV (4.3.9.3.1.) it is recommended to use a source providing a resolution less than or equal to 7.62m (25ft)

[31] This is minimum accuracy requirement for altimeter, and is dependent on the type of airspace. Many airspace regions, such as RVSM, will require better altimeter performance than specified here.

[32] As per Mode C provision in ICAO Annex 10

[33] As per Annex 10, Vol. IV (4.3.9.3.1.) it is recommended to use a source providing a resolution less than or equal to 7.62m (25ft)

The Reference radar performance values in Table 11 have been derived from the values specified in the Eurocontrol Surveillance Standard [Ref.18] and it is important to note that no distinction is made between Mode S and SSR radars with respect to their performance characteristics and therefore Monopulse characteristics have been used.

GM024. At the time of the edition of this Preliminary Safety Case, the new Eurocontrol Surveillance Standard has not yet been published. Whilst coordination between the SPR standard and the new surveillance standard is foreseen, it is suggested that implementers assess the impact of this new standard on their local safety case.

As indicated in section 2.2.2, ICAO PANS ATM Doc 4444 [Ref.3] specifies certain azimuth requirements to support certain parallel runway operations the ADS-B-RAD system was restricted in scope by nature of the comparative analysis.

ICAO allows for independent final approaches on parallel runways spaced by more than 1525m provided certain radar characteristics are met and the ADS-B-RAD system compares those characteristics in its analysis (as per Table 11 above) hence these operations are included in the scope.

Furthermore for runways spaced less than 1525m but no less than 1310m, ICAO allows those same radar characteristics to be used in support of final approaches for independent parallel runway operations provided the implementer has performed a safety assessment. Hence for runways with this spacing the ADS-B-RAD analysis is relevant if that safety assessment has or will be conducted.

If no local safety assessment has been, or will be, performed to satisfy this requirement then the scope of the ADS-B-RAD system changes, for that implementer, to only parallel runways that are greater than or equal to 1525 meters.

GM025. Implementer should ensure that a local full safety assessment exists in order to be able to considerer the case developed in this document regarding the case of two runways spaced less than 1525m but no less than 1310m, where ICAO allows those same radar characteristics to be used in support of independent final approaches on parallel runways provided the implementer has performed a safety assessment. If no local safety assessment has been, or will be, performed to satisfy this requirement then the local ADS-B-RAD system scope changes, for that implementer, to only parallel runways that are greater than or equal to 1525 meters.

GM026. The Reference logical design includes scenario related to an ATC separation task with minima (5 NM En-Route, 3 NM in TMA, 2.5NM/2.0NM in final approach) based on reference radar (per scenario) which may not correspond to those applied by implementers. The impact of a local reference radar different from the Reference radar used in this document should be assessed by implementers and in particular the impact on the derivation of the Quality indicators.

GM027. Update rates are derived from that of the Reference radar (8s En route, 5 s TMA). Implementers with local Reference radar having a different update rate should check the related impact.

ADS-B-RAD logical design performance:

The following Table 13 presents the ADS-B performance values to be required for the ADS-B receiver subsystem (i.e. at point of measurement $E2_A$ in Figure 14), in relation with the various ADS-B-RAD scenarios (as described in Table 2). They have been derived from Reference-radar performance values presented in previous Table 11.

ADS-B-RAD Performance at interface $E2_A$		En-route [RAD-2a, RAD-2b]	TMA [RAD-1, RAD-3]	Final Approach [RAD-3]
Update interval	for State Vector (state vector information including change in quality indicators)	≤ 8s	≤ 5s	≤ 5s
	for Identity (aircraft identification and Mode A code)	< 8s	< 5s	< 5s
	for Surveillance Emergency and SPI	≤ 8s	≤ 5s	≤ 5s
Update probability[34]	for State Vector	≥ 0.97	≥ 0.97	≥ 0.97
	for Identity (aircraft identification and Mode A code) change[35]	≥ 0.95	≥ 0.95	≥ 0.95
	for Surveillance Emergency and SPI change[35]	≥ 0.95	≥ 0.95	≥ 0.95
Horizontal Position	Horizontal Position Accuracy 95% See explanatory text below on	< 308 m (NAC_p=7)	< 171 m (NAC_p=8)	< 171 m (NAC_p=8)

[34] See also requirements in the failure approach case relating to the "loss of track information" in section 10

[35] Derived from the values expressed on a "per scan" basis in Table 11. See justification in section B.4.1.2. §Annex B of [Ref.1].

ADS-B-RAD Performance at interface $E2_A$		En-route [RAD-2a, RAD-2b]	TMA [RAD-1, RAD-3]	Final Approach [RAD-3]
Accuracy	accuracy.			< 121 m (NAC_p=8)
Accuracy Vertical Position	Altimeter accuracy[36]	38.1m (125ft)[37]	38.1m (125ft)	38.1m (125ft)
Vertical Position Resolution	Resolution in Mode C	≤ 100ft[38]	≤ 100ft	≤ 100ft
Horizontal Position Integrity[39]	Quality Indicators See explanatory text below on integrity. SIL[40]	1.0 NM or less (NIC_p=5) (SIL=3, /fh)	0.6 NM or less (NIC_p=6) (SIL=3, /fh)	0.2 NM or less (NIC_p=7) (SIL=3, /fh)
Latency	Maximum latency for surveillance position, identification and Emergency/SPI data at $E2_A$ See section 7.3.5.2. on the latency apportionment between airborne and ground domain.	2s	2s	2s
Time Stamp	Maximum time stamp inaccuracy of ADS-B reports by the ground system.	0.1s	0.1s	0.1s

Table 13: ADS-B Performance Parameters at Interface $E2_A$

<u>Accuracy:</u>

For ADS-B, horizontal position accuracy is defined as the radius (ra) of a circle centred on the target's reported position such that the probability of the target's actual position being inside the circle is 95%. Note that this radial error is the resultant of errors in two dimensions (x and y). Assuming that the error distributions in each dimension are independent Gaussian distributions with

[36] This is minimum accuracy requirement for altimeter, and is dependent on the type of airspace. Many airspace regions, such as RVSM, will require better altimeter performance than specified here.

[37] As per Mode C provision in ICAO Annex 10

[38] As per Annex 10, Vol. IV (4.3.9.3.1.) it is recommended to use a source providing a resolution less than or equal to 7.62m (25ft).

[39] "Horizontal Position Integrity" relates to a quality of service providing an indication on when ADS-B-RAD separations can be applied or not.

[40] For datalink version number 2 (see SAF066), SIL = 3 is required to ensure GNSS derived position information. A supplementary bit accompagnies the SIL, which can reflect "per fh" or "per sample". "Per fh" is required to ensure 10-7/fh. For datalink version number 1, SIL = 2 is required (see SAF066).

the same standard deviation (σ), the resultant radial error distribution will be Rayleigh and the 95% point of this distribution will be 2.45σ. The required accuracy is derived from comparison with a single dimension radar 95% accuracy (ε95). The required ADS-B 95% accuracy is compared against the radar ε95 accuracy without systematic biases (i.e., stochastic errors only). This ensures that the normal 95% accuracy of ADS-B is always as good as, or better than, radar accuracy at the chosen range of applicability and it also ensures that the ADS-B to ADS-B separation accuracy is always as good or better than the best-case radar to radar separation (i.e., both aircraft separated by the same radar). Knowing that the 95% point of a Gaussian distribution is 1.96σ, the required ADS-B, 95% accuracy radius (ra) is given by: ra = (2.45/1.96)*ε95 = 1.25*ε95.

For approaches scenario, the value of 171m refers to the 3 NM, to the 2.5 NM separation minima for succeeding aircraft on same final ([Ref.3], §8.7.3.2(b)) ("in-trail" single runway see illustration on Figure 3 and to the 2 NM separation minima for succeeding aircraft on adjacent ILS/MLS, in the case of dependent parallel runways [Ref.3],§6.7.3.4.3(b). – see illustration on Figure 5 The value of 121 m relates to the operation of independent parallel approaches where more strict accuracy requirements have been derived than for the other approaches, see justification in Annex D.6 of [Ref.1].

Note: the quality indicator values are presented in Table 13 under the form of NACp values for practical reasons (to ease comparison with airborne quality indicators), whereas in practice they will be expressed under an ASTERIX format.

GM028. A NACP=8 has been determined to indicate equivalent or better performance for terminal and approach environments in comparison to radar based upon the comparative analysis using radar models, taking into account the set of ADS-B-RAD Ground Domain functions applicable to the assessment. Local implementations may permit a lower NACP value under certain conditions, such as 7, based on additional ADS-B-RAD Ground Domain functions as a means of achieving the end-to-end performance necessary for the ADS-B-RAD system. Moreover, an implementer may also permit a NACP=7 encoding in line with the arguments produced in Appendix B-7 of [Ref.1].

Integrity:

The Horizontal Position Integrity values has been derived through an assessment of which quality indicator minimum level would provide less or equal surveillance separation error for the ADS-B-RAD logical design compared to the Reference logical design through the "Surveillance Separation Error" (SSE) analysis as described in § Annex D in [Ref.1] and for which a summary of the assessment and findings can be found in Annex G of this PSC.

Note: the quality indicator values are presented in Table 13 under the form of NIC, SIL values for practical reasons (to ease comparison with airborne quality indicators), whereas in practice they will be expressed under an ASTERIX format.

GM029. Implementers should check whether the SSE analysis assumptions are applicable in their local environment or should use alternative methods to derive NIC quality indicator minimum values. Implementers should check whether the Quality Indicator values as specified in Table 13 are appropriate at local logical design level. The impact for this data item upon the ground ADS-B-RAD ATC Processing and Display function relates to the management of the Position Quality Indicator that is provided together with the corresponding position.

Additional guidance relating to quality indicators:

GM030. [Ref.1] explicitly mentions that less stringent requirements might be placed on NIC/NAC_p values in radar airspaces with larger minimum separations, but also indicates that additional studies would be needed in this respect.

7.3.5.2 Performances for the Transmitting Aircraft Domain

The previous section has identified the performance at the level of the interface $E2_A$ (the ADS-B-RAD ATC Processing and Display function). This section discusses the propagation of the relevant performances required at the airborne level, i.e. at the points of measurement D_A and $B1_A$ in Figure 14:

- Position accuracy, integrity and latency
- Update interval and update probability

Position accuracy, integrity and latency

Definitions:

The total latency is the difference between the time of applicability of the horizontal position measurement to the time of transmission of that data.

The uncompensated latency is that part of the total latency that is not compensated for (within the ADS-B transmitting system).

Note: Any uncompensated latency will have the effect of degrading position accuracy. See Appendix B-1. Therefore, uncompensated latency must be limited in order to meet accuracy requirements.

The compensated latency is an interval of time over which position information is extrapolated.

For latency, an apportionment takes place for ADS-B between ground and airborne domains where both total latency and uncompensated latency are considered. Uncompensated latency characteristics considered for the avionic (see [Ref.1] B.4.2.3. and B 4.5.2. PR 36) are expressed under the form of the maximum 95% and 99.9% uncompensated latency values. The following interfaces are therefore considered:

- A1* to D_A for the airborne domain
- D_A to E2 for the ground domain

  Note: interface A1, as illustrated in Figure 14 applies to the source position time of applicability.*

For position accuracy and integrity, previous Table 13 provides the values directly applicable at interface $D_{A.}$. At interface $B1_A$ (HFOM, HPL), the effects of uncompensated latency has been taken into account as addressed in B.4.2.3. of [Ref.1] and is reflected in the values expressed below (covered by the encoding margin of the quality indicators).

Update interval and update probability

Update interval characteristics at interface D_A are not derived from the $E2_A$ characteristics, but rather considering the 1090Mhz message broadcast rate (MOPS). Update probability at interface $E2_A$ includes interference aspects (domain D_A to $E2_A$ is the responsibility of the implementer) and performance of the Receive sub-function is therefore only express at $E2_A$ and not at D_A.

The following table summarises these ADS-B performance at interface D_A:

Transmitting Aircraft Domain ADS-B-RAD Performances		En-route [RAD-2a, RAD-2b]	TMA [RAD-1, RAD-3]	App. [RAD-3]
Horizontal Position Accuracy (D_A)	Horizontal Position Accuracy 95%	308 m or less (NAC_p=7)	171 m or less (NAC_p=8)	171 m or less (NAC_p=8)
Horizontal Position Accuracy ($B1_A$)	Horizontal Position Accuracy 95% Note: these values account for uncompensated latency	0.1 NM or less (NAC_p=7)	0.05 NM or less (NAC_p=8)	0.05 NM or less (NAC_p=8)
Accuracy Vertical Position (D_R, $D_{A,}$)	Altimeter accuracy[41]	38.1m (125ft)[42]	38.1m (125ft)	38.1m (125ft)
(D_R, D_A)	Resolution in Mode C	≤ 100ft[43]	≤ 100ft	≤ 100ft

[41] This is minimum accuracy requirement for altimeter, and is dependent on the type of airspace. Many airspace regions, such as RVSM, will require better altimeter performance than specified here.

[42] As per Mode C provision in ICAO Annex 10

[43] As per Annex 10, Vol. IV (4.3.9.3.1.) it is recommended to use a source providing a resolution less than or equal to 7.62m (25ft)

Transmitting Aircraft Domain ADS-B-RAD Performances		En-route [RAD-2a, RAD-2b]	TMA [RAD-1, RAD-3]	App. [RAD-3]
Horizontal Position Integrity[44] ($B1_A$)	Quality Indicators Position source failure probability Position source alert failure probability Note the correspondence for quality indicator of the two previous parameters translates into SIL=3, 10-7 per fh[40] Time to alert (SPR 14 [Ref.1]) The time between a change in satellite reception status in the GNSS receiver and the delivery of the resulting integrity quality indicator change to $B1_A$ (SPR 13 [Ref.1])	1.0 NM or less (equivalent to NIC_p=5) 10-4/h[45] 10-3 (per position source failure event) 10s <2s	0.6 NM or less (equivalent to NIC_p=6) 10-4/h 10-3 (per position source failure event) 10s <2s	0.2 NM or less (equivalent to NIC_p=7) 10-4/h 10-3 (per position source failure event) 10s <2s
Latency (A1* to D_A)	The ADS-B Transmitting Aircraft Domain shall have a 95% total latency of 1.5s or less for surveillance position, quality indicators, identification and Emergency/SPI data at interface D (SPR 23 [Ref.1])	1.5s	1.5s	1.5s
Latency (A1* to D_A)	The ADS-B Transmitting Aircraft Domain shall have a 95% uncompensated latency of less than 0.6 seconds for horizontal position. (SPR24)	0.6	0.6	0.6
Latency (A1* to D_A)	The ADS-B Transmitting Aircraft Domain shall have a 99.9% maximum uncompensated latency of less than 1 second for horizontal position (SPR 25)	1s	1s	1s

Table 14: ADS-B Performance Parameters at Interface D

[44] "Horizontal Position Integrity" relates to a quality of service providing an indication on when ADS-B-RAD separations can be applied or not, in the nominal case.

[45] For GPS based functions, expressed as an assumption of GPS performance – see A051 in section 10.7.3 (Satellite constellation (GPS) failures)

Horizontal position accuracy and integrity values part of Table 14 above are the minimum values necessary for an aircraft to be eligible for the separation minima considered in this document.

The management of the aircraft ADS-B eligibility is the ground responsibility to decide on which separation minima will be applied based and therefore corresponding eligibility requirements will be allocated to the ground domain in section 7.5.2.3.

A005. It is assumed that horizontal position accuracy and integrity values part of Table 14 above can be nominally achieved by aircraft equipped with suitable certified ADS-B and radar transponder equipment and system.

7.4 DIFFERENCES BETWEEN ADS-B-RAD AND REFERENCE DESIGNS (ARG 2.2.1.2)

Previous section 7.2 identified the strategy for describing the elements of the ADS-B-RAD logical design, in terms of operational surveillance procedures, human tasks, operational and technical surveillance data items, functions and performance characteristics.

Where in general these elements are very similar to the Reference logical design, there are however some differences, which have been identified in previous section 7.3 and which are further discussed in the following sections in order to ensure that their possible impacts have been assessed and reconciled with **ST001**.

7.4.1 Differences on Operational Surveillance Procedures

Operational surveillance procedures have been described in section 7.3.1 and it can be concluded that there is no difference between the ADS-B-RAD and Reference logical designs with respect to ATC and Flight Crew procedures and when considering all relevant scenarios.

Therefore, the ADS-B-RAD logical design is capable of satisfying the Safety Target from section 7.1 regarding the operational surveillance procedures (**ST001:** ADS-B-RAD system shall support ATC service in preventing accident/incidents as safely as the Reference system does).

7.4.2 Differences on Data Items at ATCo and Flight Crew Interfaces Level

Operational Data Items have been described in section 7.3.2 and are identical for both the ADS-B-RAD and the Reference logical designs, and when considering all relevant scenarios for both ATCo and flight crew interfaces. The only difference at interface level relates to the capability of the flight crew to set/check/modify aircraft ID in scenarios RAD-1, RAD-2a and RAD-3. Meanwhile as this PSC assumes that the identification procedure is based on Mode A code for these scenarios, there is no difference with the Reference logical design.

Therefore, the ADS-B-RAD logical design is capable of satisfying the Safety Target from section 7.1 regarding data items at ATCo and flight crew interfaces level (**ST001:** ADS-B-RAD system shall support ATC service in preventing accident/incidents as safely as the Reference system does).

7.4.3 Differences at Technical Data items Level Including Related Performance

The ADS-B-RAD logical model presents new interfaces due to new functions (see next section 7.4.4).

These new interfaces convey the same data items as in the Reference logical model, except for:

- Aircraft identity
- Horizontal Position and corresponding Quality Indicators

Aircraft Identity: The Aircraft identification (already discussed in previous section 7.4.2) and the 24 bit ICAO address are new data items in RAD-1, RAD-2a and RAD-3 scenarios compared to the related Reference scenarios.

The 24 bits ICAO address is required to be broadcast, as Mode S does in scenario RS-2b, to permit the association of information contained in all the ADS-B Message types with the transmitting aircraft. It is a means of associating messaqes comparable to the role of Mode A code in the Reference logical model.

The technical data items have been described in section 7.3.3 for both the ADS-B-RAD and the Reference logical designs. The differences in terms of technical data items are identified below, together with an assessment of the corresponding impact at various levels (operational, functional, data items). Reference to the corresponding evidence is provided.

The differences relate to the horizontal position and the corresponding Quality Indicators data items:

Horizontal Position: is provided for ADS-B-RAD logical design by the Transmitting Aircraft Domain (derived from GNSS in the WGS 84 referential system), whereas for the Reference logical design, it is derived from the radar range and azimuth. Both ADS-B and Radar horizontal positions are then converted by the “ground ADS-B Surveillance Processing” function into a common WGS 84 coordinate system and at that level there is no difference in terms of position information in the subsequent processing.

Therefore, the difference between the ADS-B-RAD and the Reference logical designs regarding the horizontal position information is limited to the source of information, which is common to both navigation and surveillance elements of the system (see section 9.4.3 for the external positioning source and section 10.4.1.2 for the common mode of failure).

Horizontal Position Quality Indicator: In ADS-B-RAD logical design the horizontal position is provided by the Transmitting Aircraft Domain together with a Position Quality Indicator (QI) characterising its accuracy and integrity. In the Reference logical design, this data is not provided as the position is calculated by the radar sub-system and is provided to the ADS-B-RAD ATC Processing and Display function. Accuracy and integrity can be determined by this function but the principle is different. For radar, data integrity is not quantified in this way. It is assumed that the combinations of various internal self-test and external monitoring methods ensure that the radar equipment is working properly (or otherwise a fault is detected quickly). [Ref.1] specifically identifies the necessary requirements regarding Position Quality Indicator in order to support safe ATC service (separation task).

The comparison of the performance aspects of the Quality indicator is performed for the NAC in section 7.3.5 (see Table 13), and for the NIC/SIL through an assessment of which quality indicator minimum level would provide less or equal surveillance separation error for the ADS-B-RAD logical design compared to the Reference logical design through the "Surveillance Separation Error" (SSE) analysis as described in § Annex D in [Ref.1] and for which a summary of the assessment and findings can be found in Annex F of this PSC.

The required minimum values for these two quality indicators satisfying the Safety Target **ST001** can be found in section Table 13.

The impact for this data item at ATCo interface is identical to the Reference logical design: Controllers will have to be provided with an indication on the eligibility of the aircraft to receive ATC service as developed in Operational Requirement OR-4 in [Ref.1].

In conclusion, the only difference between the ADS-B-RAD and the Reference logical design regarding the technical data items relates to the horizontal position and the corresponding quality indicators. This section has demonstrated that the position information is equivalent in both logical designs and that the quality indicators for ADS-B-RAD logical design have been derived consistently by comparison with the Reference logical design.

This section has therefore demonstrated that by comparison with the Reference logical design, the ADS-B-RAD logical design is capable of satisfying the Safety Target from section 7.1 regarding the technical data items (**ST001:** ADS-B-RAD system shall support ATC service in preventing accident/incidents as safely as the Reference system does).

7.4.4 Differences at Surveillance Functions level

7.4.4.1 Differences at Transmitting Aircraft Domain Level

The new elements identified in ADS-B-RAD LM are:

- The "GNSS on-board Receive function with Horizontal position integrity monitoring", which relates to the provision of the aircraft horizontal position performed at the aircraft level for the ADS-B-RAD LM, whereas it is provided by the SSR or Mode S radar for the Reference LM.

- The "Aircraft ADS-B function", which can be compared to the SSR or Mode S transponder function due to their equivalent functionalities.

The modified elements identified in ADS-B-RAD LM are:

- "The flight crew interface", see section 7.4.2.

7.4.4.2 Differences at Ground Domain Level

The new elements identified in ADS-B-RAD LM are:

- The “Ground ADS-B Receive” function, which can be compared to the SSR radar function, due to their equivalent functionalities.

- The “Ground ADS-B Surveillance Processing” function (verifies horizontal position quality indicator in order to determine the ADS-B aircraft eligibility to support the ATC service), which has similar functionalities with the ATC Processing and Display function of the Reference LM that determines the radar plots suitability for display to ATCo.

- The “ADS-B-to-Radar Association” function, which has been defined in the ADS-B-RAD logical design to assess whether ADS-B reports and radar data sufficiently match to support display of a single ADS-B target given multiple surveillance sources. Depending on the Reference radar processing system, an equivalent of the “ADS-B-to-radar association function” may exist for radar-to-radar association.

The modified elements identified in ADS-B-RAD LM are:

- The Existing ATC Processing and Display function, which is slightly modified to include the processing of ADS-B tracks in addition to radar tracks.

- The “ATCo Interface”, which is slightly modified to include the display of ADS-B tracks.

This section has therefore demonstrated that the same <u>type of functions</u> exists between both designs (and therefore that the ADS-B-RAD logical design is complete with respect to the functions). The only difference is explained by the type of data processed by these functions which are different between both designs and which difference is assessed in previous section.

In conclusion, the ADS-B-RAD logical design is capable of satisfying the Safety Target from section 7.1 regarding its functions (**ST001:** ADS-B-RAD system shall support ATC service in preventing accident/incidents as safely as the Reference system does).

7.5 ADS-B-RAD SAFETY REQUIREMENTS (ARG 2.2.1.3)

The Requirements and Assumptions to support the above logical ADS-B-RAD design are the key elements provided by [Ref.1]. They address all elements of the system described above and are necessary to ensure the intrinsic safety of the ADS-B-RAD logical design.

This section provides the safety requirements concerning the ADS-B-RAD logical design covering all the Transmitting Aircraft Domain elements in sub-section 7.5.1 and all the Ground Domain elements in sub-section 7.5.2. These elements are identified in the logical diagram of Figure 14.

These requirements result from the description of each element that has been performed in previous section 7.3.

Additional requirements are provided in sections 8 to 10 to cover the complementary aspects related to design correctness, design robustness and the mitigation of internal failure (covered under Arg 2.2.2, Arg 2.2.3 and Arg 2.2.4 respectively).

7.5.1 Safety Requirements on Transmitting Aircraft Domain Elements

7.5.1.1 Flight Crew related Safety Requirements

Addressing	Safety Requirements on Flight Crew	RAD-x scenario
Operational Surveillance Procedures	**SAF001.** Flight crew shall apply PANS-OPS Doc 8168 [Ref.9] procedures. *Note: This includes the selection of appropriate emergency indication when necessary. It also includes the setting of SPI when instructed by ATC.*	All
	SAF002. Flight Crew shall set, check and modify the Mode A code and Aircraft Identification throughout all phases of flight as instructed by ATC or as appropriate (SPR5 [Ref.1]).	All

Table 15: Safety Requirements on Flight Crew

7.5.1.2 Flight Crew Interface related Safety Requirements

Addressing	Safety Requirements on Flight Crew interface (C1)	RAD-x scenario
Features	**SAF003.** Flight Crew interface shall enable the Flight Crew to set, check and modify Mode A code and Aircraft Identification throughout all phases of flight (SPR5 [Ref.1]).	All
	SAF004. Flight Crew interface shall enable the Flight Crew to select the appropriate Emergency/SPI indication.	All

Table 16: Safety Requirements on Flight Crew Interface

7.5.1.3 GNSS On–Board Receive Function related Safety Requirements

The following requirements are derived from Table 14, for data items expressed at interface $B1_A$.

Note: that the quality indicators values required for aircraft eligibility to support the ATC service are provided as part of the Ground Domain responsibility in Table 29.

Addressing	Safety Requirements on GNSS on-board Receive Function (between A1 and $B1_A$)	RAD-x scenario
Functions, data items	**SAF005.** The on-board horizontal position data shall be derived from GNSS (see ASSUMP 18 in section 3 of [Ref.1]).	All
	SAF006. The "GNSS onboard receive function" shall provide a horizontal position integrity monitoring capability and shall provide horizontal position integrity (HPL) and accuracy (HFOM) quality indicators (i.e., the integrity containment region and the 95% horizontal accuracy bound) (SPR 3 [Ref.1]).	All
Performance	**SAF007.** The time between a change in satellite reception status in the "GNSS onboard receive function" and the delivery of the resulting integrity quality indicator change to $B1_A$ shall be no more than 2 seconds (see SPR 13/PR19 of [Ref.1]).	All
Performance	**SAF008.** The probability (per position source failure event) that a horizontal position error exceeds the integrity containment bound for more than 10 seconds without reflecting the fault at $B1_A$ shall be no greater than 0.001 (see SPR 14 of [Ref.1]).	All

Table 17: Safety Requirements on GNSS On-Board Receive Function

7.5.1.4 Pressure Altitude Source related Safety Requirements

Addressing	Safety Requirements on Pressure Altitude Source (at $B1_A$ and $B1_R$)	RAD-x scenario
Data item	**SAF009.** The aircraft installation shall use the same source for transmission of pressure altitude from both the SSR/ Mode S transponder and "ADS-B Aircraft" function (see ENV-ASSUMP.15 of [Ref.1]).	All except RAD-1

Table 18: Safety Requirements on Pressure Altitude Source

7.5.1.5 Identity, Emergency and SPI Data Source related Safety Requirements

Addressing	Safety Requirements Emergency and SPI data Source (at $B1_A$ and $B1_R$)	RAD-x
Data item	**SAF010.** The aircraft installation shall use the same sources for transmission of aircraft identity, emergency codes and special position identification (SPI), from both the SSR/Mode S transponder and "ADS-B Aircraft" function (see ENV-ASSUMP.16 of [Ref.1]).	All

Table 19: Safety Requirements on Emergency and SPI Data Source

7.5.1.6 Aircraft ADS-B Function related Safety Requirements

Addressing	Safety Requirements on Aircraft ADS-B function (between $B1_A$ and D_A)	RAD-x scenario
Function	**SAF011.** The "Aircraft ADS-B" function shall process horizontal position and related quality indicators, pressure altitude, aircraft identity, emergency and SPI information and outputs these in ADS-B messages in accordance with the appropriate data link specifications.	All
Data Items	**SAF012.** The Transmitting Aircraft domain shall transmit a minimum data set that includes the data items listed below (SPR 1, IR 1, IR 3, IR 4, IR 6, IR 7, IR 9, IR 16 in [Ref.1]): • Aircraft identification • Mode A code (see note below). • ICAO 24 bit aircraft address • Horizontal Position information (Longitude, Latitude) • Horizontal Position Quality Indicators (see note below) • Pressure-Altitude derived level information • Special Position Indication (SPI) report • Emergency Indication	All
Function	**SAF013.** The position and related position integrity quality indicator (NIC) shall always be broadcast in the same ADS-B message (SPR 2 [Ref.1]).	All

Table 20: Safety Requirements on Aircraft ADS-B Function

Note on Mode A: it has been foreseen the possibility to inhibit Mode A code transmission by ADS-B (see SPR 4 [Ref.1]). However this is out of the scope of the PSC (see also GM018).

Note on 24 bit address: ICAO Doc 4444 – PANS-ATM [Ref.3] (Chapter 1, Definitions) defines the aircraft address as "a unique combination of 24-bits available for assignment to an aircraft for the purpose of air-ground communications, navigation and surveillance." The unique ICAO 24-bit aircraft address is not accessible or modifiable by the flight crew.

Note on Quality Indicators: The required Horizontal Position Quality Indicators to be transmitted by the aircraft in order to be considered as eligible for ADS-B-RAD are detailed in section 7.5.2.3.

Consistent definition of data required on airborne and ground domain is ensured by interoperability requirements as presented in correctness argument Arg 2.2.2 in section 8.

7.5.1.7 ADS-B Transmitting Aircraft Domain related Safety Requirements

"ADS-B Transmitting Aircraft Domain" is defined in section 7.3:

Addressing	Safety Requirements on ADS-B Transmitting Aircraft Domain (at D_A)	RAD-x scenario
Performance	**SAF014.** The ADS-B Transmitting Aircraft Domain shall have a 95% total latency of 1.5s or less for horizontal position and quality indicators (SPR 23 [Ref.1]) (between A1* and D_A).	All
	SAF015. The ADS-B Transmitting Aircraft Domain shall have a 95% uncompensated latency of less than 0.6 seconds for horizontal position (SPR 24 [Ref.1]). (between A1* and D_A).	All
	SAF016. The ADS-B Transmitting Aircraft Domain shall have a 99.9% maximum uncompensated latency of less than 1 second for horizontal position (SPR 25 [Ref.1]) (between A1* and D_A).	All
	SAF017. Altimeter accuracy - including accuracy of measurement and accuracy of reported value through use of encoding - shall be at least as good as Mode C provisions in ICAO Annex 10 [Ref.10] which specifies 38.1m (125ft)[46] [47](see PR 16 in Annex B of [Ref.1]) (at D_A).	All

Table 21: Safety Requirements on ADS-B Transmitting Aircraft Domain

[46] This is minimum accuracy requirement for altimeter, and is dependent on the type of airspace. Many airspace regions, such as RVSM, will require better altimeter performance than specified here. In addition, as per Annex 10, Vol. IV (4.3.9.3.1.) it is recommended to use a source providing a resolution less than or equal to 7.62m (25ft).

[47] See also paragraph 8.5 of [Ref.14]

Note: the transmission of the ADS-B messages is as per of the ADS-B link.

7.5.1.8 SSR Transponder Function related Safety Requirements

Addressing	**Safety Requirements on SSR/Mode S Transponder function (at D_R)**	**RAD-x scenario**
Performance	**SAF018.** Altimeter accuracy (Mode C) - including accuracy of measurement and accuracy of reported value through use of encoding - shall meet ICAO Annex 10 [Ref.10], which specifies 38.1m (125ft)[48]	All except RAD-1

Table 22: Safety Requirements on SSR Transponder Function (at D_R)

7.5.1.9 Altimeter Source and ADS-B Function related Safety Requirements

Addressing	**Safety Requirements on SSR/Mode S Transponder function (at D_R)**	**RAD-x scenario**
Performance	**SAF019.** The resolution of the Pressure altitude shall be ≤100 feet (PR 18 [Ref.1]).	All except RAD-1

Table 23: Safety Requirements on Altimeter Source and ADS-B Function

[48] This is minimum accuracy requirement for altimeter, and is dependent on the type of airspace. Many airspace regions, such as RVSM, will require better altimeter performance than specified here. In addition, as per Annex 10, Vol. IV (4.3.9.3.1.) it is recommended to use a source providing a resolution less than or equal to 7.62m (25ft).

7.5.2 Safety Requirements on Ground Domain Elements

7.5.2.1 General Ground Requirements

As explained in section 4.2, four ADS-B-RAD scenarios are considered covering the three different radar technologies with which ADS-B is combined: PSR, SSR and Mode S (**Cn002)**. The following minimum safety requirement has been defined for all scenarios:

Addressing	General Ground Safety Requirements	RAD-x scenario
General	**SAF020.** The ADS-B-RAD sector shall have sufficient ADS-B and radar coverage so that each aircraft is seen by all surveillance sources.	All

Table 24 : General Ground Safety Requirements

7.5.2.2 Air Traffic Controller related Safety Requirements

Addressing	Safety Requirements on Air Traffic Controller	RAD-x scenario
Operational Surveillance Procedures	**SAF021.** For providing ATC services, controllers shall apply the same procedures as in the Reference system and these procedures are consistent with PANS ATM Doc4444 [Ref.3] procedures. *Note: This includes the procedures related to the aircraft identification.*	All
	SAF022. Separation minima of 5NM shall only be applied by ATCo to ADS-B eligible aircraft in en-route, with SSR radar available as back-up (See SPR 6 in [Ref.1]). *Note: see aircraft ADS-B eligibility conditions in section 7.5.2.3 in Table* 27. *Note: the case of non eligible ADS-B aircraft is dealt with in section* 10 (failure approach)	RAD-2
	SAF023. Separation minima of 3NM shall only be applied by ATCo to ADS-B eligible aircraft in TMA, with PSR radar available (See SPR 7 in [Ref.1]).. *Note: see aircraft ADS-B eligibility conditions in section 7.5.2.3 in Table* 27. *Note: the case of non eligible ADS-B aircraft is dealt with in section 10 (failure approach)*	RAD-1

Addressing	Safety Requirements on Air Traffic Controller	RAD-x scenario
	SAF024. Separation minima of 2.5NM and 2NM shall only be applied by ATCo to ADS-B eligible aircraft respectively for succeeding aircraft on same final and for succeeding aircraft on adjacent ILS/MLS, with SSR radar available as back-up and PSR radar available (See SPR 7 in [Ref.1]). *Note: see aircraft ADS-B eligibility conditions in section 7.5.2.3 in Table* 27. *Note: the case of non eligible ADS-B aircraft is dealt with in section 10 (failure approach).*	RAD-3

Table 25: Safety Requirements on Air Traffic Controller

7.5.2.3 ADS-B-RAD ATC Processing and Display Function related Safety Requirements

As shown in the Logical Model and as described in section 7.3.4.2, the ADS-B-RAD ATC Processing and Display function encompasses the following new functions:

- Ground ADS-B Surveillance processing function
- ADS-B to Radar Association function

In addition, the existing ATC Processing and Display function provides the same function as for the Reference system (with slight changes compared to the Reference system).

Addressing	Safety Requirements on ADS-B-RAD ATC Processing and Display function (at G2)	RAD-x scenario
	SAF025. ADS-B-derived data items shall be the principal information presented to the controller. *Note: for RAD-2 and RAD-3, SSR radar is available as back-up.* *Note: in RAD-1 and RAD-3, horizontal position information from PSR can also be provided to the controller in addition to ADS-B depending on the selected display techniques - see Annex G for further detail.* *Note: this requirement is applicable in the success approach. The failure approach is addressed in section 10.*	All

Addressing	Safety Requirements on ADS-B-RAD ATC Processing and Display function (at G2)	RAD-x scenario
Data items	**SAF026.** The ADS-B-RAD ATC Processing and Display function shall provide the following list of ADS-B-derived surveillance data items to the controller (OR 1 [Ref.1]): • Aircraft identification • Mode A Code[49] • Horizontal Position • Vertical Position (Pressure-Altitude) • Ground Speed • Emergency indication • Special Position Identification (SPI)	All
Features	**SAF027.** The ADS-B-RAD ATC Processing and Display function shall present clear information so that the ATCo is able to determine which ‘part’ of the horizontal position symbol is to be used for applying separation standards (i.e. centre or the edges)(ENVT-ASSUMP.29-2 [Ref.1])	All
	SAF028. The ADS-B-RAD ATC Processing and Display function shall display the horizontal position information with a constant refresh cycle (same as in the Reference radar-based system) and time synchronized (ENV-ASSUMP-18 [Ref.1]). *Note: [Ref.18] indicates that “surveillance information updates shall enable the display updates to be no more than 5 seconds (s) for major terminal areas, and no more than 8 seconds (s) in en-route airspace.”* *Note: time synchronized means that ADS-B horizontal positions are extrapolated to a common display time.*	All
	SAF029. The ADS-B-RAD ATC Processing and Display function shall provide an indication that an aircraft is transmitting an emergency code in a clear and expeditious manner (OR 14 in [Ref.1]).	All
	SAF030. The ADS-B-RAD ATC Processing and Display function shall extrapolate the ADS-B position data, based on time-registering the asynchronously received updates, to a common display time.	All

Table 26: Safety Requirements on ADS-B-RAD ATC Processing and Display Function

[49] It is planned that the ICAO DOC PANS ATM and Doc 9871 will be modified accordingly (i.e. to suppress the geographic Mode A Code filtering).

GM031. Implementers should ensure the surveillance data items are presented in a manner similar (symbology, colours, etc.) to the Reference System, otherwise an impact assessment should be performed.

Addressing	Safety Requirements on Ground ADS-B Surveillance processing function	RAD-x scenario
	SAF031. The "Ground ADS-B Surveillance Processing" function shall receive ADS-B reports from the Ground ADS-B receive function	All
	SAF032. The "Ground ADS-B Surveillance Processing" function shall check the ADS-B position quality indicators and determines the aircraft eligibility. *Note: see ADS-B eligibility criteria below.*	All
	SAF033. The "Ground ADS-B Surveillance Processing" function shall transform the ADS-B data into a common reference system (e.g. coordinate system) with radar (e.g. time synchronisation with radar, co-ordinate conversion) (see Environ.Assump-17, [Ref.1]).	All
	SAF034. In En-route, an aircraft is eligible for receiving 5Nm separation minima when its horizontal position quality indicators are NACp=7 or more and NICp=5 or more and with a minimum SIL of 3 (per flight hour) (SPR 8, SPR 15 in [Ref.1]). *Note: : NACp = 7 means a 95% accuracy of horizontal position less than 308 meters and NICp=5 means a maximum 1.0 NM integrity containment radius)*	RAD-2
	SAF035. In TMA, an aircraft is eligible for receiving 3Nm separation minima when its horizontal position quality indicators are NACp=8 or more and NICp=6 or more and with a minimum SIL of 3 (per flight hour) (SPR 9, SPR 16 [Ref.1]). *Note: NACp = 8 means a 95% accuracy of horizontal position less than 171 meters and NICp=6 means a maximum 0.6 NM integrity containment radius).*	RAD-1 some parts of RAD-3

Addressing	Safety Requirements on Ground ADS-B Surveillance processing function	RAD-x scenario
Horizontal Position Accuracy and integrity	**SAF036.** An aircraft is eligible for receiving 2.5Nm separation minima in-trail on final approach, when its horizontal position quality indicators are NACp=8 or more and NICp=7 or more and with a minimum SIL of 3 (per flight hour) (SPR 10, SPR 17 [Ref.1]). *Note: NACp = 8 means a 95% accuracy of horizontal position less than 171 meters and NICp=7 means a maximum 0.2 NM integrity containment radius).*	RAD-3
	SAF037. An aircraft is eligible for receiving 2Nm separation minima on final approach for dependent parallel runways operations[50], when its horizontal position quality indicators are NACp=8 or more and NICp=7 or more and with a minimum SIL of 3 (per flight hour) (SPR 11, SPR 18 [Ref.1]). *Note: NACp = 8 means a 95% accuracy of horizontal position less than 171 meters and NICp=7 means a maximum 0.2 NM integrity containment radius)*	RAD-3
	SAF038. An aircraft is eligible for independent parallel approach operation[51], when its horizontal position quality indicators are NACp=8 or more and NICp=7 or more and with a minimum SIL of 3 (per flight hour) (SPR 12, SPR 19 [Ref.1]). *Note: NACp = 8 means a 95% accuracy of horizontal position less than 121 meters and NICp=7 means a maximum 0.2 NM integrity containment radius)* *Note: see more explanation on the process used in annex B - PR14 of [Ref.1])*	RAD-3

Table 27: Safety Requirements on Ground ADS-B Surveillance Processing Function

[50] - 2 NM separation minima between successive aircraft on adjacent ILS localizer courses or MLS final approach tracks, in the case of dependent parallel runways – see section 2.2.2

[51] where radar separation minima between aircraft on adjacent extended runway centre lines are not prescribed – see section 2.2.2.

Addressing	Safety Requirements on ADS-B-to-Radar Association function	RAD-x scenario
Function	**SAF039.** The ADS-B to Radar Association function shall compare ADS-B and radar common data items, such as horizontal position, Aircraft Identity, Pressure Altitude, Emergency codes and SPI to determine if they sufficiently match to support display of a single ADS-B information given multiple surveillance sources (see Environ. Assump-20, [Ref.1]) *Note: the case of data not sufficiently matching (horizontal position, altitude, aircraft identity) will derive requirements through the failure case that are defined in section 10.*	All (for RAD-1 only horizontal position applies)

Table 28: Safety Requirements on ADS-B to Radar Association Function

Addressing	Safety Requirements on the Existing ATC Processing and Display function	RAD-x scenario
Function	**SAF040.** The Existing ATC Processing and Display function shall provide typical radar data processing functions as performed by the Reference system: • receive radar reports • receive ADS-B track data • maintain track data including correlation with flight plan information, • reconstruct ground velocity from position information received from surveillance sources, etc.) • support procedures that enable the use of automated transfer of identification between ATS units (ENV-ASSUMP-21 [Ref.1]) • display ADS-B track data on the ATCo interface	All

Table 29: Safety Requirements on the "Existing ATC Processing and Display" Function

7.5.2.4 Radar Surveillance related Safety Requirements

Requirements presented in this section are related to radar functions as required by each of the RAD scenarios in Table 3.

Addressing	Safety Requirements on Radar Surveillance	RAD-x scenario
Function	**SAF041.** Primary Surveillance Radar function shall provide Radar Reports to the ADS-B-RAD ATC processing and Display function. *Note : identical to the Reference system performance and functions*	RAD-1, RAD-3
	SAF042. Secondary Surveillance Radar function shall provide radar reports to the ADS-B-RAD ATC processing and Display function. *Note : identical to the Reference system performance and functions*	RAD-2, RAD-3

Table 30: Safety Requirements on Radar Surveillance

7.5.2.5 Ground ADS-B Receive Function related Safety Requirements

Addressing	Safety Requirements on ADS-B Receive function (between D_A and $E2_A$)	RAD-x scenario
Function	**SAF043.** The “Ground ADS-B Receive” function shall receive ADS-B messages, decode, package and time-stamp the data, and send ADS-B reports to the “Ground ADS-B surveillance Processing” function (SPR 26 [Ref.1]).	All
Function	**SAF044.** The “Ground ADS-B Receive” function shall provide the following ADS-B data items in the ADS-B Reports ([Ref.1] §3.4.1 SPR-27): • Aircraft Identification • Mode A code • Aircraft Horizontal Position information (Longitude, Latitude) • Pressure-Altitude derived level information • Quality Indication of the Aircraft Horizontal Position • ICAO 24 bit aircraft address • Emergency indicators • Special Position Information (SPI) • Time of applicability	All

Addressing	Safety Requirements on ADS-B Receive function (between D_A and $E2_A$)	RAD-x scenario
	SAF045. Each type of ADS-B Surveillance data (i.e. position, identity and/or Emergency/SPI data) provided in ADS-B report(s) shall have a time of applicability (SPR 29 [Ref.1]).	All
Time of Applicability	**SAF046.** The time of applicability conveyed in the ADS-B Report shall have an absolute accuracy relative to UTC of +/- 0.1 seconds or less (SPR 36 [Ref.1]).	All
Surveillance Report Latency	**SAF047.** The 95% latency for ADS-B Reports shall be no greater than 0.5s, excluding communication latency to the ATC processing system (SPR 35 [Ref.1]) **A006.** It is assumed that all known latencies on the “Ground ADS-B Receiver” function are compensated for. (note below PR 30 in [Ref.1])	All

Table 31: Safety Requirements on Ground ADS-B Receive Function - General

Addressing	Safety Requirements on ADS-B Receive function (between DA and E2A)	RAD-x scenario
Update Interval and Time Requirements **in En-Route**	**SAF048.** For supporting 5NM separation minima in En-Route: The time interval for Reports containing newly received ADS-B Position data of sufficient quality associated with any single aircraft shall be no longer than 8s with a probability of 97% (SPR 49 [Ref.1]).	RAD-2
	SAF049. For supporting 5NM separation minima in En-Route: The time interval between a change of identity (aircraft identification or Mode A code) at ADS-B aircraft domain level and the reception of an ADS-B report containing the new Mode A code at interface E2 shall be no longer than 8s with a probability of 95% (SPR 50 [Ref.1]).	RAD-2
	SAF050. For supporting 5NM separation minima in En-Route: The time interval between a change of Emergency / SPI information at ADS-B aircraft domain level and the reception of an ADS-B surveillance report containing the new emergency and SPI information at interface E2 shall be no longer than 8s with a probability of 95% (SPR 51[Ref.1]).	RAD-2

	SAF051. For supporting 5NM separation minima in En-Route, if the position accuracy quality indicator (NACp) is not received within 24 seconds of a position message, then the ADS-B Ground Domain shall determine the position accuracy requirement has been met using a NIC encoding that corresponds to 926 meters (or less) as a substitute for the NACp requirement (SPR 52 [Ref.1]). *See A007 below*	RAD-2

Table 32: Safety Requirements on Ground ADS-B Receive Function - Update Interval and Time Requirements in En-Route

Addressing	Safety Requirements on ADS-B Receive function (between DA and E2A)	RAD-x scenario
Update Interval and Time Requirements **in TMA**	**SAF052.** For supporting 3, 2.5, 2NM separation minima in TMA, the time interval for Reports containing any newly received ADS-B Position data of sufficient quality associated with any single aircraft shall be less than 5s with a probability of 97% (SPR 53 [Ref.1]).	RAD-1, RAD-3
	SAF053. For supporting 3, 2.5, 2NM separation minima in TMA, the time interval between a change of identity (aircraft identification or Mode A code) at ADS-B aircraft domain level and the reception of an ADS-B report containing the new Mode A code at interface E2 shall be no longer than 5s with a probability of 95% (SPR 54 [Ref.1]).	RAD-1, RAD-3
	SAF054. For supporting 3, 2.5, 2NM separation minima in TMA: the time interval between a change of Emergency / SPI information at ADS-B aircraft domain level and the reception of an ADS-B report containing the new emergency and SPI information at interface E2 shall be no longer than 5s for TMA with a probability of 95% (SPR 55 [Ref.1]).	RAD-1, RAD-3
	SAF055. For supporting 3, 2.5, 2NM separation minima in TMA, if the position accuracy quality indicator (NACp) is not received within 15 seconds of a position message, then the ADS-B Ground Domain shall determine the position accuracy requirement has been met using a NIC encoding that corresponds to 513 meters (or less) as a substitute for the NACp requirement. (SPR 56 [Ref.1]). *See A007 below*	RAD-1, RAD-3

Table 33: Safety Requirements on Ground ADS-B Receive Function - Update Interval and Time Requirements in TMA

Assumption related to SAF051 and SAF055:

A007. GNSS avionic systems reporting position integrity can be assumed to have a corresponding 95% position accuracy measure no greater than 33% of the reported position integrity.

The reported integrity may be used to meet position accuracy requirements normally satisfied through NACP when this quality measure is not reported. For TMA, a reported integrity less than or equal to 513 meters assures the 171 meter accuracy requirement is met. For En Route, a reported integrity less than or equal to 926 meters assures the 308 meter accuracy requirement is met.

GM032. SAF049 and SAF053 should be considered by implementers when deciding on the extend of their coverage for initial acquisition and identification procedures.

GM033. The above requirements have been allocated according to an ADS-B-RAD logical design. Implementers should explicit the mapping of their physical architecture to this logical design and in particular the functional architecture model in order to propagate these requirements to their physical (local) elements.

GM034. It is recommended to use/apply EUROCAE ED-129 Technical Specification for 1090MHz Extended Squitter Ground Station.[52]

[52] Under developpement at the time of edition of this document

7.5.2.6 ADS-B Ground Domain related Safety Requirements

Addressing	Safety Requirements on the ADS-B Ground Domain (between D_A and G2)
Performance	**SAF056.** The ADS-B Ground Domain shall not introduce any additional horizontal position error greater than that which might otherwise be introduced by a linear extrapolation using the instantaneous velocity (SPR 37 [Ref.1]). (see note below)
	SAF057. The ADS-B Ground Domain shall not degrade altitude resolution to worse than 100 ft (SPR 38 [Ref.1]).
	SAF058. The ADS-B Ground Domain shall have capacity to handle the reports from the maximum load of all aircraft in the environment as described in section 2.2 without degradation (SPR 39 [Ref.1]).

Table 34: Safety Requirements on ADS-B Ground Domain

Note: The purpose of this requirement is for the ADS-B Ground Domain to preserve the accuracy of the position information provided by the aircraft, introducing only an error associated with the extrapolation of the position information, as time-registration of the position information has been assumed.

7.6 EXTERNAL ELEMENTS (ARG 2.2.1.4)

Main (relevant) elements have been identified as external elements to the ADS-B-RAD logical design supporting the ATC service, as described in Figure 14 (ADS-B-RAD Logical Model):

- The air-ground communication systems.
- The other airborne systems (navigation systems, safety nets).
- The GNSS signal in space (external positioning source).
- Other Ground Systems (safety net, FPL management).
- Other ATS units.

GM035. Due to the difficulties associated with describing highly detailed environmental characteristics (including specific operations and external systems) that would cover all local environments, the list presented here includes only relevant generic external elements. It is unavoidable that gaps will exist between this list and the list of local external elements and therefore implementers should expand this generic list with those specific external elements related to local characteristics and address the corresponding impact in order to ensure that the local ADS-B RAD system or the local external elements are not adversely affected.

These elements are external to the ADS-B-RAD system but support the ATC service. Due to their “external” nature, requirements have been assigned to them only when possible. When not possible, several assumptions have then been stated for each of these elements, in order to establish a baseline for the assessment performed in this document. This baseline relates to their behaviour and to the information and services they can provide.

Abnormal modes or failure of the external elements are described in the section 9.

*Note: all aircraft are assumed to be equipped and certified (**I006**). The case of transmitting aircraft failure is described in section 10.*

GM036. Implementesr for which the assumption of 100% equipped and certified aircraft is not valid will need to describe this case as part of these external elements.

7.6.1 Air-Ground Communication Systems

The ADS-B-RAD and the Reference systems require the same communication systems.

For air-ground communication aspects, the following Safety Requirements have been defined:

SAF059. Direct Controller Pilot Communication (VHF) shall be available, as it would be for the Reference system ([Ref.1], ENV-ASSUMP.12).

SAF060. Direct Controller Pilot Communication (VHF) shall be independent of ADS-B surveillance [Ref.1], ENV-ASSUMP.12).

7.6.2 Other Airborne Systems (Navigation Systems, Airborne Safety Nets)

Navigation Systems:

The ADS-B-RAD and the Reference systems require the same navigation systems:

For navigation capability, capabilities that would exist for the Reference system would also exist for the ADS-B-RAD one, i.e. that the track-keeping (navigation) performance of aircraft is as per the Reference system environments (i.e. no change) ([Ref.1], ENV-ASSUMP.13).

SAF061. The track-keeping (navigation) performance of aircraft shall be the same as for the Reference system environments ([Ref.1], ENV-ASSUMP.13).

Moreover:

A008. Non-GNSS-based navigation landing systems (i.e., Instrument Landing Systems (ILS)) are assumed to be used by aircraft to support final approaches description in §B.2.2.2 and ASSUMP 9 in §3.2.1.1 of [Ref.1].

GM037. In case GNSS-based approaches are implemented in airspace where it is intended to implement ADS-B-RAD, a local safety analysis should be performed in order to investigate the impact of GNSS failures in that environment.

Airborne Safety Nets:

A009. It is assumed that Airborne Safety Nets exist as part of external systems of ADS-B-RAD and Reference systems.

> *Note: Although A009, no credit for Airborne Safety Nets has been made in the hazard effect assessment (see A016).*

7.6.3 GNSS Signal-in-Space (External Positioning Source)

For external positioning service aspects, the following assumption has been stated regarding the availability of GPS for the provision of eligible position information:

A010. It is assumed that the GPS constellation is sufficient to assure the continuity of service to support ATC, i.e. providing eligible surveillance position data.

7.6.4 Other Ground Systems (Ground Safety Nets, FPL Correlation)

Ground Safety Nets:

The ADS-B-RAD and the Reference systems do not require or assume Ground Safety Nets availability and as such no credit for Ground Safety Nets has been made in the hazard effect assessment (see A017).

> *Note: ICAO does not establish the minimum requirements for safety nets to support ATC Surveillance Services. As such the ADS-B-RAD design does not include Safety Nets, which will be dealt with from an ADS-B surveillance perspective when considering the ADS-B-ADD application[53] (Aircraft Derived Data).*

GM038. Implementers for whom the ATS system includes Ground Safety Nets should determine whether additional or modified requirements have to be identified for the (local) ADS-B-RAD system.

Flight Plan Management:

The ADS-B-RAD and the Reference systems assume Flight Plan system availability for the correlation of the flight plan aircraft identification to the surveillance tracks for scenarios RAD1, RAD2a and RAD3[20].

> *Note: RAD2b involves the direct display of the aircraft identification as broadcast by the aircraft and therefore correlation is not required for the aircraft identification data item (but may exist in principle for other non surveillance items such as destination airports, etc.).*

A011. It is assumed the presence of a Flight Plan system.

7.6.5 Other ATS Units

This section focuses on the transfer of aircraft between ATS units.

As further developed in Annex J , the procedures for both the transfer of aircraft identification and separation minima to be applied by pilots and controllers are the same as in the Reference system and are addressed in section 7.3.1.1 (ICAO procedures).

GM039. Implementers should comply with local agreements established between ATC units regarding separation standards to be established prior to entry into a bordering ATC unit.

[53] ADS-B-ADD application covers Aircraft Derived Data for ATC tools

GM040. Implementers should consider the ramifications of the change of airspace status upon ATCO licensing, rating/sector qualifications, training and familiarisation and competence assessment processes in addition to operational surveillance procedure development.

As for the Reference system, the following requirements are made to support the application of appropriate separation minima for aircraft entering the airspace:

SAF062. All aircraft shall be acquired by ATC processing prior to entering the ADS-B-RAD airspace (ASSUMP 16 of [Ref.1]).

GM041. Implementers should ensure that the requirement above is satisfied, e.g. by extending both the radar and ADS-B surveillance coverage sufficiently beyond the ATC sector to enable timely acquisition.

7.7 CONCLUSIONS ON ARG 2.2.1 – LOGICAL DESIGN DERIVATION

In this section, the ADS-B-RAD logical design has been described and compared to the Reference logical design, in terms of operational surveillance procedure, human tasks, operational and technical surveillance data items, functions and related performances, when considering the ADS-B-RAD and the Reference scenarios. Differences between the ADS-B-RAD and Reference Logical Designs have been described and their impact reconciled with the safety target **ST001**.

It has been shown that:

- The operational surveillance procedures (as per PANS ATM Doc.4444 [Ref.3] for those relevant to ATC procedures) are identical for both designs. Any specific local operational surveillance procedures are to be addressed by each implementer.

- The operational surveillance data items required from ATCo and Flight Crew interfaces have been described and compared with Reference Logical design. The only difference is on the fact that aircraft identification is to be set by flight crew in all the ADS-B-RAD scenarios while in the Reference scenarios is only set in RS-2b.

- Concerning the associated human tasks, it has been highlighted that the ADS-B-RAD and the Reference system are identical from that perspective (see Annex I). Human factors related to the ATCo interface will have however to be addressed at local level, due to the close dependence with the physical implementation. It has to be noted that human errors are partially addressed in the PSC in section 10, when discussing failure approach and when considering mitigation means.

- Similarly, the technical surveillance data items have been identified. They are mainly the same as in the reference Logical Design, except for the source of the horizontal position and related quality indicator, and aircraft identity as mentioned above. Note that besides mode A code and Aircraft ID, the ICAO 24bit address is also to be broadcast by the aircraft via ADS-B for technical reasons.

- The surveillance functions of the ADS-B-RAD logical design have also been described, element by element. The main differences with respect to the Reference logical design concerns the new airborne and ground ADS-B related functions, and in particular "ADS-B to Radar association function" which associates data received from ADS-B and radar for the same aircraft. It has also been highlighted the fact that advanced fusion techniques between ADS-B and SSR/Mode S data are not used, and that ADS-B will be used as the principal surveillance source with radar providing a backup surveillance source in case of loss or degradation of ADS-B data .

- Finally, the surveillance performance characteristics required for ADS-B-RAD logical design have been defined, showing an equivalent performance for both the Reference and the ADS-B-RAD logical design. Part of that, data position quality (in terms of accuracy and integrity) defining the eligibility of an aircraft for the application of separation minima of 5 NM in En-route airspace, 3 NM in Terminal airspace and 2.5/2 NM in approach (respectively for succeeding aircraft on same final and for succeeding aircraft on adjacent ILS/MLS) have also been established.

Based on that, all related requirements concerning the nominal operation of the system have been specified, addressing the previous items (i.e. operational surveillance procedures, human tasks, surveillance data, functions, performances) for each element of the ADS-B-RAD Logical Design. In the same way, related requirements and assumptions, as necessary, on external elements have also been captured.

Additional requirements are provided in sections 8 to 10 to cover the complementary aspects related to design correctness, design robustness and the mitigation of internal failure.

8 ADS-B-RAD DESIGN CORRECTNESS (ARG 2.2.2)

The objective of this section is to show that the ADS-B-RAD design operates correctly and coherently under all normal[54] environmental conditions that it is expected to encounter in day-to-day operations.

The main question here is whether the opportunity to reduce risk has been maximised, considering the full range of conditions that the system is likely to be subjected to in its operational environment.

8.1 STRATEGY FOR ARG 2.2.2

As indicated in SAME Part 2 [Ref.22], the behaviour of the system is to be assessed from a static and dynamic perspective.

Only the static assessment can be provided in this PSC and therefore it is suggested that the dynamic assessment of the coherency and correctness of the system is performed locally based e.g. on simulations or tests.

GM042. Implementers should consider the possibility to assess the dynamic coherency of ADS-B-RAD e.g. through simulations or tests. This is proposed to be performed in two stages (recommended):

- Real time simulations could be performed to ensure the coherency of ADS-B-RAD operations in defining a set of operational scenarios based on the definition of phases made in section 3 (and including the operational surveillance procedures and associated human tasks);

- Tests at a more technical level, i.e. at the level of the logical design identified in Figure 14.

Sections 7.4.1 and 7.4.2 have demonstrated that operational surveillance procedures and human tasks are equivalent between ADS-B-RAD and Reference systems, it is therefore not necessary to address the correctness of ADS-B-RAD system at this level.

The main difference between ADS-B-RAD and the Reference systems is on the elements defined in the logical model in Figure 14, and more specifically on the broadcast of data from the aircraft (Transmitting Aircraft Domain) to the ground (Ground Domain).

[54] Abnormal conditions are addressed under Arg 2.2.3 in section 9. The distinction between *normal* and *abnormal* is not important provided all issues are addressed by the two sub-Arguments.

Note: the emphasis is made between airborne and ground systems and therefore only this interface is addressed in this section 8.2.

Data between these domains need to be consistent in order that the system functions correctly and consistently. The key question relates here to the interoperability between these elements.

This aspect has been addressed in §4 of [Ref.1], through the Interoperability requirements, to ensure that exchanged data and information are indeed mutually consistent between airborne and ground views over the full range of conditions to which the system is expected to be subjected in its operational environment. In the case of surveillance, this range of conditions mainly relates to traffic conditions and to GNSS constellation.

The argument consists in ensuring the format of the data exchange between each domain is defined and understood between them. Data transmitted by the Transmitting Aircraft Domain are the following ones as per SAF012 at interface D_A:

- Aircraft identity
- Aircraft horizontal position
- Pressure altitude
- QI
- ICAO 24 Bit address
- Emergency indicators
- SPI

8.2 DATA ITEMS AT INTERFACE D_A

ADS-B surveillance information is assembled and transmitted in ADS-B messages from airborne to ground. Message formats and transmission rates are dependent on the supporting ADS-B link technology.

For a given ADS-B data link protocol or version, it is necessary that the messages transmitted comply with the appropriate standard of the ADS-B data link protocol in use. This means that the elements necessary to the ADS-B-RAD system are transmitted in a manner compliant with the standards, but does not imply that every element mentioned in the standard needs to be transmitted for the ADS-B-RAD system. The following standards are applicable to ADS-B-RAD:

- DO-242A (version 1) - Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B) [Ref.25],

- ED-102A/DO-260B[55] (version 2) - Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B) [Ref.28].

  *Note: DO-242 (version 0) does not satisfy ADS-B-RAD requirements (**L002**).*

The following interoperability requirements are defined for each of the data items identified:

- Aircraft ID:

SAF063. As per ICAO Doc 4444, PANS/ATM (Appendix 2, 2.2) [Ref.3], on of the following aircraft identifications, not exceeding seven characters, shall be used by the Transmitting Aircraft Domain:

◊ the registration marking of the aircraft (e.g. EIAKO, 4XBCD, N2567GA), or

◊ the ICAO designator for the aircraft operating agency followed by the flight identification (e.g. KLM511, NGA213, JTR25) when in radiotelephony the call sign to be used by the aircraft will consist of the ICAO telephony designator for the operating agency followed by the flight identification (e.g. KLM511, NIGERIA 213, HERBIE 25). (see IR 5 in [Ref.1]).

note: (chapter 1 [Ref.3], definition Aircraft Identification is 'A group of letters, figures or a combination thereof which is either identical to, or the coded equivalent of, the aircraft call sign to be used in air-ground communications and which is used to identify the aircraft in ground-ground air traffic services communications'.

- Mode A code: no specific requirement in addition to SAF012.

- Aircraft horizontal position:

SAF064. The Transmitting shall reference all geometric position elements to the World Geodetic System 1984 (WGS-84) ellipsoid (see IR 8 in [Ref.1]).

Note: In the Reference logical design, the conversion of radar derived position elements to WGS-84 is also realised.

- Pressure altitude:

SAF065. The Transmitting Aircraft Domain shall formulate altitude measurements as barometric altitude relative to a standard pressure of 1013.25 hectopascals (29.92 inches of Mercury (Hg)). (see IR 10 in [Ref.1])

[55] DO-242B (version 2) or equivalent is under development at the time of the edition of this document.

Rec1. The Transmitting Aircraft Domain should be capable of manually deselecting the transmission of pressure altitude. (See IRec 1 in [Ref.1])

Rec2. Gilham® altitude encoders should not be used by aircraft implementations. (See IRec 1 in [Ref.1])

Rec3. The Transmitting Aircraft Domain should transmit geometric altitude information in addition to the Pressure Altitude information. (See IRec 1 in [Ref.1])

- Horizontal Position Quality Indicators:

SAF066. The indicators of horizontal position quality transmitted by the Transmitting Aircraft Domain shall be in accordance with the respective version number (version 1 or 2) of the data link protocol in use transmitted (see IR 11, IR 13 in [Ref.1]).

Notes:

◊ *With respect to "version 2" (ED-102A/DO-260B[55]), these are Navigation Integrity Category (NIC), Navigation Accuracy Category for Position (NACp), Source Integrity Level (SIL) and System Design Assurance Level (SDA).*

◊ *With respect to "version 1" (DO-242A), these are NIC, NACp and Surveillance Integrity Level (SIL, definition different from "version" 2 SIL).*

◊ *The MOPS Version Number is a number broadcast by ADS-B systems compliant to RTCA DO-242A specifications and ED-102A/DO-260B, to indicate the version of the formats and protocols used in the ADS-B avionics installed on the aircraft.*

SAF067. The reported horizontal position quality indicators NIC and NACP shall be encoded exclusively from the respective integrity and accuracy metrics that are provided by the horizontal position source (see IR 12 in [Ref.1]).

Rec4. When the data source is GPS, then use of RTCA DO-208 RAIM calculations to determine HPL is acceptable as a minimum. However, NIC values should be determined using HPL values based on RTCA DO-229D RAIM methodology or equivalent when feasible (see IRec 4 in [Ref.1]).

Rec5. The NACP values should be determined using the HFOM value of a RTCA DO-208 or a RTCA DO-229D GPS receiver or equivalent (see IRec 5 in [Ref.1]).

- ICAO 24 Bit address: no specific requirement in addition to SAF012.

- Emergency indicators:

SAF068. The Transmitting Aircraft Domain shall transmit the emergency indicator(s) for as long as the emergency mode is selected. (see IR 15 in [Ref.1])

- SPI: no specific requirement in addition to SAF012.

- Additional information :

SAF069. The Transmitting Aircraft Domain shall provide information in each ADS-B message, according to the standard of the ADS-B data link, from which the Ground Domain can determine the time of applicability (see IR 2 in [Ref.1]).

8.3 DATA ITEMS AT INTERFACE D_R

Data items transmitted at interface D_{SR} corresponds to SSR / Mode S transponder outcomes and are equivalent to those of the Reference System.

8.4 CONCLUSIONS ON ARG 2.2.2 - DESIGN CORRECTNESS

This section has provided adequate Argument and supporting Evidence that the ADS-B-RAD logical design functions correctly and coherently under all normal environmental conditions. In that perspective interoperability requirements between various domains have been defined in order to ensure that exchanged data and information are indeed mutually consistent.

Next section 9 considers the reaction of the system to <u>ab</u>normal events in its operational environment.

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9 LOGICAL DESIGN ROBUSTNESS (ARG 2.2.3)

The objectives of this section are to show that the ADS-B-RAD Logical Design is robust (i.e. work through), or at least resilient (i.e. recover easily from), against external abnormalities in the operational environment.

The decomposition of this argument is shown in the figure below:

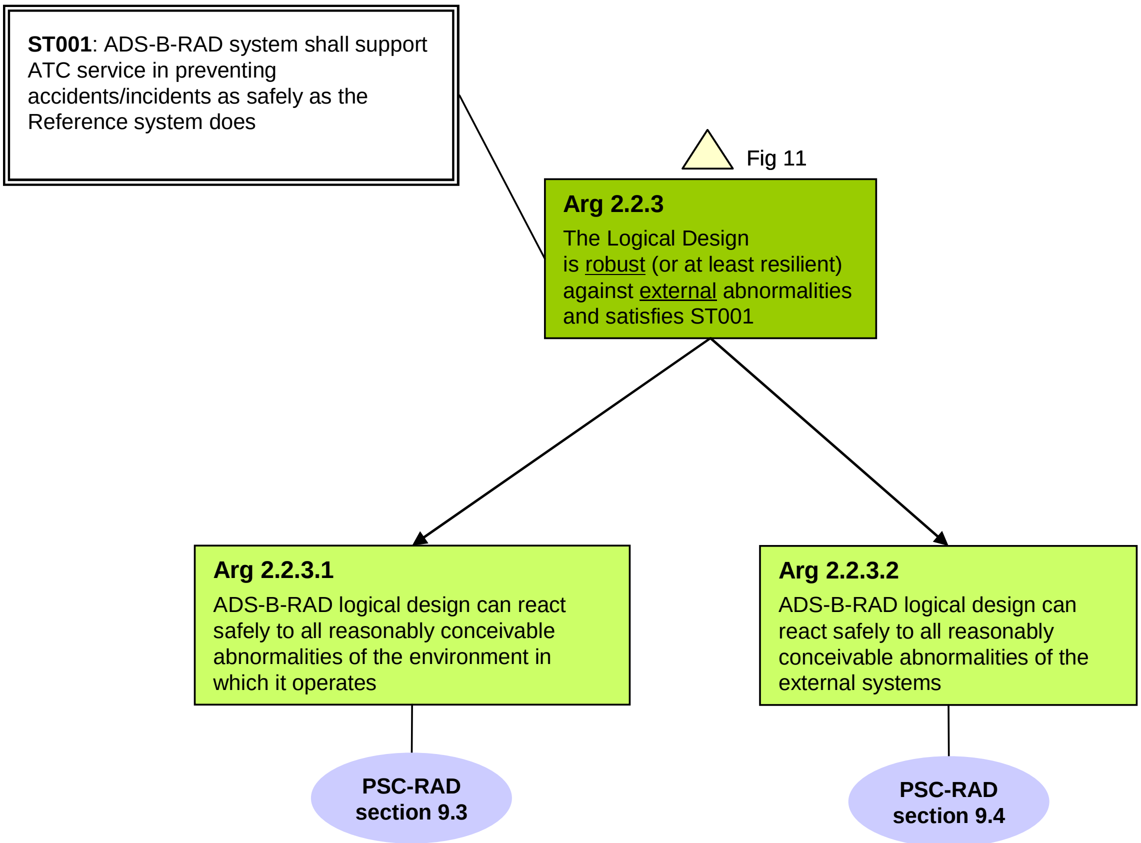

Figure 16: Decomposition of Argument 2.2.3

9.1 SAFETY TARGET

The Safety Target considered for this argument Arg 2.2.3 is the same as for Arg 2.2.1 i.e. (as defined in section 7.1):

ST001: ADS-B-RAD system shall support the ATC service in preventing accidents/incidents as safely as the Reference system does.

9.2 STRATEGY FOR DECOMPOSING ARG 2.2.3

The reaction of the ADS-B-RAD system to abnormal events of its operational environment or of external systems/elements was considered from the following perspectives:

- Can the system continue to operate?
- Could such conditions cause the system to behave in a way that introduces additional risk?

The strategy for satisfying Arg 2.2.3 is to provide Evidence that both of the following lower-level Arguments are true:

a) **Arg 2.2.3.1**. ADS-B-RAD logical design can react safely to all reasonably conceivable abnormalities of the environment in which it operates.

b) **Arg 2.2.3.2**. ADS-B-RAD logical design can react safely to all reasonably conceivable abnormalities of the external systems.

Note: Failures internal to the ADS-B-RAD system are addressed under Arg 2.1.1.5, in section 10 below.

The following figure identifies the operational environment characteristics and the external elements (defined in section 7.6), which abnormalities are further assessed in this section.

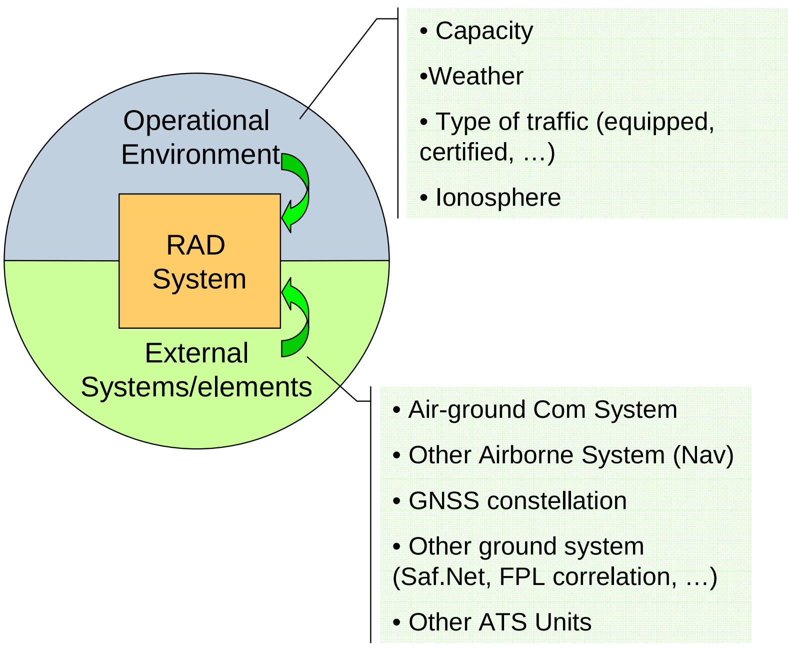

Figure 17: RAD System Robustness.

These are addressed in turn, in sections 9.3 and 9.4 below. Conclusions regarding Arg 2.2.3 are then drawn, in section 9.5.

9.3 REACTION TO ABNORMALITIES OF THE ENVIRONMENT (ARG 2.2.3.1)

The following possible abnormalities have been identified for each of the characteristics of the operational environment in which ADS-B-RAD logical design operates:

- Capacity overload.
- Extreme Weather.
- Unequipped/uncertified SSR/ADS-B traffic.
- Solar phenomena (solar flares, scintillation, and fast moving ionosphere gradients …) affecting the ionosphere.

9.3.1 Capacity Overload

This case corresponds to the situation where traffic demand exceeds ATC sector capacity. The following statement applies:

A012. It is assumed that the management of demand versus capacity (e.g. Flow Management Function) is implemented for the ADS-B-RAD sector as it would be implemented in the Reference system.

ADS-B-RAD is considered to be applicable to areas of medium or high density traffic depending on the environment, but implementation is assumed to be able to accommodate higher levels of traffic (see section 2.2.1), and provisions have been made in the assessment of ADS-B-RAD to ensure this. The defining factor is then more related to operational aspects than to technical limitations.

Therefore, ADS-B-RAD design is as robust against capacity overload as the reference design (**ST001**).

9.3.2 Extreme Weather

In terms of the high level design, there is nothing to indicate that the ADS-B-RAD design will be any less robust to extreme weather conditions than the Reference logical design.

> **GM043.** Robustness and Resilience of the physical system (against e.g. lightning, extreme temperature phenomena) will have to be considered at local level as it is closely related to the environment in which the ADS-B-RAD system is going to be used.

9.3.3 Unequipped /Uncertified SSR/ADS-B Traffic

A number of possible abnormal modes are considered in the following table, as function of the aircraft SSR/ADS-B equipage and certification situation. These are implementation issues.

Condition	ADS-B-RAD equipage/certification status				Discussion
	SSR equipped	SSR certified	ADS-B equipped	ADS-B certified	
Normal is	Y	Y	Y	Y	Normal mode.
Abnormal 1	N		N		Case of airspace penetration: identical situation as for the Reference system, (**ST001**) where the coordination procedures remain the same so the controller will either accept it or refuse entry. If they accept it then local procedures will define how to manage that flight (and thus it becomes a mixed equipage scenario which is not covered by this PSC). In that case implementers to assess this case as part of the mixed equipage situation.
Abnormal 2	Y	Y	N		Covered by the failure case.
Abnormal 3	Y	N	N		Identical to the Reference system case (**ST001**).
Abnormal 4	N		Y	Y	ADS-B-RAD system more resilient than the Reference system (because of the detection) (**ST001**).
Abnormal 5	N		Y	N	Comparable to the Reference system case (**ST001**) – see abnormal condition 3.

As a conclusion, the ADS-B-RAD design is not less resilient against aircraft equipage/certification abnormal modes than the reference design (**ST001**).

9.3.4 Solar Phenomena

Solar activity affects the propagation of GNSS signals when crossing the ionosphere.

The sun exhibits an 11-year cycle in its activity and the next maximum is expected around 2013. Moreover, there are abnormal "out of season" phenomena that could affect many GNSS receivers used in aviation.

These phenomena may be planned and for the case where severe disturbance could impact ATC service, mitigation means have to be put in place (e.g. reduction in capacity and alternate separation minima).

Eurocontrol is currently performing a study on the assessment of the impact of solar activities (ionosphere effects) on Aviation applications based on GNSS in ECAC and on the identification of mitigation techniques (NOTAM to users, etc.). It is expected that high-level measures (that are beyond of the scope of the surveillance only as they also concern navigation and especially critical approach phases of flight) will be implemented throughout ECAC.

GM044. Implementers should consider and address the possibilities of solar phenomena (e.g. based on the results on this study) when implementing local ADS-B-RAD in their local environment.

9.4 REACTION TO ABNORMALITIES OF THE EXTERNAL SYSTEMS (ARG 2.2.3.2)

Section 7.6 identifies the main (relevant) external elements to the ADS-B-RAD logical design supporting the ATC service, as described in Figure 14 (ADS-B-RAD Logical Model). In this section, the term "abnormalities" principally corresponds to failures of the external systems but also covers abnormal conditions for GNSS:

- The air-ground communication systems failures.
- The other airborne systems (navigation systems, safety nets) failures.
- The GNSS signal in space (external positioning source) failures or abnormal conditions.
- Other Ground Systems (safety net, FPL correlation) failures.
- Other ATS units failures.

GM045. The failures related to the specific external elements related to local characteristics identified by implementer (see GM035) should also be taken into account and assessed here.

9.4.1 Air-Ground Communication Systems Failure

Concerning this external failure, it has been asserted that:

A013. Because voice communication is entirely independent of the ADS-B-RAD system, then it is assumed that the likelihood of voice-communication failure would be no greater than for the Reference system case (see ENV-ASSUMP.12 in [Ref.1] and [Ref.12]).

Further, in case of voice communication failure, the following safety requirements have been defined:

SAF070. Concerning procedures in case of voice communication failure, the same contingency procedure as for the Reference system shall apply (PANS-ATM).

Therefore, the ADS-B-RAD design is not less resilient against voice-communications failure than the Reference logical design (**ST001**).

GM046. In order to reduce the impact of complete ground radio equipment failure on the safety of air traffic, the implementer should establish contingency procedures to be followed by control positions and ATC units in the event of such failures (PANS-ATM 8.8.6.1).

9.4.2 Other Airborne Systems Failure

Navigation failure

Two cases can be distinguished:

a) Case of navigation failure not affecting the ADS-B positioning: fully identical to the Reference system case.

Therefore, the ADS-B-RAD design is as robust in that case against aircraft failures as the reference design (**ST001**).

b) Common mode of failure (related to positioning) between navigation and surveillance: this case is integral part of the failure approach, therefore more information concerning GNSS abnormal conditions or failures is provided in section 10.4.1.2 (effects) and 10.7.3 (causes).

Airborne Safety Net failure

Concerning safety net, it has been asserted that:

A014. Aircraft safety net failures are assumed to be independent of ADS-B out transmissions, then it is assumed that the likelihood of such failures would be no greater than for the Reference logical design case.

In case of aircraft Safety Net failure (e.g. TCAS failure), this would involve application of the same procedures as in today's Reference logical design.

Therefore, the ADS-B-RAD design is as robust against aircraft safety net failures as the Reference system case (**ST001**).

Other Aircraft failure

In case of other aircraft failure (e.g. engine failure), this would involve application of the same procedures as in today's Reference logical design. It has been asserted that:

A015. Because the aircraft failures are independent of ADS-B operations, then it is assumed that the likelihood of such failures would be no greater than for the Reference logical design case.

Therefore, the ADS-B-RAD design is as robust against aircraft failures as the Reference logical design (**ST001**).

9.4.3 GNSS Signal-in-Space (External Positioning Source) Failure

Although GNSS signal-in-space is identified as part of the external elements, its failure modes are an integral part of the basic causes considered in the failure approach, therefore more information concerning GNSS failures is provided in section 10.

Predicted degradation of GNSS (poor constellation geometry or satellite failure) might be determined through the use of prediction tools by implementers.

This condition can be compared against maintenance works on radar antennas in the Reference system.

Unavailability of GNSS or RAIM function might also be checked during the flight preparation phase by flight crews.

GM047. Implementers may use RAIM prediction as a possible way to ensure availability of GNSS service in own local implementation, as the OSED in [Ref.1] assumes that the coverage is sufficient in terms of both range and availability of adequate data (ASSUMP 16 in section 3 of [Ref.1]).

GM048. During periods of predicted unavailability of GNSS, implementers should implement specific measures to manage the traffic (e.g. by alleviating traffic density and by applying alternate separation minima).

Therefore, the ADS-B-RAD design is not less resilient against predicted GNSS SIS failures than the Reference design (**ST001**).

9.4.4 Other Ground Systems Failure

Ground Safety Net failure

The ADS-B-RAD and the Reference systems do not assume the presence of a ground safety net. This section is therefore a placeholder for implementers for which a ground safety net is part of their local Reference system. In addition, as ICAO does not establish the minimum requirements for safety nets to support ATC Surveillance Services, this issue can only be resolved at local level.

Ground Safety nets are designed to receive and process surveillance information and therefore ground safety net failures do not impact ADS-B-RAD system.

Evidence would normally have to be developed by implementers in this section to cover the argument stating that safety net failure are not more frequent under ADS-B-RAD system than for the (local) Reference system case. This argument would directly relate to the consideration of the impact of an ADS-B failure on safety nets.

GM049. Implementer should consider Ground Safety Net possible failure modes in relation with ADS-B and should assess the corresponding safety impact. Implementer may consider covering this argument and evidence as part of the failure approach.

FPL correlation failure

As explained in 7.6.4, RAD2b involves the direct display of the aircraft identification as broadcast by the aircraft and therefore correlation is not required for the aircraft identification data item. For this scenario, the ADS-B-RAD system is therefore more robust than the Reference system which relies on the Flight Plan system correlation.

For RAD1, RAD2a and RAD3, ADS-B-RAD and the Reference system have identical behaviour and the ADS-B-RAD system is therefore not less resilient than the Reference system.

In conclusion, when considering all scenarios, the ADS-B-RAD design is not less resilient against Flight Plan correlation failure than the reference design (**ST001**).

9.4.5 Other ATS Units Failure

In case a severe failure occurs in the adjacent ATS unit (e.g. ACC failure) resulting in a significant reduction or interruption of its service (e.g. due to the evacuation of the adjacent centre) contingency procedures in the adjacent sector will apply involving all neighbouring units (EC2096/2005 [Ref.12]).

As the ADS-B-RAD system has not utilised mitigations provided by adjacent units (see section 10.4.1.1), the impact on the ADS-B-RAD system would be not greater than on the Reference system and therefore, ADS-B-RAD design is not less resilient against adjacent sectors failures than the reference system design (**ST001**).

9.5 CONCLUSIONS ON ARG 2.2.3 - DESIGN ROBUSTNESS

This section addresses the reaction of the ADS-B-RAD logical design to events where both abnormalities of the operational environment and abnormalities of the external systems have been considered.

Adequate Evidence that the ADS-B-RAD logical design is as robust or as resilient against these abnormalities as the Reference logical design has been provided when direct comparison with radar situation is appropriate, and supports Safety Target **ST001**.

It is to be noted that although GNSS signal-in-space is identified as part of the external elements, its failures and abnormal modes are an integral part of the basic causes considered in the failure approach and are therefore considered as part of section 10.

Next, section 10 considers the risks associated with internal failure of the system.

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10 MITIGATION OF INTERNAL FAILURES (ARG 2.2.4)

The objective of this section is to show that all risks from internal system failure have been mitigated sufficiently and satisfy the safety targets defined in section 5.

The Safety Objectives related to the failure mode of operation of the ADS-B-RAD system, have not been defined at service level but at equipment level, because ADS-B-RAD system does not modify the role of the controllers and Flight Crew, i.e. procedures are not modified (cf. section 7.4.1). The corresponding Safety objectives derived from the Safety Targets are presented in section 10.5.

The decomposition of Arg 2.2.4 is shown in the following figure below:

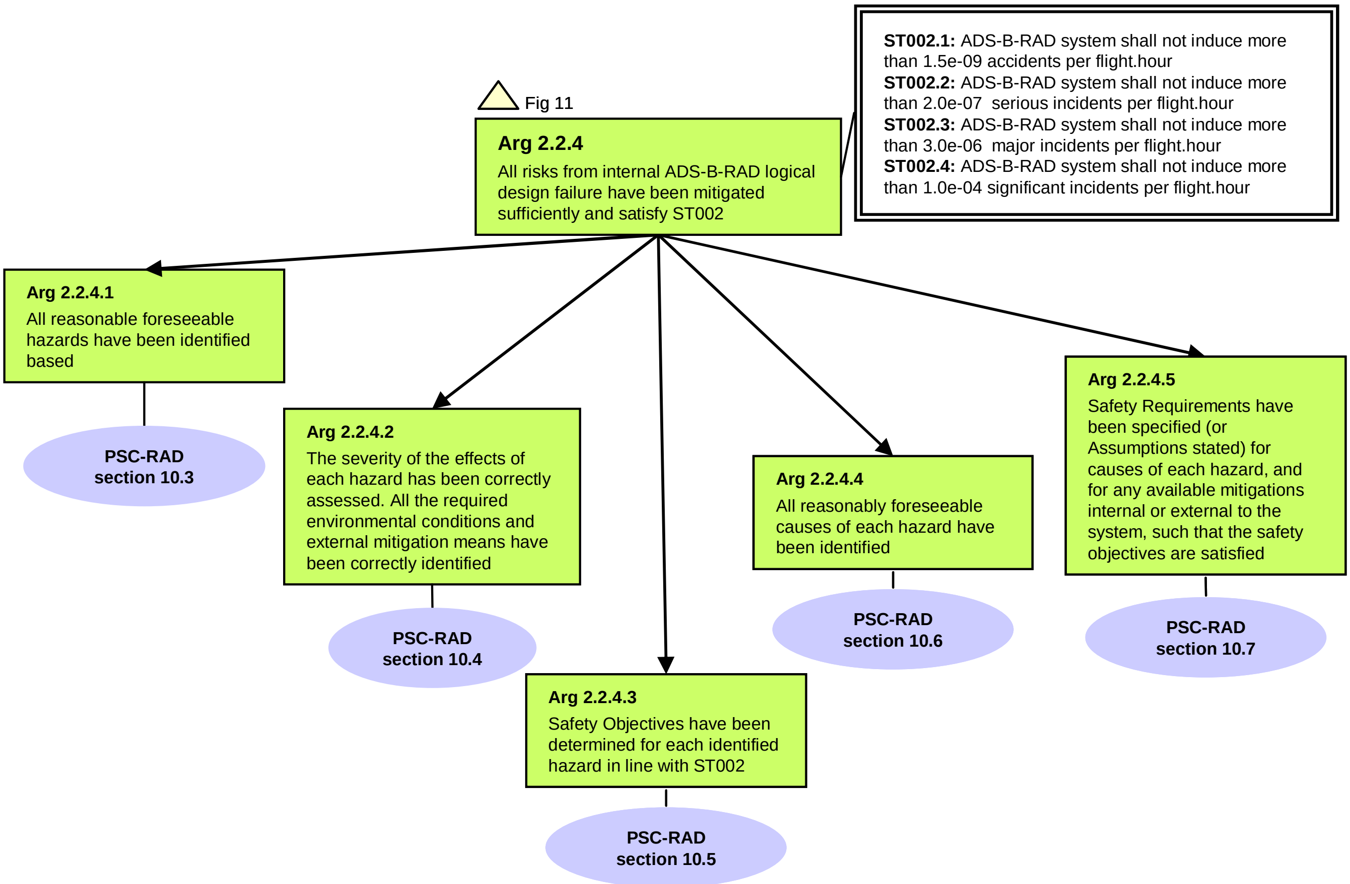

Figure 18: Decomposition of Argument 2.2.4

10.1 SAFETY TARGETS

The Safety Targets considered for this argument Arg 2.2.4 are:

ST002.1: ADS-B-RAD system shall not induce more than 1.5e-09 accidents per flight.hour.

ST002.2: ADS-B-RAD system shall not induce more than 2.0e-07 serious incidents per flight.hour.

ST002.3: ADS-B-RAD system shall not induce more than 3.0e-06 major incidents per flight.hour.

ST002.4: ADS-B-RAD system shall not induce more than 1.0e-04 significant incidents per flight.hour.

10.2 STRATEGY FOR DECOMPOSING ARG 2.2.4

Internal failures of the system have been assessed from the perspective of how anomalous behaviour of the system could induce risks that might otherwise not occur. Common[56] mode failures have also been assessed.

The strategy to decompose Arg 2.2.4 is based on the Operational Safety Assessment (OSA) performed by [Ref.1] where it is realised in two steps: Operational Hazard Assessment (OHA) and Allocation of Safety Objectives and Requirements (ASOR). This is illustrated in the Figure 19 below, which introduces various terms that are essential in the OSA.

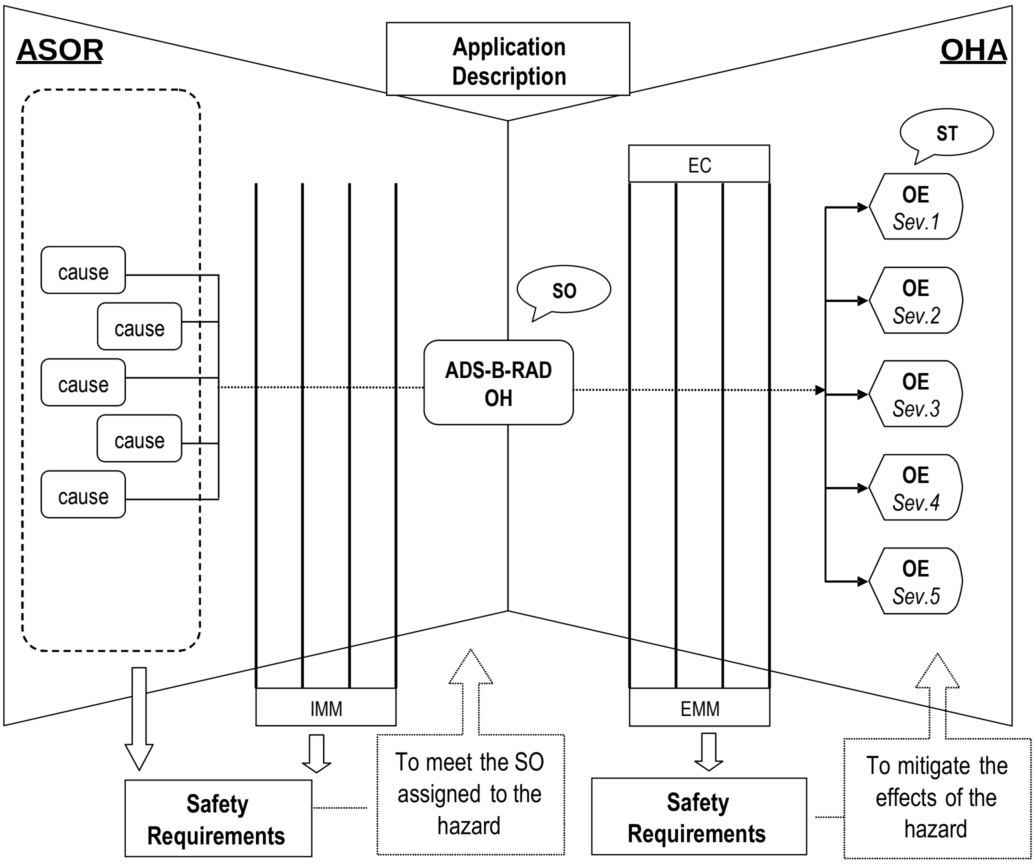

Figure 19: OSA Process Overview

Environmental conditions (EC) make up the Operational Environment in which ADS-B-RAD will be used. The safety assessment is performed within the assumed Operational Environment. Note that ECs may reduce or increase

[56] Common with one or more non ADS-B functions

the severity of a hazard (for example, if a hazard is treated in a low versus high traffic density environment).

EMMs are mitigation means that help reduce the effects of a hazard once the hazard has occurred.

IMMs are mitigation means that help to meet the safety objective assigned to the hazard. Certain IMMs must fail in order to produce the identified hazard and are captured in fault trees accordingly.

In the figure above, OE stands for Operational Effects, ST for Safety Targets and SO for Safety Objectives. All these terms are heavily used in the rest of the document.

The strategy for satisfying Arg 2.2.4 is then, to provide Evidence that the following lower-level Arguments are true:

a) **Arg 2.2.4.1**. All reasonably foreseeable hazards at technical level have been identified.

b) **Arg 2.2.4.2**. The severity of the operational effects of each hazard has been correctly assessed, taking account of any mitigation that may be available (external mitigation means and environmental conditions).

c) **Arg 2.2.4.3**. Safety Objectives at technical level have been determined for each identified and assessed hazard based on the safety targets.

d) **Arg 2.2.4.4**. All reasonably foreseeable causes of each hazard have been identified, including common mode of failure, together with internal mitigation means.

e) **Arg 2.2.4.5**. Safety Requirements have been specified (or Assumptions stated) for the causes of each hazard, such that the safety objectives are satisfied.

These Arguments presented above are addressed in turn, in sections 10.3 to 10.7 below.

Conclusions regarding **Arg 2.2.4** are then drawn in section 10.8.

10.3 HAZARDS IDENTIFICATION (ARG 2.2.4.1)

The functional architecture of the system evaluated in this OSA for the ADS-B-RAD system is depicted in Figure 14. Because the ADS-B-RAD system does not modify the existing radar processing functions nor the role of the controllers and Flight Crew (cf. section 7.4.1 and 7.4.2), the OSA focuses on the functions of the ADS-B-RAD system that are “new” (compared to the Reference system) and also on the data items (blue/grey boxes in the Figure 14).

During the safety assessment, it was considered suitable to identify hazards at the level where the change (i.e. the difference between RAD and Ref system) can be more easily evaluated by operational people. Consequently ADS-B-RAD system operational hazards (OH) have been identified at the output of the ATC interface function (interface G2) and address the loss of or erroneous **ADS-B information. This PSC does not cover radar failures when ADS-B is working correctly (L005).** Therefore hazards related to radar only failures are not part of the assessment.

GM050. Implementers should analyse **radar failures** while ADS-B surveillance is still available and determine the appropriate procedures to be applied by the controllers (e.g. determine the appropriate separation minima in case only ADS-B is available).

Potential hazards have been identified based on brainstorming sessions in which operational and safety experts participated (§C.4.1 [Ref.1]). These hazards apply for the various ADS-B-RAD scenarios RAD-1, RAD-2a/2b and RAD-3.

These hazards may be caused by a combination of satellite failure, transmit aircraft failure, or ground domain failures, depending on the specific hazard (see [Ref.1], §C.3.1).

Then, internal system failures in this Arg 2.2.4.1 will focus on all data items (horizontal position and its associated quality indicator, aircraft identification information, pressure-altitude, SPI, Emergency modes), and on the impact on ADS-B-RAD separation task.

Failures associated to the QI management (not related to the position itself, but to the provision, or not, of the information on the ATCo interface as specified by 7.3.2.1), e.g. oscillation of QI value, as this aspect is very dependent upon the local implementation of the ADS-B-RAD system are not developed here. Further analysis needs to be considered at local level.

GM051. Implementers should address failures associated with the QI management (e.g. the provision or not of the information on the controller interface) and to the potential associated failures (e.g. oscillation of QI value) which have not been considered in this Preliminary Safety Case as they are very dependent upon the local implementation of the ADS-B-RAD system.

When applicable, the same kind of hazard (e.g. OH1 and OH2) has been specified for single and multiple[57] aircraft because they have different effects and different causes. The Hazards identified during these sessions are as follows:

[57]The term ‘multiple’ aircraft covers the worst case in terms of severity assignment compared to one aircraft (single case). Meanwhile the barriers in the event tree analysis apply regardless if the hazards affect some or all aircraft.

Hazard	Title **Single Aircraft**	Hazard	Title **Multiple Aircraft**
OH01	Sudden and Unexpected Loss of ADS-B Position Information for a *Single* Aircraft	**OH02**	Sudden and Unexpected Loss of ADS-B Position Information for *Multiple* Aircraft
OH03	Loss of All ADS-B Data for a *Single* Aircraft	**OH04**	Loss of All ADS-B Data for *Multiple* Aircraft
OH05	Incorrect Position Information for a *Single* Aircraft – divided into three sub cases:	**OH06**	Incorrect Position Information for *Multiple* Aircraft – divided into three subcases:
OH05-1	Horizontal position error resulting from a GNSS position source error not detected by the aircraft integrity monitoring for a *Single* Aircraft	**OH06-1**	Horizontal position error resulting from a GNSS position source error not detected by the aircraft integrity monitoring for *Multiple* Aircraft
OH05-2	*Horizontal position error resulting from a sustained credible corruption of the position information for a* Single *Aircraft*	***OH06-2***	*Horizontal position error resulting from a sustained credible corruption of the position information for* Multiple *Aircraft*
OH05-3	*Horizontal position error resulting from a sustained credible corruption of the quality indicator for a* Single *Aircraft*	***OH06-3***	*Horizontal position error resulting from a sustained credible corruption of the quality indicator for* Multiple *Aircraft*
OH07	Loss of Emergency Mode after Selected by Flight Crew		
OH08	Incorrect but Plausible Emergency Mode		
OH09	Two 'Dispersed' Position Symbols for the *Same* Aircraft	**OH10**	*Multiple* 'Dispersed' Position Symbols
OH11	Incorrect Level Information for a *Single* Aircraft	**OH12**	Incorrect Level Information for Multiple Aircraft
OH13	Loss of Level Information for *Single* Aircraft	**OH14**	Loss of Level Information for *Multiple* Aircraft
OH15	Incorrect Identity data for a *Single* Aircraft	**OH16**	Incorrect Identity data for *Multiple* Aircraft – divided into two sub cases:
		OH16-1	*Incorrect ID resulting from a sustained credible corruption of ID for* Multiple *Aircraft*
		OH16-2	*Transposition of IDs between at least two aircraft (swap ID)*
OH17	Loss of Identity data for a *Single* Aircraft	**OH18**	Loss of Identity data for *Multiple* Aircraft
OH19	*Single* False[58] Target	**OH20**	*Multiple* False Targets

Table 35: ADS-B-RAD Hazards List

[58]This hazard corresponds to the situation where the ATCO is presented with one target on the CWP that appears to be a real aircraft, but wich does not in fact represent a real aircraft in that place and time.

Note: The failure mode 'late or delay' has been conservatively considered as "loss of".

Note: Hazards associated with Emergency modes apply for single aircraft case only and not for multiple aircraft case because of the low likelihood of two aircraft in emergency condition simultaneously in the same sector.

Note: Sub cases of OH16 do not apply to single aircraft case.

The analysis of OH5 and OH6 has been broken into three cases based on three distinct hazard causes. The operational effects and potential mitigations related to each cause are different, and so a set of separate event trees and fault trees have been developed to analyze each case individually. The three causes of incorrect position for a single or multiple aircraft that have been identified for these hazards are as follow:

Case 1, **Horizontal Position Source Failure**: The position error is at the source of the position information (e.g., GNSS constellation) and is not detected by the airborne horizontal position integrity monitoring function;

Case 2, **Data Corruption**: The position error is the result of a sustained credible corruption of the position information (in either the ground or airborne domain); and

Case 3, **QI Corruption**: An incorrect position detected by the horizontal position source and subsequent corruption of the quality indicator by either the on-board avionics or the ADS-B ground processing system (system integrity failure).

In the same manner, for OH16 two causes of incorrect identity for multiple aircraft have been identified and have been assessed as having different operational effects. This led to considering them as different hazards for this hazard, as presented here-after:

Case 1, **ID Corruption**: The display of incorrect ID is the result of a sustained credible corruption of the ID information (in either the ground or airborne domain); and

Case 2, ID Swap: A transposition of IDs between (at least) two aircraft, where the ID of one aircraft is associated with the track of another, and vice versa.

The detailed analysis of each OH (OHA and ASOR) are described in §C.5 of [Ref.1].

GM052. The operational hazard assessment performed in [Ref.1] has relied heavily on the involvement of qualified operational staff (mainly ATCOs) supported by Safety experts. Implementers may nevertheless identify new – local – hazards which have not been considered in this PSC or may even reconsider the severity of the potential effects of identified hazards (e.g. because of significant differences in traffic conditions) or the probability of effect (Pe).

GM053. Additional hazards resulting from the partial equipage issue (see **I006** and GM012) will have to be equally considered. If the safety approach performed in [Ref.1] is followed (see section 10.2 above), then the inclusion of such new operational hazards or severities in the OSA should be performed consistently with the methodology adopted (see [Ref.1] particularly sections 2 and 3 of Annex C).

GM054. The impact of a change in the ratio between the numbers of RAD and overall ATM hazards (for each severity) should be reviewed by implementers as apportionment of the safety objectives in a local environment will depend on the complexity of the local implementation and such values will have to be adapted. It is recommended to implementers to use the ED125 document as input for determining the level of granularity at which hazards have to be defined, and for determining the number of ATM hazards to be considered based on the airspace complexity definitions included in ED-125.

10.4 HAZARDS EFFECT ASSESSMENT AND SEVERITY ASSIGNMENT (ARG 2.2.4.2)

10.4.1 Hazards Effect Assessment

10.4.1.1 Generalities

As explained in section §C.2.1 of [Ref.1], a thorough hazard effect assessment has been performed, by identifying all the potential effects of each hazard by way of the development of an event tree. The modelling of the effects includes the identification and quantification of mitigation means (including procedural and environmental factors) being barriers to effects. The list of these External Mitigation Means and Environmental Conditions is provided in next section 10.4.4.

During this assessment the following conservative assumption has been made:

A016. No credit for Airborne Safety Nets and Flight Crew visual avoidance has been made in the hazard effect assessment.

A017. No credit for Ground Safety Nets has been made in the hazard effect assessment.

An Event Tree is a graphical representation of a logic model that identifies and quantifies all possible outcomes following an initiating event, i.e. the hazard. It is typically built on a binary accounting for the “success” or “failure” of a barrier in becoming effective. At the end of each branch, the effects of the hazard are assessed along with the corresponding Severity Class (see next section 10.4.2 for more details on severity classes), and the probability that the hazard generates that effect is calculated based on the success/failure probability of each concerned barrier.

The effects of each hazard have been assessed in all ADS-B-RAD scenarios (RAD1, RAD2a/RAD2b and RAD3): for example §C.5.1.2.1 in [Ref.1] provides the description of the effects of OH01 in RAD1 environment and §5.1.2.2 includes the description of OH01 effects in RAD2a/RAD2b and RAD3 scenarios.

Detection of ADS-B-RAD hazards may be facilitated by a combination of system functions, procedures and / or human performance. The radar(s), humans and ATC procedures have thus been considered as External Mitigation Means to the hazards. In addition the event when radar cannot mitigate a hazard effect (in case of radar failure) is also addressed in the Event trees.

Failures of some procedures have also been considered during the hazards effects analysis.

10.4.1.2 Specific Point on Common Failures

Effects of hazards OH5 and OH6 (incorrect position information) have been assessed based on the following conservative assumptions:

A018. ATCo is assumed to be applying the minimum surveillance separation standard applicable for the considered environment (ENVT-1 to ENVT-3 see definition in section 2.2 e.g. 5Nm in ENVT-2) (see appendix C, §C-1.5 [Ref.1]).

As extracted from Annex C3.3 in [Ref.1], if GNSS is used as sole-means for aircraft navigation and for the positioning source in the context of ADS-B-RAD, its (loss of signal…) could lead to a loss or corruption of both navigation and surveillance capabilities simultaneously (i.e. common mode of failure). The "ADS-B to radar association" function (described in more details in section 10.4.4.2.2) mitigates the impact of this common mode by ensuring that a surveillance source that is independent of GNSS (i.e., MSSR and/or PSR radar) is available.

A019. An error in positioning (GNSS) leading in a common mode of failure of both navigation and surveillance has been considered in the assessment of the effects of related hazards OH5 and OH6 (see corresponding event trees illustrated in figures C-19 and C-23 in [Ref.1]).

In case of a detected ADS-B position failure, ATC service can continue to be applied but using alternate separation minima (either immediately or a gradual change is permitted) based on radar data as the sole source of surveillance (e.g. cf. OH4 as indicated by requirement SAF072 in section 10.4.4.2.1) in this failure situation, and as stated by OSA-ASSUMP.42 and 43 in [Ref.1].

Hazards effects have been assessed at sector level. Conservatively mitigations do not rely on the possible positive support by adjacent sector(s) during the effects analysis. The common failure affecting multiple sectors has not been specifically considered in this OSA as too locally dependent.

However conservative severities have been used regarding workload effects and depending on the local conditions and procedures they may be validated for the common failure affecting multiple sectors.

GM055. Although severities assigned for workload effects on the ATCo are conservative (e.g. including severity up to 1), any possible cumulative workload effects on failures affecting multiple sectors should be assessed by implementers in their specific environment.

10.4.2 Severity Assignment

At the end of each branch of the event trees, effects of the OH are described along with the corresponding severity class of a common classification scheme (from severity 1, accident, to severity 5, no safety impact). This scheme is presented in Annex A and it is compliant with ESARR4.

A severity class finally assigned for each hazard is included in Table 42 below. It corresponds to the "most demanding severity" for each scenario (RAD-1, RAD-2a/RAD-2b and RAD-3), from which the most stringent safety objective is derived as presented in section 10.5 and using the quantification of each hazard effects occurrence as detailed in next sections 10.4.3.

GM056. [Ref.1] analysis considered the event trees approach. It is recommended, when considering the updated hazard identification (as per GM052 and GM053) to perform the same kind of hazard effect assessment.

10.4.3 Determination of Pe Values

Pe value is the probability that the occurrence of a hazard will result in a given severity of operational effect. In other words, this probability tries to quantify the effectiveness of the Environmental Conditions (ECs) and the External Mitigation Means (EMM) identified during the hazards assessment (see §C.2.2.2.3 of [Ref 1] is also explained).

All the outcomes of each hazard have been quantified and the Pe for the most demanding severity is provided in Table 42, for each of the three environments (RAD-1, RAD-2a/2b, and RAD-3).

The Pe values can be found in the event tree of each hazard as well as the probability of failure / success of each barrier, which latter is traced as a combination of safety requirement(s) and / or assumption(s) in [Ref.1] and provided in the tables of next section 10.4.4.

GM057. The operational safety assessment referred to in this document is based on a traffic level assumed (cf. section 2.2 of this document) to be typical of areas where ADS-B-RAD could be implemented. Implementers will have to check whether these figures are appropriate for their local operational environment.

GM058. The order of magnitude of these traffic conditions was used for the severities determination. Implementers will have to check whether these severity figures remain appropriate for their local environment.

GM059. In case that separation minima locally considered differs from the ones considered in this PSC (i.e. 5, 3 and 2.5/2 NM in approach,(respectively for succeeding aircraft on same final and for succeeding aircraft on adjacent ILS/MLS)), implementers will have to check that Pe values are still valid in their local environment.

GM060. Pe values changes would generally lead to significant OSA modifications that will have to be taken into account by implementers.

10.4.4 Safety Requirements and Assumptions related to the Event Tree Analysis

As mentioned before, *Environmental Conditions (EC)* and *External Mitigation Means (EMM)* are identified during the assessment of the hazards effects and taken into account for the severity assignment and Safety Objective allocation process (this latter is explained in section 10.5).

Note that the characteristics of the Typical Operational Environment, i.e. the EC, in which ADS-B-RAD system is expected to operate, such as available CNS means, traffic density, airspace configuration, etc., have already been captured in section 2.2 and therefore are not recalled in this section. It is of course recognized that these elements have an impact on the hazards, either by mitigating or aggravating their effects.

GM061. Implementers should determine whether the characteristics of their local Operational Environment are compatible with the assumptions made in this Preliminary Safety Case. Any deviation should be considered when reviewing the safety assessment.

Other assumptions have been identified during the event trees development and correspond mainly to the assessment of the likelihood of occurrence of some particular events such as the likelihood of encountering an aircraft emergency in a given sector. They are provided in the following table:

Miscellaneous Assumptions – Event Trees	OH	RAD-x
A020. For ADS-B position error hazards (OH05 and OH06), ADS-B position errors are considered in different magnitude bands (**“slight”, “significant”** and **“large”**) that are defined by the following boundaries: Slight < NIC, where NIC is the minimum applicable for a particular airspace; NIC ≤ Significant < 0.4*S, where S is the applicable separation minimum; 0.4*S ≤ Large < 10 NM (See OSA-ASSUMP.13 in [Ref.1]). *Note: The error bands have been characterized based on the severity classification scheme (effects on the ATS row) and have been assessed on a per scenario basis (RAD-1, RAD-2 and RAD-3) and the most demanding one has been used in the calculation of the safety objectives.* *Note: These magnitude bounds are used by the ADS-B-to-radar association function to detect inconsistencies between horizontal position information from two surveillance sources. In [Ref.1] this has been done considering ADS-B errors only (not radar errors) see **L005.***	OH05, OH06	All
A021. It is assumed that ADS-B position errors greater than 10 NM are always detected by the ground system (See OSA-ASSUMP.14 in [Ref.1]).	OH05, OH06	All
A022. Based on A020, given an ADS-B position error due to data corruption (case 2), the following error distribution is assumed: Slight ~ 2%; Significant ~ 6%; Large ~ 92% (See OSA-ASSUMP.12 in [Ref.1]).	OH05 case 2 and case 3, OH06 case 2 and case 3	All
A023. Based on A020, given an undetected ADS-B position error due to position source failure (case 1), the following error distribution is assumed: Slight ~ 99.9%; Significant ~ 0.1%; Large ~ 0% (See OSA-ASSUMP.11 in [Ref.1]).	OH05 case 1, OH06 case 1	All
A024. It is assumed that the likelihood of encountering an aircraft emergency in a given sector is 1.0E-03 per flight hour (See OSA-ASSUMP.22 in [Ref.1]).	OH07, OH08	All
A025. It is assumed that an undetected loss of all ADS-B data does not lead to a collision (i.e. another aircraft does not come into close approach with the true position of the problem aircraft) more than 0.1% of the time (See OSA-	From OH01 to OH04	All

Miscellaneous Assumptions – Event Trees	OH	RAD-x
ASSUMP.61 in [Ref.1]).		
A026. It is assumed that the lack of ATCO assistance actively contributes to the severity of the emergency in 1 out of 10 cases (See OSA-ASSUMP.10 in [Ref.1]).	OH07, OH08	All
A027. It is assumed that displayed position errors greater than 40% of the applicable separation minima could lead to a collision (i.e., severity 1) (See OSA-ASSUMP.17 in [Ref.1]).	OH05, OH06	All
A028. Given that a “significant” ADS-B position error exists, it is assumed that an undetected ADS-B position error does not lead to a large loss of separation more than 90% of the time (See OSA-ASSUMP.18 in [Ref.1]). *Note: large loss of separation is defined as per table C-2 in [Ref.1]).*	OH05, OH06	All
A029. Given that a “large” ADS-B position error exists, it is assumed that an undetected ADS-B position error does not lead to a collision more than 1% of the time (See OSA-ASSUMP.19 in [Ref.1]).	OH05, OH06	All
A030. It is assumed that the probability that an altitude error is large (i.e. more than 10,000 feet from the true altitude) and therefore detected is 80% (See OSA-ASSUMP.38 in [Ref.1]).	OH11, OH12	All
A031. Given that an undetected ADS-B altitude error of more than 200 feet exists, it is assumed that the error does not lead to a large loss of separation more than 1% of the time (See OSA-ASSUMP.47 in [Ref.1]). *Note: large loss of separation is defined as per table C-2 in [Ref.1]).*	OH11, OH12	All
A032. It is assumed that duplicate aircraft identity data with active flight plans does not correspond to aircraft in the same sector on the same frequency more than 90% of the time (See OSA-ASSUMP.51 in [Ref.1]).	OH15, OH16 case 1	All
A033. It is assumed that the probability that the ATCO's use of an incorrect ADS-B ID leads to or fails to prevent a collision is not more than 0.1%.(See OSA-ASSUMP.54 in [Ref.1]).	OH15, OH16	All

Miscellaneous Assumptions – Event Trees	OH	RAD-x
A034. Given that an undetected ADS-B altitude error of more than 200 feet exists, it is assumed that the error does not lead to controlled flight into terrain or a collision more than 1% of the time (See OSA-ASSUMP.64 in [Ref.1]).	OH11, OH12	All
A035. It is assumed that the ground system ADS-B to radar association function cannot detect ADS-B position errors characterized as "slight" in assumption A020 - OSA-ASSUMP.12 in [Ref.1] (See OSA-ASSUMP.15 in [Ref.1]).	OH05, OH06	All
A036. It is assumed that the probability that an altitude error is more than 500 feet is 97% (See OSA-ASSUMP.41 in [Ref.1]).	OH11, OH12	All
A037. It is assumed that the probability that an altitude error is more than 200 feet is 98% (See OSA-ASSUMP.46 in [Ref.1]).	OH11, OH12	All
A038. The probability that the hazard "multiple dispersed position symbols" occurs during a busy period is assumed to be 10%.	OH10	All
A039. The probability that an ID error results in an implausible value is 99.5% (See second part of OSA-ASSUMP.49 in [Ref.1]).	OH15, OH16 case 1	All
A040. It is assumed that the probability of a ground system integrity failure actually corrupts the ID field as opposed to other corruptions is less than 0.1.	OH16 cases 1 and 2	All

Table 36: List of Miscellaneous Assumptions (Event Tree)

A list of External Mitigation Means has been identified in [Ref.1]. They either concern ATCo or Flight Crew detection or application of procedures, or system detection of a given hazard. They are presented in the following tables as requirements or assumptions and are classified per elements of the ADS-B-RAD logical model as shown in Figure 14. The third column indicates which hazard is concerned by this assumption or requirement.

Note: during the safety assessment performed in [Ref.1], no probability was assigned to the following events (appearing in the event trees):

- *The ADS-B ID does or does not match the ID of an active flight plan – applicable to OH15 and OH16 case 1 (See OSA-ASSUMP.50 in [Ref.1]).*

- *There is or is no Flight Crew response when the ATCO attempts to communicate using "incorrect" aircraft ID, given that there is a different voice channel for each sector – applicable to OH15 and OH16 case 1 (See OSA-ASSUMP.52 in [Ref.1]).*

- *An ADS-B false target may or may not produce implausible target position, characteristics, or behaviour such that the ATCO suspects the target is false – applicable to OH19 and OH 20 (See OSA-ASSUMP.55 in [Ref.1]).*

- *The aircraft for which an incorrect level is displayed to the ATCO is or is not within close vertical proximity to terrain or another aircraft – applicable to OH11 and OH12 (See OSA-ASSUMP.63 in [Ref.1]).*

10.4.4.1 Safety Requirements and Assumptions on Transmitting Aircraft Domain Elements

In the Transmitting Aircraft Domain, only the flight crew is involved in the detection and recovery of ADS-B-RAD hazards.

10.4.4.1.1 Flight Crew related Safety Requirements and Assumptions

Addressing	Safety Requirement or Assumption	OH	RAD-x
Flight Crew	**A041.** It is assumed that the Flight Crew is able to report an emergency to the ATCO, given that the emergency does not entail a radio communication failure or unlawful interference, 99% of the time (See OSA-ASSUMP.21 in [Ref.1]).	OH07, OH08	All
Procedures	**SAF071.** Flight Crew (and ATCO) shall apply altitude verification procedures (See OSA-ASSUMP.48 in [Ref.1]).	OH11, OH12	All

Table 37: List of Flight Crew related Safety Requirements and Assumptions (Event Tree)

10.4.4.2 Safety Requirements and Assumptions on Ground Domain Elements

At the ground domain level, a number of human and technical elements are involved in the detection and recovery of hazards.

10.4.4.2.1 Air Traffic Controller related Safety Requirements and Assumptions

Addressing	Safety Requirement or Assumption	OH	RAD-x
	SAF072. The ATCo shall apply appropriate alternate separation minima when radar position is displayed (i.e. in case of loss or degradation of ADS-B position) for a single or multiple aircraft (See OSA-ASSUMP.30, 31, 36, 37, 39, 40, 42, 43 in [Ref.1]). *Note: See more explanation below the table.* *Note: It also applies to a loss of all ADS-B data.*	Single case: OH01, OH03, OH05 Multiple case: OH02, OH04, OH06, OH10	All
	SAF073. The ATCo shall apply alternate procedures and separation minima immediately in the event of a loss of all surveillance (ADS-B and radar) for a single aircraft or multiple aircraft (See OSA-ASSUMP.29 in [Ref.1])). *Note: alternate procedures and minima are the same as in the Reference system.*	All	All
	SAF074. The ATCo shall use pilot reports to determine altitude per ICAO Doc 4444 PANS-ATM and shall record the pilot reported altitude in case of total loss of altitude (See barrier XXVIII in table C-78 and in table C-82 in [Ref.1]).	OH13, OH14	All
	SAF075. The ATCO shall follow local procedures to identify false targets versus intruders (See OSA-ASSUMP.56 in [Ref.1]). *Note: false targets and intruders are defined in a separate note following the table.* *Note: these local procedures are the same as applied today in the Reference system.*	OH19, OH20	All
	SAF076. The ATCO shall follow procedures to respond to confirmed false targets, including reporting the anomaly to an air traffic supervisor and system technical support (See OSA-ASSUMP.60 in [Ref.1]). *Note: these local procedures are the same as applied today in the Reference system.*	OH19, OH20	All

Addressing	Safety Requirement or Assumption	OH	RAD-x
ATCO performance	**A042.** It is assumed that the ATCO will always detect that a loss of ADS position data has occurred when an indication is presented on the ATCO interface for the affected aircraft (See OSA-ASSUMP.06 in [Ref.1]).	OH01, OH02, OH03, OH04	All
	A043. It is assumed that the ATCO detects the ADS-B false target 99% of the time, in an environment with PSR (See OSA-ASSUMP.26 in [Ref.1]).	OH19, OH20	RAD-1, RAD-3
	A044. It is assumed that the ATCO will always detect a lack of Flight Crew response when the ATCO attempts to communicate using an "incorrect" aircraft ID (See OSA-ASSUMP.53 in [Ref.1]).	OH15, OH16 case 1	All

Table 38: List of ATCo related Safety Requirements and Assumptions (Event Tree)

Note: An intruder refers to an aircraft without approval or clearance for operations on the ADS-B-RAD sector (and thus not on ATC frequency). A false target corresponds to an aircraft which does not physically exist at the location depicted on the ATCo interface.

*Note related to **SAF072**: There are different ways of applying alternate separation minima. In Europe the application of alternate separation minima (after the display of SSR position information) was analyzed in [Ref.1] for completeness, using two different variations:*

1. *Alternate minima being applied immediately ,*
2. *Alternate minima being applied gradually over time.*

The analysis in [Ref.1] found that in the case 1 safety objectives were very difficult to meet and further investigation with ANSPs in Europe showed that case 1 was not consistent with real practice.

*Therefore in this PSC, only case 2 is further considered in case of application of alternate separation minima (**L004**).*

10.4.4.2.2 ADS-B-RAD ATC Processing and Display Function related Safety Requirements and Assumptions

As shown in the Logical Model and as described in section 7.3.4.2, the ADS-B-RAD ATC Processing and Display function encompasses the following functions:

- Ground ADS-B Surveillance processing function.
- ADS-B to Radar Association function.
- Existing ATC Processing and Display function.

As the ADS-B-RAD logical design does not assume the presence of a fusion style tracking system, "ADS-B to Radar Association" is a new function compared to the Reference logical design. The objectives of this function are mainly derived from ADS-B failure conditions and are provided below:

1. To permit a wide area coverage switch to occur from ADS-B to radar surveillance information without requiring the controller to perform a re-identification or re-verification of altitude.

   a) For scenario RAD 2 & RAD 3, for individual aircraft, to permit the automatic display of radar data if position, identification or pressure altitude is not available via ADS-B.

   b) For scenario RAD 1, for individual aircraft, to permit the maintenance of identification of data when it is not available via ADS-B.

2. To present two individual tracks, each from the surveillance sources of radar and ADS-B, where operationally significant position errors have been detected between them and the ground system is unable to determine which position source is the correct one to be displayed.

   Note: the RAD 1 scenario assumes the PSR surveillance position data is already maintained on the display in the non-nominal case where ADS-B position data is not available regardless if PSR data is presented in a combined or individual technique as detailed in Annex H .

> **GM062.** Implementers should make explicit the mechanics surrounding their ADS-B to radar association function when considering the detailed display technique they apply – see GM021.

3. To present an alert to the controller in the case where two different emergency codes/modes are detected by the system for the same aircraft.

   Note: In relation to point 1 above, no assumptions are made with regards to the mechanics surrounding the switch itself (e.g. how much *automation is involved or whether it is a function available to the controller directly or not to choose the surveillance source for their display). This is a design consideration for the implementer.*

GM063. Implementers should make explicit the mechanics surrounding the switch and ensure the appropriate requirements are derived.

Note: In relation to point 2 above the automatic display of radar data also implies maintenance of identification data on the display for the RAD1 scenario where the backup is a PSR.

GM064. Implementers should make explicit the mechanics for the maintenance of identification data for the RAD1 scenario where the back-up is a PSR and ensure the appropriate requirements are derived.

Note: In relation to point 4 the term 'modes' refers to the ADS-B squitter register whereas 'codes' refers the Mode A emergency equivalent.

Safety requirements that have been defined during the event tree analysis, concern the **detection** of a loss of ADS-B data or of an inconsistency between ADS-B and radar data and the provision of a **notification** of this detection to the controller and/or in some cases the switch to the equivalent radar data:

- For inconsistency in horizontal position, pressure altitude and aircraft identity, the notification takes the form of a split track.
- For loss of ADS-B horizontal position, the controller needs to be notified (e.g. coasting function) before the radar horizontal position is displayed.
- For loss of other ADS-B data, the replacement by radar occurs without any notification to the controller.

As per the logical model, these safety requirements have been derived on the ADS-B-RAD ATC Processing and Display function (from interface E2 up to the ATCo interface (G2)).

Moreover, as indicated in [Ref.1] the detection of a loss of ADS-B data item can also be performed by the Ground ADS-B receive function, this latter is therefore considered in SAF077, SAF083 and SAF086.

Addressing	Safety Requirement	OH	RAD-x
	SAF077. The Ground ADS-B receive function and the ADS-B-RAD ATC Processing and Display function shall detect a loss or degradation of ADS-B horizontal position quality below the required threshold for a specific or multiple aircraft and provide an indication of such to the controller with a probability of at least 99.99% (SPR 40, ASSUMP 44 in [Ref.1] *Note: This should be implemented in the same way as in the Reference system, e.g. a coasting function – see GM065.*	OH01, OH02, OH03, OH04	All
	SAF078. In case of loss or degradation of ADS-B horizontal position quality below the required threshold for a single or multiple aircraft after the notification to the controller (as per SAF077), the ADS-B-RAD ATC Processing and Display function shall automatically provide the corresponding SSR radar data item to the controller. (SPR 32 in [Ref.1])	OH01, OH02, OH03, OH04	RAD-2 and RAD-3
	SAF079. In case of loss of ADS-B data AND radar data for a specific or multiple aircraft, the ADS-B-RAD ATC Processing and Display function shall provide a notification to the controller. *Note: This should be implemented in the same way as in the Reference system, e.g. a coasting function – see GM065.*	OH01, OH02, OH03, OH04	All
	SAF080. In the case the ADS-B horizontal position is no more available for a single or multiple aircraft, the ADS-B-RAD ATC Processing and Display Processing function shall provide the PSR horizontal position to the controller.	OH01, OH02, OH3, OH4	RAD-1
Horizontal position	**SAF081.** The ADS-B–RAD ATC Processing and Display function shall detect a “large” difference in horizontal position information between ADS-B and radar and provide separate system tracks to the controller for each source, with a probability of at least 99% (SPR 46 and ASSUMP 43 in [Ref.1]). *Note: See A020 for the definition of “large” values.* *Note: Only the ADS-B label will include the call sign (the radar label will present the raw aircraft identity (e.g. mode A code)).* *Note: the detection is performed at the level of the “ADS-B-to-radar association” function.*	OH05, OH6	All

Addressing	Safety Requirement	OH	RAD-x
	SAF082. The ADS-B–RAD ATC Processing and Display function shall detect a "significant" difference in horizontal position information between ADS-B and radar and provide separate system tracks to the controller for each source, with a probability of at least 90% (SPR 47 and ASSUMP 43 in [Ref.1]) *Note: See A020 for the definition of "significant" values.* *Note: the detection is performed at the level of the ADS-B-to-radar association function.* *Note: Only the ADS-B label will include the call sign (the radar label will present the raw aircraft identity (e.g. mode A code)).*	OH05, OH6	All
Pressure Altitude	**SAF083.** The Ground ADS-B receive function and the ADS-B-RAD ATC processing and Display function shall detect a loss of ADS-B-reported altitude and provide the corresponding SSR-reported altitude to the controller with a probability of at least 99%. (SPR 32, SPR 41, ASSUMP 46 in [Ref.1]) *Note: this detection can either be performed by the existing ATC Processing and Display function or by the ADS-B Ground domain.* *Note: the re-verification of altitude data by the ATCo is not required as the ADS-B-to-radar association function compares both ADS-B and SSR altitudes.* *Note: see GM066 below*	OH13, OH14, OH03, OH04	RAD-2 and RAD-3
	SAF084. The ADS-B–RAD ATC Processing and Display function shall detect an inconsistency of more than 500 ft between radar and ADS-B pressure altitude, and provide an indication of such to the controller with a probability of at least 99%. (SPR 48, SPR 44, ASSUMP 48 in [Ref.1]) *Note: It was assumed for analysis purposes that the notification is a split track.* *Note: the detection is performed at the level of the ADS-B-to-radar association function*	OH11, OH12	RAD-2 and RAD-3

Addressing	Safety Requirement	OH	RAD-x
Emergency indications	**SAF085.** The ADS-B-RAD ATC Processing and Display function shall detect an inconsistency between ADS-B- and radar-reported emergency codes, and provide an indication of such to the controller with a probability of at least 99%. (SPR 42, ASSUMP 37 in [Ref.1]) *Note: the detection is performed at the level of the ADS-B-to-radar Association function.* *Note: this is also applicable for the loss of ADS-B emergency code*	OH07, OH08	RAD-2 and RAD-3
Identity data	**SAF086.** The Ground ADS-B receive function and the ADS-B-RAD ATC processing and Display function shall detect a loss of ADS-B aircraft identity and provide the same SSR aircraft identity to the controller with a probability of at least 99.99% (SPR 32, See ASSUMP 41 in [Ref.1]). *Note: the re-identification by the ATCo is not required as the ADS-B-to-radar association function compares both ADS-B and SSR aircraft identities.* *Note: « same » to be understood as if correlation was performed before the loss, then correlation is also performed after.* *Note: see GM066 below*	OH17, OH18, OH03, OH04	RAD-2 and RAD-3
	SAF087. The ADS-B-RAD ATC processing and Display function shall detect a loss of ADS-B aircraft identity and continue to display the previously displayed aircraft identity temporarily until the controller is able to manually correlate (see SAF088) with a probability of at least 99% (See ASSUMP 40 in [Ref.1])	OH17, OH18, OH03, OH04	RAD-1
	SAF088. The ADS-B-RAD ATC Processing and Display function shall provide an access to the controller through the ATCo interface to manually enter identification for affected aircraft in the event the aircraft identity is no more available (ENV-ASSUMP-33 and -30 [Ref.1]).	OH17, OH18, OH03, OH04	RAD-1
	SAF089. In the event that the aircraft identity maintenance as expressed in SAF087 (ASSUMP 40 in [Ref.1]) and SAF086 (ASSUMP 41 in [Ref.1]) fails, and both ADS-B- and radar-reported aircraft identity data are no longer available to the display processing, the ADS-B-RAD ATC processing and Display function shall remove it from the displayed target label within one refresh cycle. (See ASSUMP 42 in [Ref.1])	OH17, OH18, OH03, OH04	RAD-2 and RAD-3

Addressing	Safety Requirement	OH	RAD-x
	SAF090. The ADS-B-RAD ATC Processing and Display function shall detect of an inconsistency between radar an ADS-B Identity data (i.e. Mode A or aircraft identification) and provide separate system tracks to the controller for each source, with a probability of least 99%. (SPR 43, ASSUMP 38 in [Ref.1]) *Note: the detection is performed at the level of the ADS-B-to-radar association function.* *Note: Only the ADS-B label will include the call sign (the radar label will present the raw aircraft identity (e.g. mode A code)).*	OH15, OH16	RAD-2 and RAD-3
	SAF091. The ADS-B-RAD ATC processing and Display function shall detect duplicate ADS-B Aircraft Identities (i.e. discrete Mode A or aircraft ID) within the same sector and provide an indication of such to the controller with a probability of at least 99%. (SPR 45, ASSUMP 39 in [Ref.1])	OH15, OH16	RAD-2 and RAD-3

Table 39: List of the ADS-B-RAD ATC Processing and Display Function related Safety Requirements (Event Tree)

If the coasting function is not used (see **SAF077** and **SAF079**), the following guidance applies:

GM065. Implementer should ensure that Human Factors are taken into account concerning the operational management of quality indicators by the controllers. See also "Guidance for the Provision of Air Traffic Services Using ADS-B in Radar Airspace" [Ref.20].

Clarification regarding **SAF083** and **SAF086**:

In this PSC, SAF083 and SAF086 mean that the loss of individual ADS-B data item results in the display of the corresponding radar data item.

GM066. Implementers should assess the impact of displaying the whole radar data in case of the loss of individual ADS-B data item (other than position) and in particular, the fact that this would imply the application of alternate separation minima.

GM067. For SAF081, SAF082, SAF084, SAF090, the notification is a split track. Implementers selecting an alternate means of notifying ATCO of inconsistency between ADS-B and radar need to conduct their own assessment.

10.4.4.2.3 Radar Surveillance related Assumptions

Both the availability and non-availability of radar at the time of the ADS-B fault have been considered in the effects analysis of hazards (through event trees).

On the other hand the undetected radar failure (such as erroneous position, etc.) has not been considered at the same time as an ADS-B failure as it was assumed that the occurrence of both failures would be very small and thus insignificant:

It is assumed that the likelihood for the PSR, SSR and Mode S radars failures are the following:

Addressing	Assumption	OH	RAD-x
Radar Surveillance function	**A045.** The inherent availability of the Primary Surveillance Radar is assumed to be at least 99.7% (see OSA-ASSUMP.32 of [Ref.1]).	All	RAD-1 and RAD-3
	A046. It is assumed that the inherent availability of the Secondary Surveillance Radar is at least 99.9% (see OSA-ASSUMP.33 of [Ref.1]	All	RAD-2 and RAD-3
	A047. The probability that an undetected radar fault occurs at the same time as an ADS-B fault is considered to be very small and therefore insignificant (see also OSA-ASSUMP.05 and §3.1.3 of [Ref.1]).	All	All

Table 40: List of the “Radar Surveillance” Function related Assumptions (Event Tree)

10.5 SAFETY OBJECTIVES DETERMINATION (ARG 2.2.4.3)

As stated before, ADS-B-RAD operational hazards (OH) have been identified at the output of the ATC display system function (interface G2) and only address the ADS-B aspects of the system considered.

Safety Objectives per ADS-B-RAD hazard are calculated based on the Safety Targets (STRADi) per severity class per flight.hour presented in Annex F of this present document for each ADS-B-RAD scenario (environment)[59], on the probability of effects (Pei) and on the number of ADS-B-RAD system hazards (NRADi) determined during the event tree analysis (as provided in next Table 41, based on the results presented in Table 42), as shown in the following formula (where i represents the severity class) (see more detail in section §C.2.2.2.4 of [Ref.1]):

$$SOi = \frac{ST_{RADi}}{Pei * N_{RADi}}$$

For implementers, they should use the values corresponding to their own environment and local "RAD scenario".

Severity	Nmax	N_{RADi}		
		RAD-1	RAD-2	RAD-3
1	2	3	3	3
2	25	6	4	4
3	25	5	7	7
4	73	7	7	8
Total	**125**	**21**	**21**	**22**

Table 41: ADS-B-RAD Hazards Distribution Towards Severity Classes

[59] Safety Targets presented in section 5.2 and in section 10.1 have been rounded to present one set applicable to all ADS-B-RAD scenarios / environments. Annex F presents the detailed Safety Targets values on a per ADS-B-RAD scenario basis.

Note that the number of hazards presented above differs from [Ref.1], see Annex F section F.2 the corresponding explanation.

Note: Only the “most demanding severity” is shown in this table for each hazard, corresponding to the one from which the most stringent safety objective has been derived. For example, the highest severity assigned to OH01 in the event tree is 1 (see figure C-9 in [Ref.1]), but the most demanding one is in fact 4, as this is from this latter severity that the most stringent safety objective is derived for OH01 (and is equal to 4.67e-3 per flight hour, see table C-21 in [Ref.1]).

Next table provides also a summary of all the identified hazards for ADS-B-RAD, and for each of the three ADS-B-RAD scenarios (RAD-1, RAD-2a/2b and RAD-3) based on the results of [Ref.1] that were adapted to reflect limitation **L004** (this PSC is limited to the application of gradual alternate separation minima in case of loss of ADS-B data where SSR data are displayed): the most demanding effects, the corresponding severities together with the calculated Pe, and the Environmental Conditions (EC) and External Mitigation Means (EMM) taken into account.

In the third column related to the ADS-B-RAD scenario (RAD-1, RAD-2a/2b, RAD-3) in the following table, the roman numerals into brackets refer to the specific event-tree path, in [Ref.1], that corresponds to the most stringent safety objectives for each concerned environment (i.e. the most critical path). The rows highlighted in grey correspond to the most stringent ADS-B-RAD scenario amongst RAD-1, RAD-2a/2b and RAD-3, which were used during the fault tree analysis in [Ref.1].

Meanwhile in the next steps of the safety assessment (i.e. the safety objective allocation and safety requirements definition activity) only one Safety Objective has been retained, corresponding to the most stringent one amongst the three environments. Indeed the evidence provided in this PSC is derived from [Ref.1], which objective is mainly to obtain the most stringent aircraft and ground requirements derived from the several environments assessed.

GM068. Implementers could select Safety Objectives corresponding to their own local environment, which could relax some safety requirements on ground systems.

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
OH01	Sudden and Unexpected Loss of ADS-B Position Information for a *Single* Aircraft	RAD-1 (XII)	Slight increase in controller's and Flight Crews' workload to implement alternate ATC procedures and procedural separation following a loss of both ADS-B and PSR radar for one aircraft as well as alternate separation minima for the other aircraft following a complete loss of PSR radar surveillance.	4	3.00e-3	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, A045, A047, SAF073	4.67e-3
		RAD-2a/2b (IX and XIII)	- Slight reduction in safety margins given that alternate separation minima should have been applied but were not because of the non detection of the hazard (scenario IX). - Slight increase in controller's and Flight Crews' workload to implement alternate ATC procedures and minima immediately for all aircraft following a loss of radar surveillance (scenario XIII).	4	1.00e-4	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, A046, A047, SAF073	1.40e-1
		RAD-3 (IX and XIII)	As above	4	1.00e-4	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, A045, A046, A047, SAF073	1.40e-1
OH02	Sudden and Unexpected Loss of ADS-B Position Information for *Multiple* Aircraft	RAD-1 (XIII)	Detected loss of all surveillance (both ADS-B and PSR radar) for multiple aircraft credibly leading to a large reduction in separation.	2	2.97e-3	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, A045, A047, SAF073	1.35e-5
		RAD-2a/2b (VIII)	Significant increase in ATC workload to gradually apply alternate separation minima, though ID correlation is maintained.	4	9.989e-1	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, A046, A047, SAF073	1.40e-5
		RAD3 (VIII)	As above	4	9.989e-1	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, A045, A046, A047, SAF073	1.40e-5

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
OH03	Loss of All ADS-B Data for a *Single* Aircraft	RAD-1 (XIV)	Slight increase in controller's and Flight Crews' workload to implement alternate ATC procedures and procedural separation following a loss of both ADS-B and PSR radar for one aircraft as well as alternate separation minima for the other aircraft following a complete loss of PSR radar surveillance.	4	3.00e-3	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, SAF083, SAF086, SAF087, SAF088, SAF089, A045, A047, SAF073	4.67e-3
		RAD-2a/2b (V)	Detected loss of all surveillance data for single aircraft given common avionics failure between ADS-B and radar transponders; slight reduction in separation and reduction in ATC capability.	4	9.999e-1	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, SAF083, SAF086, SAF087, SAF088, SAF089, A046, A047, SAF073	1.4e-5[60]
		RAD-3 (XIV)	Slight increase in controller and Flight Crew workload to implement alternate ATC procedure and minima immediately.	4	3.00e-3	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, SAF083, SAF086, SAF087, SAF088, SAF089, A045, A046, A047, SAF073	4.67e-3
	Loss of All ADS-B Data for *Multiple* Aircraft	RAD-1 (XIII)	Detected loss of all surveillance for multiple aircraft credibly leading to a large reduction in separation.	2	2.97e-3	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, SAF083, SAF086, SAF087, SAF088, SAF089, A045, A047, SAF073	1.35e-5

[60] Note: OH01 and OH03 have different severities and safety objectives in RAD2a/RAD2b environments as for OH03 it is assumed a common avionics failure between ADS-B and radar transponders leading to a loss of all surveillance information for that aircraft with more severe effects.

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
OH04		RAD-2a/2b (VIII)	Significant increase in ATC workload to gradually apply alternate separation minima, though ID correlation is maintained.	4	9.989e-1	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, SAF083, SAF086, SAF087, SAF088, SAF089, A046, A047, SAF073	1.40e-5
		RAD-3 (VIII)	As above	4	9.989e-1	A025, SAF072, A042, SAF077, SAF078, SAF079, SAF080, SAF083, SAF086, SAF087, SAF088, SAF089, A045, A046, A047, SAF073	1.40e-5
OH05-1	Horizontal position error resulting from a GNSS position source error not detected by the aircraft integrity monitoring for a *Single* Aircraft	RAD-1 (III)	Significant ATCO workload increase to respond to detected hazard due to significant position error. ATCO will coordinate with Flight Crew to determine if navigation failure / error exists and may ask Flight Crew to cease ADS-B transmission if unable to filter on ground. ATCO will rely on PSR returns only and must re-identify, manually correlate, and apply alternate separation standard.	4	8.97e-4	A020, A021, A023, A027, A028, A029, A035, SAF072, SAF081, SAF082, A045, A047, SAF073	1.56e-2
		RAD-2a/2b (VI)	Significant ATCO workload increase to respond to detected hazard due to significant position error. ATCO will rely on radar to filter/remove ADS-B data, re-identify the aircraft, and potentially apply an alternate separation standard.	4	9.00e-4	A020, A021, A023, A027, A028, A029, A035, SAF072, SAF081, SAF082, A046, A047, SAF073	1.56e-2
		RAD-3 (VI)	As above	4	9.00e-4	A020, A021, A023, A027, A028, A029, A035, SAF072, SAF081, SAF082, A045, A046, A047, SAF073	1.56e-2
	Horizontal position error resulting	RAD-1 (X)	Large reduction in separation due to the non detection by the ground system of a large position error.	2	9.08e-3	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A045, A047, SAF073	4.40e-6

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
OH05-2	from a sustained credible corruption of the position information for a *Single* Aircraft	RAD-2a/2b (XIII)	As above	2	9.08e-3	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A046, A047, SAF073	4.40e-6
		RAD-3 (XIII)	As above	2	9.08e-3	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A045, A046, A047, SAF073	4.40e-6
OH05- 3	Horizontal position error resulting from a sustained credible corruption of the quality indicator for a *Single* Aircraft	RAD-1 (X)	Large reduction in separation due to the non detection by the ground system of a large position error.	2	9.08e-3	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A045, A047, SAF073	4.40e-6
		RAD-2a/2b (XIII)	As above	2	9.11e-3	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A046, A047, SAF073	4.39e-6
		RAD-3 (XIII)	As above	2	9.11e-3	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A045, A046, A047, SAF073	4.39e-6
OH06-1	Horizontal position error resulting from a GNSS position source error not detected by the aircraft integrity monitoring for *Multiple* Aircraft	RAD-1(III)	Significant reduction in ATC capability. Significant ATCO workload increase to respond to detected hazard of a significant error. ATCO may ask Flight Crew to cease ADS-B transmission if unable to filter on ground. ATCO will rely on PSR returns only and must re-identify, manually correlate, and apply alternate separation standard.	3	8.97-4	A020, A021, A023, A027, A028, A029, A035, SAF081, SAF082, A045, A047, SAF073	4.46e-4
		RAD-2a/2b (VI)	Significant reduction in ATC capability. Significant ATCO workload increase to respond to detected hazard of a significant error. ATCO will rely on radar to filter/remove ADS-B data, re-identify the aircraft, and potentially apply an alternate separation standard.	3	9.00e-4	A020, A021, A023, A027, A028, A029, A035, SAF081, SAF082, A046, A047, SAF073	4.44e-4

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
		RAD-3 (VI)	As above	3	9.00e-4	A020, A021, A023, A027, A028, A029, A035, SAF081, SAF082, A045, A046, A047, SAF073	4.44e-4
OH06-2	Horizontal position error resulting from a sustained credible corruption of the position information for *Multiple* Aircraft	RAD-1 (IX)	Significant reduction in ATC capability. Significant ATCO workload increase to respond to detected hazard of a large position error. ATCO will rely on radar to filter/remove ADS-B data, re-identify the aircraft, and potentially apply an alternate separation standard.	3	9.08e-1	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A045, A047, SAF073	4.40e-7
		RAD-2a/2b (XII)	As above	3	9.11e-1	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A046, A047, SAF073	4.39e-7
		RAD-3 (XII)	As above	3	9.11e-1	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A045, A046, A047, SAF073	4.39e-7
OH06-3	Horizontal position error resulting from a sustained credible corruption of the quality indicator for *Multiple* Aircraft	RAD-1 (IX)	Significant reduction in ATC capability. Significant ATCO workload increase to respond to detected hazard of a large position error. ATCO will rely on radar to filter/remove ADS-B data, re-identify the aircraft, and potentially apply an alternate separation standard.	3	9.08e-1	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A045, A047, SAF073	4.40e-7
		RAD-2a/2b (XII)	As above	3	9.11e-1	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A046, A047, SAF073	4.39e-7
		RAD-3 (XII)	As above	3	9.11e-1	A020, A021, A022, A027, A028, A029, A035, SAF081, SAF082, A045, A046, A047, SAF073	4.39e-7

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
OH07	Loss of Emergency Mode after Selection by Flight Crew	RAD-1 (III)	Hazard not detected; possible collision or flight into terrain. Lack of ATCO assistance due to ADS-B failure contributes to severity. Note 12: Scenario is equivalent to existing system today, where SSR (in a combined SSR / PSR environment) may fail to provide emergency mode.	1	9.87e-3	A024, A026, A041, SAF085, A045, A047, SAF073	5.1e-8
		RAD-2a/2b (IX)	Hazard not detected in case radar unavailable and Flight Crew unable to report the emergency to ATCO; possible collision or flight into terrain. Lack of ATCO assistance due to ADS-B failure contributes to severity.	1	1.00e-2	A024, A026, A041, SAF085, A046, A047, SAF073	5.0e-8[61]
		RAD-3 (IX)	Same as above	1	1.00e-2	A024, A026, A041, SAF085, A045, A046, A047, SAF073	5.0e-8[61]
OH08	Incorrect but Plausible Emergency Mode	RAD-1 (III)	Significant reduction in safety margins and ATC capability. Inappropriate emergency response services may be initiated given that ATCO responds to displayed emergency mode which is incorrect. *Note: Scenario is equivalent to existing system today, where SSR (in a combined SSR / PSR environment) may fail to provide emergency mode.*	3	1.00e-2	A024, A026, A041, SAF085, A045, A047, SAF073	4.00e-5
		RAD-2a/2b (XII)	Same as above, but Pe different because of the combination of the ADS-B-to-radar association function.	1	1.00e-4	A024, A026, A041, SAF085, A046, A047, SAF073	5.00e-4

[61] This value differs between this PSC and [Ref.1] as the grouping of severity 1hazards hasn't been retained in this PSC – see more explanation in Annex F section F.3

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
		RAD-3 (XII)	Same as above, but Pe different because of the combination of the ADS-B-to-radar association function.	1	1.00e-4	A024, A026, A041, SAF085, A045, A046, A047, SAF073	5.00e-4
OH09	Two 'Dispersed' Position Symbols for the *Same* Aircraft	RAD-1	No impact	5	-		
		RAD-2a/2b	No impact	5	-		
		RAD-3	Significant impact on ATCo workload, and slight increase in Flight Crew workload.	4	1	N/A	1.40e-5
OH10	Mul*t*iple 'Dispersed' Position Symbols	RAD-1	Significant reduction in ATC capability due to the application of larger separation standard	3	0.1	A038, SAF072, A045, A047, SAF073	4e-6
		RAD-2a/2b	As above	3	0.1	A038, SAF072, A046, A047, SAF073	4e-6
		RAD-3	As above	3	0.1	A038, SAF072, A045, A046, A047, SAF073	4e-6
OH11	Incorrect Level Information for a *Single* Aircraft	RAD-1 (V)	Potential large reduction in separation given the error is more than 500ft and is not detected by ATCO (nor by radar because PSR).	2	9.41e-4	A030, A031, A034, A036, A037, SAF071, SAF084, A045, A047, SAF073	4.25e-5
		RAD-2a/2b (XVI)	Potential large reduction in separation given the error is between 200ft and 500ft (thus not detected by radar) and is not detected by ATCO.	2	2.91e-4	A030, A031, A034, A036, A037, SAF071, SAF084, A046, A047, SAF073	1.37e-4
		RAD-3 (XVI)	As above	2	2.91e-4	A030, A031, A034, A036, A037, SAF071, SAF084, A045, A046, A047, SAF073	1.37e-4
OH12	Incorrect Level Information for Mul*t*iple Aircraft	RAD-1 (V)	Potential large reduction in separation given the error is more than 500ft and is not detected by ATCO (nor by radar because PSR).	2	9.41e-4	Same as OH11, RAD-1	4.25e-5

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
		RAD-2a/2b (XVI)	Potential large reduction in separation given the error is between 200ft and 500ft (thus not detected by radar) and is not detected by ATCO.	2	2.91e-4	Same as OH11, RAD-2	1.37e-4
		RAD-3 (XVI)	As above	2	2.91e-4	Same as OH11, RAD-3	1.37e-4
OH13	Loss of Level Information for *Single* Aircraft	RAD-1	Slight ATCO increase to initiate PANS ATM procedures associated with non-verified altitude.	5	-	SAF074, SAF083, A045, A047, SAF073	-
		RAD-2a/2b	Slight ATCO increase to initiate PANS ATM procedures associated with non-verified altitude in case of loss Level information from both sources (ADS-B and radar).	5	-	SAF074, SAF083, A046, A047, SAF073	-
		RAD-3	As above	5	-	SAF074, SAF083, A045, A046, A047, SAF073	-
OH14	Loss of Level Information for *Multiple* Aircraft	RAD-1 (I)	Significant ATCo workload increase to initiate PANS ATM procedures associated with non-verified altitude for multiple aircraft.	4	1	Same as OH13, RAD-1	1.40e-5
		RAD-2a/2b (III)	Significant ATCO increase to initiate PANS ATM procedures associated with non-verified altitude in case of loss Level information coming from both sources (ADS-B and radar) for multiple aircraft.	4	1.00e-2	Same as OH13, RAD-2	1.40e-3
		RAD-3 (IV)	As above	4	1.00e-4	Same as OH13, RAD-3	1.40e-1

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
OH15	Incorrect Identity data for a *Single* Aircraft	RAD-1 (IV)	Total loss of separation in case of plausible ID which is not detected by ATC and which matches an ID of an aircraft in the sector who follows an ATC instruction and converges towards another aircraft or into terrain.	1	5.00e-7	A032, A033, A039, A044, SAF090, SAF091, A045, A047, SAF073	1.00e-03[62]
		RAD-2a/2b (X)	As above	1	5.00e-9	A032, A033, A039, A044, SAF090, SAF091, A045, A047, SAF073	1.00e-1
		RAD-3 (X)	As above	1	5.00e-9	A032, A033, A039, A044, SAF090, SAF091, A045, A046, A047, SAF073	1.00e-1
OH16-1	Incorrect Identity data for *Multiple* Aircraft **Case 1: ID corruption**	RAD-1 (I)	Significant increase in ATCo workload given multiple aircraft.	4	9.95e-2[63]	Same as OH15 in addition to A040, RAD-1	1.41e-4
		RAD-2a/2b (VI)	Significant reduction in ATC capability given environment and resulting significant increase in ATCo workload given multiple aircraft.	3	9.90e-2[63]	Same as OH15 in addition to A040, RAD-2	4.04e-6
		RAD-3 (VI)	As above	3	9.90e-2[63]	Same as OH15 in addition to A040, RAD-3	4.04e-6
OH16-2	Incorrect Identity data for *Multiple* Aircraft **Case 2: Swap ID**	RAD-1 (I)	Total loss of separation	1	1e-4[63]	A033, A040, SAF090, SAF091, A045, A047, SAF073	5.0e-6
		RAD-2a/2b (III)	Significant reduction in safety margins given environment; significant increase in ATCo workload given multiple aircraft.	3	9.90e-2[63]	A033, A040, SAF090, SAF091, A046, A047, SAF073	4.04e-6
		RAD-3 (III)	As above	3	9.90e-2[63]	A033, A040, A040, SAF090, SAF091, A045, A046, A047, SAF073	4.04e-6

[62] This value differs between this PSC and [Ref.1] as the grouping of severity 1hazards hasn't been retained in this PSC – see more explanation in Annex F section F.3

[63] Accounts for A040, as described in § C.5.16.5 in [Ref.1], but which was not reflected in tables C-91 and C-92 of that standard.

OH	OH description	RAD-x (*Most demanding path*)	Most demanding Effects	Sev	Pe	EMM / EC	SO [per flight.hour]
OH17	Loss of Identity data for a *Single* Aircraft	RAD-1	Slight increase in ATCo workload to issue Mode A code and re-identify single aircraft.	5	-	SAF086, SAF087, SAF088, SAF089, A045, A047, SAF073	-
		RAD-2a/2b	N/A	5	-	SAF086, SAF087, SAF088, SAF089, A046, A047, SAF073	-
		RAD-3	N/A	5	-	SAF086, SAF087, SAF088, SAF089, A045, A046, A047, SAF073	-
OH18	Loss of Identity data for *Multiple* Aircraft	RAD-1 (I)	Significant increase in ATCo workload to manually correlate ID for multiple aircraft.	4	1	SAF086, SAF087, SAF088, SAF089, A045, A047, SAF073	1.40e-5
		RAD-2a/2b (III)	Excessive ATCo workload increase to issue Mode A code and re-identify multiple aircraft (as it is combined with a failure of the ground system to maintain identity in the track label).	3	1e-1	SAF086, SAF087, SAF088, SAF089, A046, A047, SAF073	4.00e-6
		RAD-3 (III)	As above	3	1e-1	SAF086, SAF087, SAF088, SAF089, A045, A046, A047, SAF073	4.00e-6
OH19	*Single* False Target	RAD-1	Slight increase in ATCo workload	5	-	SAF075, SAF076, A043, A045, A047, SAF073	-
		RAD-2a/2b	Slight increase in ATCo workload	5	-	SAF075, SAF076, A043, A046, A047, SAF073	-
		RAD-3	Slight increase in ATCo workload	5	-	SAF075, SAF076, A043, A045, A046, A047, SAF073	-
OH20	*Multiple* False Targets	RAD-1 (I)	Significant increase in ATCo workload	4	9.87e-1	Same as OH19, RAD-1	1.42e-5
		RAD-2a/2b (IV)	Significant increase in ATCo workload	4	1	Same as OH19, RAD-2	1.40e-5
		RAD-3 (VI)	Significant increase in ATCo workload	4	9.9e-1	Same as OH19, RAD-3	1.41e-5

Table 42: ADS-B-RAD Hazards Effects, Severity, Pe and EMM & EC and SO for all Hazards

10.6 HAZARDS CAUSES IDENTIFICATION AND INTERNAL MITIGATION MEANS (ARG 2.2.4.4)

Once the Safety Objective (SO) has been determined for each hazard, further analysis has been performed to identify all the potential causes leading to these hazards, in order to be able to allocate the SO over the different elements having an impact upon the hazard occurrence.

10.6.1 Hazards Causes

The fault tree analysis performed in [Ref.1] (ASOR in § Annex C) identified the possible causes (called Basic Causes - BC) and combinations of causes leading to each of the hazards mentioned in previous sections. Common mode failures have also been considered during this process.

A fault tree for each individual hazard is presented in a specific sub-section of the corresponding hazard assessment section in [Ref.1] (e.g. §C.5.2.4 for OH2 fault tree). This sub-section also lists the basic causes included in the corresponding fault tree (e.g. table C-26 for the same hazard example).

These basic causes have been determined at functional CNS/ATM system components level, i.e. ground domain, airborne domain, and some subsystems as presented in previous Figure 14.

This PSC does not cover radar failures when ADS-B is working correctly (L005). Therefore basic causes related to radar-only failures are not part of the assessment.

In this Figure 14 aircraft ADS-B and SSR Transponder functions are drawn as separate functions, but it is recognised that these are likely to be implemented in the same physical “box”. Consequently the worst case continuity failure is considered (i.e., assume ADS-B and radar transponder functions are both lost).

More explanation concerning these functions has already been provided in section 7.3.4.

Note: During the research of the causes (ASOR), for hazards impacting multiple aircraft simultaneously, it was conservatively assumed that the simultaneous failure affecting two (2) aircraft could lead to these hazards.

Note that failures of certain systems external to the ADS-B-RAD, such as GNSS constellation failure leading to the identified hazards have also been considered in the ASOR.

Some typical examples of basic causes for the same hazard example are listed below:

ADS-B FCN INTG: POS ERR (AC1,2):	ADS-B function integrity failure leads to ADS-B data corruption
GPS RCV INTG: POS ERR (AC1,2)	GPS receiver integrity failure leads to ADS-B position corruption
GND ATC PROC INTG: POS LOSS MULTI	Ground ADS-B surveillance processing function integrity failure leads to loss of ADS-B position for multiple aircraft

GM069. Implementers for which the ATS system includes Ground Safety Nets should assess the impact of potential ADS-B failure on such devices.

10.6.2 Internal Mitigation Means

Apart from these basic causes, mitigation means allowing hazards prevention called Internal Mitigation Means - IMM) have also been identified. Failures related to these IMM have been included in the fault trees too.

The IMMs identified for ADS-B-RAD are presented as part of the Safety Requirements and Assumptions listed in the next section, together with a reference to the corresponding hazards for which they apply.

10.7 SAFETY REQUIREMENTS AND ASSUMPTIONS RELATED TO FAULT TREE ANALYSIS (ARG 2.2.4.5)

In principle, three different ADS-B-RAD systems could be specified, each of them supporting the service in one of the specific typical Operational Environment. The approach followed in [Ref.1] has conservatively derived one set of ADS-B-RAD system requirements by considering the most demanding requirements when considering all the ADS-B-RAD scenarios.

After the identification of hazards causes, the next step consisted of allocating the Safety Objectives and in deriving the corresponding Safety Requirements.

Each Safety Objective has then been apportioned to causes leading to the corresponding hazard through the dedicated fault trees. This allocation has been performed based on discussions involving operational, technical and safety experts (as described in §C.2.3.2.2 of [Ref.1]).

Specific Safety Requirements have been determined for each cause (Basic Cause or Internal Mitigation Means failure) based on this apportionment (as described in §C.2.3.2.3 of [Ref.1]). At the end and based on this apportionment, the top level result for each fault tree has been recalculated to be sure that the corresponding Safety Objective is met, in order to validate this allocation as far as practicable. Indeed for some hazards, the safety objective has not been achieved, the reasons why are explained at the end of this section.

The frequency of occurrence of each ground cause per sector hour has been converted into per flight.hour unit. This conversion has been used during the development of the fault trees, in order to get the same units towards the fault trees. At the end, quantitative safety requirements and assumptions made on the ground domain have been made per sector hour.

Different results could have been determined because of the different traffic characteristics of the considered ADS-B-RAD scenarios (RAD1, RAD2a/2b and RAD3. The assumptions made on the traffic densities are explained in section2.2.

A048. A ratio of 6 flight hours per sector hour is used to convert per sector hour probabilities for ground systems and non-aircraft systems to per flight hour probabilities (see §A.4.2.2 of [Ref.1]).

GM070. Conversion between "sector hour" and "flight.hour" is widely used in the OSA, particularly during the fault tree analysis where common units are to be obtained between ground and airborne related basic causes. Probabilities of ground basic causes, usually expressed per sector hour have then been translated in the fault trees into flight.h. If local traffic conditions result in a different conversion rule, it would then be necessary to review whether values of ground basic causes need to be modified.

GM071. In case Safety Objectives values need to be modified in the local environment, implementers will have to check the fault trees so as to ensure that the Safety Objectives are still met with the Safety Requirements defined in [Ref.1] or otherwise that the appropriate related requirements are derived.

For some specific causes in the fault trees, some assumptions were determined instead of safety requirements due to the nature of these causes (e.g. failure of external elements or technical system design). These assumptions are provided in section 10.7.3 for GNSS related failures.

Note that due to the nature of the ADS-B-RAD system itself and its dependability upon external elements, the assessment performed and requirements obtained for ADS-B-RAD are based on agreed performance and characteristics of GPS system (**L003**).

The results of this allocation are provided in the following section 10.7.1 related to the Transmitting Aircraft Domain and in section 10.7.2 related to the Ground Domain.

10.7.1 Safety Requirements and Assumptions on Transmitting Aircraft Domain Elements (Fault Tree Side)

10.7.1.1 GNSS On-Board Receive Function Safety Requirements

Addressing	Safety Requirement	OH	RAD-x
”GNSS on-board Receive” Function	**SAF092.** The likelihood of a GNSS on-board Receive function system integrity failure shall be 1.0E-05 or less per flight hour. (SR 01, SPR 21 in [Ref.1])	OH01,OH02, OH05 case 2&3, OH06 case 2&3, OH19, OH20	All
	SAF093. The likelihood of a GNSS on-board Receive function system continuity failure shall be 2E-04 or less per flight hour. (SR 06, SPR 20 in [Ref.1])	OH01, OH02	All
	SAF094. The likelihood that onboard integrity monitoring fails to detect a satellite fault that leads to a horizontal position error exceeding the declared integrity containment bound for more than 10 seconds without indicating a fault shall be 1.00E-03 or less per flight hour. (SR 03 in [Ref.1])	OH05 case 1, OH06 case 1	All

Table 43: List of “GNSS On-Board Receive” Function Safety Requirements (Fault Tree)

10.7.1.2 Aircraft ADS-B function Safety Requirements

Addressing	Safety Requirement – Aircraft ADS-B Function	Related OH#	RAD-x
”Aircraft ADS-B” function	**SAF095.** The likelihood of the Aircraft ADS-B function system integrity failure shall be 1.0E-05 or less per flight hour. (SR 04, SPR 22 in [Ref.1])	All OH except OH03, OH04, OH05 case 1, OH06 case 1, OH09, and OH10	All
	SAF096. The likelihood of an Aircraft ADS-B function system continuity failure shall be 2.0E-04 or less per flight hour. (SR 08, SPR 20 in [Ref.1])	OH03, OH04	All

Table 44: List of the Aircraft ADS-B Function Safety Requirements (Fault Tree)

Note with respect to SAF095: in ED161 [Ref.1]), since the allocation of this rate to a particular data item cannot be quantified in the analysis, it *has been conservatively assumed that the entire rate applies to each data item under analysis (see OSA-ASSUMP.04 in [Ref.1]).*

Note with respect to SAF095: if the aircraft is certified according to ED-102A/DO-260B[55]*, this corresponds to a SDA value equal to 2.*

Note with respect to SAF096: in ED161 [Ref.1]), it is assumed that the probability that ADS-B avionics will exhibit a continuity failure is 2E-04 per flight hour, based on a typical Mode S transponder MTBF of 5000 hours (see OSA-ASSUMP.08 in [Ref.1]).

10.7.2 Safety Requirements and Assumptions on Ground Domain Elements (Fault Tree Side))

10.7.2.1 ADS-B-RAD ATC Processing and Display Function related safety Requirements

Addressing	Safety Requirement	OH	RAD-x
continuity	**SAF097.** The likelihood of a continuity failure of the ADS-B-RAD ATC Processing and Display function shall be 1E-05 or less per sector hour (OSA-ASSUMP.57 in [Ref.1])	OH04	All

Table 45: List of the ADS-B-RAD ATC Processing and Display Function Safety Requirements (Fault Tree)

Note: The rationale for the requirements above is provided by the following justification: The probability is based on a FAA NAS-SS-1000 availability requirement of 1.0E-05. The contribution of a specific failure mode to the overall failure rate cannot be quantified in this analysis, so the entire rate is conservatively assumed for any specific failure mode (OSA-ASSUMP.57 and OSA-ASSUMP.58 in [Ref.1]).

10.7.2.2 "Ground ADS-B Receive" Function related Safety Requirements and Assumptions

Addressing	Safety Requirement	OH	RAD-x
continuity	**SAF098.** The likelihood of system continuity failure of the Ground ADS-B receive function shall be 1E-05 or less per sector hour. (SPR 34 in [Ref.1])	OH04	All

Table 46: List of the Ground ADS-B Receive function Safety Requirements (Fault Tree)

Note: same justification as above.

10.7.2.3 ADS-B Ground Domain related Safety Requirements and Assumptions

Addressing	Safety Requirement	OH	RAD-x
Integrity	**SAF099.** The likelihood of an ADS Ground Domain (Ground ADS-B receive function, Ground ADS-B Surveillance processing function and the ADS-B-to-radar association function) system integrity failure shall be 2.0E-05 or less per sector hour. (SPR 33 in [Ref.1])	All OH except OH05 case 1, OH06 case 1, OH19, and OH20	All
	A049. It is assumed that 99% of ADS-B position errors greater than 10NM will be outside the area displayed to the ATCo. (See OSA-ASSUMP.09 in [Ref.1]). *Note: this assumption implies that the ground system detects and filters position errors greater than 10NM.*	OH01, OH02, OH09, OH10	All

Table 47: List of the ADS-B Ground Domain Safety Requirements and Assumptions (Fault Tree)

GM072. **SAF098 and SAF099** are expressed per sector hour. The conversion into ATSU hour has not been performed in the standard [Ref.1]. In that perspective, implementers should convert sector hour into ATSU hour taking into account their own local characteristics.

10.7.3 Assumptions on External Elements

This section lists the assumptions related to the performance / failure of the GNSS (external) system. Although GNSS is listed as an external system, it is also a failure cause considered in the safety assessment (see operational hazards OH4, OH5, OH6 in that section).

It is assumed that the following likelihoods of GPS failures (GNSS):

A050. It is assumed that the likelihood of a GPS signal-in-space interference event causing a wide-area loss of horizontal position is 1E-07 per flight hour (OSA-ASSUMP.07 in [Ref.1]).

A051. It is assumed that a GPS satellite system integrity failure leading to a horizontal position error is 1.00E-04 per flight hour (OSA-ASSUMP.59 in [Ref.1]).

A052. It is assumed that the (sustained) loss of horizontal position data of sufficient quality (i.e. to support the ATC service) affecting multiple aircraft, due to environmental conditions, is 3.4E-04 per sector hour or less (see OSA-ASSUMP.20 in [Ref.1]).

10.7.4 Safety Objectives Achievement

The safety objectives determined in section 10.5 are compared to the likelihood of occurrence of each hazard obtained from fault trees development based on the safety requirements and assumptions previously identified. The last column "SO Met?" of the following table indicates if the safety objective is met and provides some further explanation for local implementation if the safety objective is not met by the ADS-B-RAD design.

This table is extracted from Table C-19B of [Ref 1], which has been adapted[64] to account for limitation **L004** (this PSC is limited to the application of gradual alternate separation minima in case of loss of ADS-B data where SSR data are displayed) and retains the results of the ESARR 4 method.

OH #	OH description	RAD-x	SO [per flight.hour]	Top Event Results [per flight.hour]	SO met?
OH01	Sudden and Unexpected Loss of ADS-B Position Information for a *Single* Aircraft	RAD-1	4.67e-3	2.43e-4	Yes
		RAD-2	1.40e-1		Yes
		RAD-3	1.40e-1		Yes
OH02	Sudden and Unexpected Loss of ADS-B Position Information for *Multiple* Aircraft	RAD-1	1.35e-5	5.85e-5	See **note A** below
		RAD-2	1.40e-5		See **note A** below
		RAD-3	1.40e-5		See **note A** below
OH03	Loss of All ADS-B Data for a *Single* Aircraft	RAD-1	4.67e-3	2.03e-4	Yes
		RAD-2	1.4e-5[65]		See **note B** below
		RAD-3	4.67e-3		Yes
OH04	Loss of All ADS-B Data for Multiple Aircraft	RAD-1	1.35e-5	6.02e-5	See **note A** below
		RAD-2	1.40e-5		See **note A** below

[64] These adaptations only affect OH02 and OH04 Safety Objectives.

[65] Note: OH01 and OH03 have different severities and safety objectives in RAD2a/RAD2b environments as for OH03 it is conservatively assumed a common avionics failure between ADS-B and radar transponders leading to a loss of all surveillance information for that aircraft with more severe effects.

OH #	OH description	RAD-x	SO [per flight.hour]	Top Event Results [per flight.hour]	SO met?
		RAD-3	1.40e-5		See **note A** below
OH05*: Incorrect Position Information for a Single Aircraft – divided into three sub cases:*					
OH05-1	Horizontal position error resulting from a GNSS position source error not detected by the aircraft integrity monitoring for a *Single* Aircraft	RAD-1 RAD-2 RAD-3	1.56e-2	1e-7	Yes
OH05-2	Horizontal position error resulting from a sustained credible corruption of the position information for a *Single* Aircraft	RAD-1 RAD-2 RAD-3	4.40e-6	2.34e-8	Yes
OH05-3	Horizontal position error resulting from a sustained credible corruption of the quality indicator for a *Single* Aircraft	RAD-1 RAD-2 RAD-3	4.40e-6	2.34e-9	Yes
OH06: *Incorrect Position Information for Multiple Aircraft – divided into three sub cases*					
OH06-1	Horizontal position error resulting from a GNSS position source error not detected by the aircraft integrity monitoring for *Multiple* Aircraft	RAD-1 RAD-2 RAD-3	4.44e-4	1e-10	Yes
OH06-2	Horizontal position error resulting from a sustained credible corruption of the position information for *Multiple* Aircraft	RAD-1 RAD-2 RAD-3	4.39e-7	3.4e-9	Yes
OH06-3	Horizontal position error resulting from a sustained credible corruption of the quality indicator for *Multiple* Aircraft	RAD-1 RAD-2 RAD-3	4.39e-7	3.4e-10	Yes
OH07	Loss of Emergency Mode after Selected by Flight Crew	RAD-1 RAD-2 RAD-3	5.0e-8[66]	1.34e-8	Yes
OH08	Incorrect but Plausible Emergency Mode	RAD-1	4.00e-5	1.34e-8	Yes
		RAD-2	5.00e-4		Yes

[66] This value differs between this PSC and [Ref.1] as the grouping of severity 1hazards hasn’t been retained in this PSC – see more explanation in Annex F section F.3

OH #	OH description	RAD-x	SO [per flight.hour]	Top Event Results [per flight.hour]	SO met?
		RAD-3	5.00e-4		Yes
OH09	Two ‘Dispersed’ Position Symbols for the *Same* Aircraft	RAD-1	N/A		
		RAD-2	N/A		
		RAD-3	1.4e-5	1.68e-5	Yes - See **note C** below
OH10	*Multiple* ‘Dispersed’ Position Symbols	RAD-1	4e-6	6.77e-6	Yes – See **note C** below
		RAD-2			
		RAD-3			
OH11	Incorrect Level Information for a *Single* Aircraft	RAD-1	4.25e-5	1.34e-5	Yes
		RAD-2	1.37e-4		Yes
		RAD-3	1.37e-4		Yes
OH12	Incorrect Level Information for Multiple Aircraft	RAD-1	4.25e-5	3.4e-6	Yes
		RAD-2	1.37e-4		Yes
		RAD-3	1.37e-4		Yes
OH13	Loss of Level Information for *Single* Aircraft		*N/A*	*1.34e-5*	*N/A*
OH14	Loss of Level Information for *Multiple* Aircraft	RAD-1	1.4e-5	3.4e-6	Yes
		RAD-2	1.4e-3		Yes
		RAD-3	1.4e-1		Yes
OH15	Incorrect Identity data for a *Single* Aircraft	RAD-1	1.00e-3[66]	1.34e-5	Yes
		RAD-2	1.0e-1		Yes
		RAD-3	1.0e-1		Yes
***OH16**: Incorrect Identity data for Multiple Aircraft – divided into two sub cases:*					
OH16-1	Incorrect ID resulting from a sustained credible corruption of ID for *Multiple* Aircraft	RAD-1	1.41e-5	3.4e-6	Yes
		RAD-2	4.04e-6		Yes
		RAD-3	4.04e-6		Yes
OH16-2	transposition of IDs between at least two aircraft (swap ID)	RAD-1	5.0e-6	3.4e-6	Yes
		RAD-2	4.04e-6		Yes
		RAD-3	4.04e-6		Yes
OH17	Loss of Identity data for a *Single* Aircraft	All	N/A	1.34e-5	N/A
OH18	Loss of Identity data for *Multiple* Aircraft	RAD-1	1.4e-5	3.4e-6	Yes
		RAD-2	4e-6		Yes

OH #	OH description	RAD-x	SO [per flight.hour]	Top Event Results [per flight.hour]	SO met?
		RAD-3	4e-6		Yes
OH19	*Single* False[67] Target	*All*	*N/A*	*2e-7*	*N/A*
OH20	*Multiple* False Targets	RAD-1	1.4e-5	3.99e-12	Yes
		RAD-2			
		RAD-3			

Table 48: Safety Objectives versus Top Event Results

Explanation note A (OH02, OH04): for all scenarios the hazard likelihoods (i.e. Top Event Result) do not fully satisfy the Safety Objectives. However, as they are of equivalent orders of magnitude (in the worst case 1.3e-5 versus 6.0e-5) they are considered as met in this PSC. The likelihood of these 2 hazards is mainly driven by the assumption A052 related to the loss of sufficient quality data provided by GNSS positioning data source. Therefore implementers are encouraged to verify this assumption in their local context.

GM073. The safety objectives are considered as met in this PSC (because hazards likelihoods and SO are of equivalent orders of magnitude) but at local level, the acceptability criteria for the SO satisfaction should be determined by the implementer in coordination with the corresponding NSA.

Explanation note B (OH03): the hazard likelihood (i.e. Top Event Result) satisfies the Safety Objective for all scenarios except for RAD-2. As mentioned in §5.3.5 of [Ref.1], the main contributor of this hazard is the common failure of an aircraft's radar and ADS-B functions. Nevertheless, the same failure of an aircraft radar transponder in the reference system currently exists (with the same effects) without any regulated or standardized mitigations. Given that the OPA analysis (see Annex B in [Ref.1]) have established comparative transponder availability requirements, RAD-2 scenario is also considered sufficiently safe (if compared qualitatively to the reference system**)**. Additionally, this analysis has not taken into account the potential mitigations of having dual transponder equipage particularly in air transport class aircraft. Similarly, the fact that this common failure does not exist for aircraft that contain separate radar and ADS-B transponders, has not been considered either.

[67]This hazard corresponds to the situation where the ATCO is presented with one target on the ATC display that appears to be a real aircraft, but which does not in fact represent a real aircraft in that place and time.

Apart from that, note that the corresponding Safety Objective for RAD-2 scenario has been derived from the case of a detected loss of track on the ATCo interface, always leading to a significant increase of the controller workload (i.e. Severity 4 effect). This SO is quite demanding (1.4e-5 per fh) due to the absence of PSR as compared to the other 2 scenarios. Considering that this is strongly related to human aspects, the acceptability of the hazard likelihood should be locally addressed by implementers in their specific physical implementation.

Based on all previous justifications, the SO for OH3 in RAD-2 is considered as met in this PSC.

GM074. The determination of the Safety Objective for OH3 in RAD-2 scenario should be locally addressed by implementers in their specific physical implementation, considering that this is strongly related to human aspects and local reference system.

Explanation note C (OH09, OH10): for all scenarios the differences between the Safety Objectives and the hazards likelihoods (top events likelihoods) are considered to be negligeable. Therefore, as in note A, the safety objectives are considered as met.

10.8 CONCLUSIONS ON ARG 2.2.4 - INTERNAL FAILURES

This section has provided adequate Argument and supporting Evidence that the ADS-B-RAD system is robust against internal failures, by:

- Identifying all hazards at the boundary of the system (at ATC display level) related to ADS-B-RAD ATC separation task.

- Assessing the severity of the effects from each hazard, taking account of any external mitigation means and environmental condition.

- Determining, for each external mitigation means and environmental condition, specific Safety Requirements or Assumptions concerning their functionality. The associated performance and probability that the mitigation will be successful have been quantified via the Pe. The Pe value indicates the probability that the occurrence of a hazard will result in a given operational effect taking into account all the applicable external mitigation means and environmental conditions for this hazard.

- Deriving Safety Objectives such that the aggregate risk, from all hazards, is within the Safety Criteria for the “failure case”.

- Identifying all potential causes of each hazard (deductive analysis) as well as any internal mitigation means that would reduce the probability that those causes would actually lead to the corresponding hazard(s).

- Specifying, for each internal mitigation means, the corresponding Safety Requirement or Assumption concerning its functionality, performance and probability that the mitigation will be successful.

- Deriving Safety Requirements (or Assumptions when appropriate) for each of the causes of each hazard such that the Safety Objective for that hazard is satisfied, taking account of any internal mitigation means.

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11 LOGICAL DESIGN REALISM (ARG 2.3)

The objectives of this section is to show that the Logical Design is realistic i.e. that all requirements allocated to each domain or sub-system and assumptions stated are capable of being satisfied in a typical implementation of equipment, people and procedures.

Note that for typical aspects of ADS-B-RAD, equipment has been designed at functional level only. The Local Safety Case will address the physical part of the equipment.

11.1 STRATEGY

The strategy for showing that the Logical Design is realistic is to provide evidence demonstrating that:

- All Safety Requirements are verifiable (i.e. satisfaction can be demonstrated by direct means or indirectly through appropriate assurance processes).
- All Safety Requirements are capable of being satisfied in a typical implementation in hardware, software, people and procedures.
- All assumptions are necessary and valid.

11.2 VALIDATION OF DESIGN REQUIREMENTS AND ASSUMPTIONS

The results presented in the previous sections (requirements and assumptions) are obtained and validated, at least for this typical design, following the RFG working approach: working groups including technical and operational experts formalising their activities as per ED78A [Ref.8] process and EUROCONTROL SAM methodology [Ref.5]. Participants to these working groups represent a large number of perspectives, in particular from industry (e.g. EUROCAE, RTCA).

Concerning procedures and operational results, as most of those results have been obtained by comparison with a Reference radar, they are in general capable of being satisfied as radar is.

Functional requirements for ADS-B-RAD design are similar to the Reference logical design.

Continuity and integrity requirements on ground and airborne elements have been defined based on feedback experience on existing systems and certification material (for more details see section 10.7 of this document).

Finally the validity of each assumption is provided in section 13.1 of this document.

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12 TRUSTWORTHINESS OF THE EVIDENCE FOR THE LOGICAL DESIGN (ARG 2.4)

The objective of this section is to show that Evidence for the logical design of ADS-B-RAD is trustworthy.

12.1 STRATEGY

The strategy for showing the trustworthiness of the evidence for the logical design is the demonstration of the following:

- Approach and methods applied during the design of the ADS-B-RAD system are well recognised, and specific adaptations of the methods for surveillance have been done and documented when necessary.

- These approaches and methods were applied by competent personnel.

- Concerning safety aspects, these methods and approaches are compliant with regulatory requirements (i.e. ESARR).

12.2 APPROACH AND METHODS FOR DESIGN

All the requirements and assumptions related to ADS-B extracted from [Ref.1] have been obtained based on ED-78A [Ref.8] process and SAM [Ref.5] methodology. The main Assumptions related to the methodology applied are included in §2 from [Ref.1].

The list of organisations involved in the design process of ADS-B-RAD in [Ref.1] is provided in Annex B of this document. The large number of RFG participants, the variety of perspectives (US, Europe, etc), the involvement of operational people (ATCo & Pilots), the number of implementers including future European implementers, all these elements contribute to demonstrate that the RFG brought key competence to apply the mentioned methodologies and approaches.

This Preliminary Safety Case for ADS-B-RAD passed a Safety Regulatory Review Process conducted by representatives of National Supervisory Authorities/States within the SRC Coordination Group acting on behalf of the Safety Regulation Commission. This review cycle took place during six months. The SRC Position Paper [Ref.29] is the formal output of the review of the PSC.

Concerning regulatory requirements, the following table summarises compliance with ESARR-4 [Ref.6] requirements concerning hazard assessment process (section 5 of [Ref.6]):

ESARR4 section	Compliance
5.1:HAZARD ASSESSMENT ADDRESSES:	
5.1a) complete life-cycle	NO, only design part is addressed in PSC; other Arguments will address the other aspects.
5.1b) air and ground aspects	OK
5.1c) ATM elements (procedures, human, equipment)	OK[68]
5.2: HAZARD ASSESSMENT INCLUDES:	
5.2a) system description	OK
5.2b) safety objectives determination	OK
5.2c) risk mitigation strategy (requirements, EC, etc.)	OK
5.2d) verify that SO and Safety Requirements are met (prior implementation, during transition, during operation, until decommission.)	NO (as this is the responsibility of the implementer)
5.3: RESULTS	
5.3a) demonstrate that is and will remain tolerably safe (monitoring tools)	NO (as this is the responsibility of the implementer)
5.3b) traceability	OK

Table 49: Compliance with ESARR4 Section 5

GM075. As shown in previous table, almost all relevant parts of ESARR4 have been followed in this generic Preliminary Safety Case. A local safety assessment and safety case is then required to be done by the implementers in order to fill in the 3 remaining parts [i.e. 5.1a), 501c, 5.2d) and 5.3a)].

[68] For generic aspects of ADS-B-RAD, “equipment” has been specified at functional level only. Local full Safety Case will have to address the physical architecture supporting the local implementation.

13 ASSUMPTIONS, ISSUES AND LIMITATIONS

The following caveats apply to this Preliminary Safety Case and need to be considered in the context of the overall conclusions presented in section 14:

13.1 ASSUMPTIONS

Ref	Assumption	Source	Validation / Justification
A001	It is assumed that the Area and Approach Control Services are the most demanding tasks for deriving safety requirements for the ADS-B-RAD	PSC ADS-B-RAD section 2.1	The selection of these demanding services for deriving ADS-B-RAD requirements was based on operational and technical RFG expertise.
A002	It is assumed that there is no change in design of airspace between the reference and ADS-B-RAD systems (OSED ENV-ASSUMP 6 in [Ref.1]).	PSC ADS-B-RAD section 2.2.3	This assumption was based on RFG operational and technical expertise.
A003	At the level of the PSC, it has been assumed that there is no major change regarding ATCo actions for ADS-B-RAD logical design compared to those performed in the Reference logical design.	PSC ADS-B-RAD section 7.3.2	This assumption was based on RFG and CASCADE operational expertise.

Ref	Assumption	Source	Validation / Justification
A004	With the exception of the aircraft identification (see RAD Flight Crew manual [Ref.11] section §6.2), it is assumed that there are no change regarding Flight Crew actions for ADS-B-RAD and the same functionalities are applied regarding emergency situation, Mode A code change, SPI or deselecting of the Pressure-Altitude.	PSC ADS-B-RAD section 7.3.2	Implementers should verify against the EASA Certification Specification (under development at the time of the PSC edition) *Note from [Ref.1], §3.2.2.1: If the aircraft's avionics are not capable of allowing a single point of entry for aircraft identity, emergency codes and SPI, the Flight Crew would have to ensure that conflicting codes are not transmitted to ATC. Operational procedures would have to be developed, including specific guidance, instructions, or training material provided by the equipment manufacturer. This may also include operator training programs, manuals, and operations specifications to ensure that conflicting codes are not transmitted.*
A005	It is assumed that horizontal position accuracy and integrity values part of Table 14 above can be nominally achieved by aircraft equipped with suitable certified ADS-B and radar transponder equipment and system	PSC ADS-B-RAD section 7.3.5.2	This assumption is validated by the results of CASCADE airborne monitoring activities.
A006	It is assumed that all known latencies on the "Ground ADS-B Receiver" function are compensated for.	PSC ADS-B-RAD section 7.5.2.5	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A007	GNSS avionic systems reporting position integrity can be assumed to have a corresponding 95% position accuracy measure no greater than 33% of the reported position integrity.	PSC ADS-B-RAD section 7.5.2.5	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A008	Non-GNSS-based navigation landing systems (i.e., Instrument Landing Systems (ILS)) are assumed to be used by aircraft to support final approaches description in §B.2.2.2 and ASSUMP 9 in §3.2.1.1 of [Ref.1].	PSC ADS-B-RAD section 7.6.2	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A009	It is assumed that Airborne Safety Nets exist as part of external systems of ADS-B-RAD and Reference systems.	PSC ADS-B-RAD section 7.6.2	PSC assumption based on operational judgement
A010	It is assumed that the GPS constellation is sufficient to assure the continuity of service to support ATC, i.e. providing eligible surveillance position data	PSC ADS-B-RAD section 7.6.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A011	It is assumed the presence of a Flight Plan system.	PSC ADS-B-RAD section 7.6.4	The ADS-B-RAD and the Reference systems assume Flight Plan system availability for the correlation of the flight plan aircraft identification to the surveillance tracks for scenarios RAD1, RAD2a and RAD3

Ref	Assumption	Source	Validation / Justification
A012	It is assumed that the management of demand versus capacity (e.g. Flow Management Function) is implemented for the ADS-B-RAD sector as it would be implemented in the Reference system.	PSC ADS-B-RAD section 9.3.1	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A013	Because voice communication is entirely independent of the ADS-B-RAD system, then it is assumed that the likelihood of voice-communication failure would be no greater than for the Reference system case (see ENV-ASSUMP.12 in [Ref.1] and [Ref.12]).	PSC ADS-B-RAD section 9.4.1	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A014	Aircraft safety net failures are assumed to be independent of ADS-B out transmissions, then it is assumed that the likelihood of such failures would be no greater than for the Reference logical design case.	PSC ADS-B-RAD section 9.4.2	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A015	Because the aircraft failures are independent of ADS-B operations, then it is assumed that the likelihood of such failures would be no greater than for the Reference logical design case.	PSC ADS-B-RAD section 9.4.2	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A016	No credit for Airborne Safety Nets and Flight Crew visual avoidance has been made in the hazard effect assessment.	PSC ADS-B-RAD section 10.4.1.1	Conservative assumption.

Ref	Assumption	Source	Validation / Justification
A017	No credit for Ground Safety Nets has been made in the hazard effect assessment.	PSC ADS-B-RAD section 10.4.1.1	Conservative assumption.
A018	ATCo is assumed to be applying the minimum surveillance separation standard applicable for the considered environment (ENVT-1 to ENVT-3 see definition in section 2.2 e.g. 5Nm in ENVT-2) (see appendix C, §C-1.5 [Ref.1]).	PSC ADS-B-RAD section 10.4.1.2	Conservative assumption.
A019	An error in positioning (GNSS) leading in a common mode of failure of both navigation and surveillance has been considered in the assessment of the effects of related hazards OH5 and OH6 (see corresponding event trees illustrated in figures C-19 and C-23 in [Ref.1]).	PSC ADS-B-RAD section 10.4.1.2	Conservative assumption.
A020	For ADS-B position error hazards (OH05 and OH06), ADS-B position errors are considered in different magnitude bands (**"slight", "significant"** and **"large"**) that are defined by the following boundaries: Slight < NIC, where NIC is the minimum applicable for a particular airspace; NIC ≤ Significant < 0.4*S, where S is the applicable separation minimum; 0.4*S ≤ Large < 10 NM (See OSA-ASSUMP.13 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	The justification of this assumption is made in Annex C Appendix C-1 in [Ref.1] for additional details).
A021	It is assumed that ADS-B position errors greater than 10 NM are always detected by the ground system (See OSA-ASSUMP.14 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A022	Based on A020, given an ADS-B position error due to data corruption (case 2), the following error distribution is assumed: Slight ~ 2%; Significant ~ 6%; Large ~ 92% (See OSA-ASSUMP.12 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	The justification of this assumption is made in Annex C Appendix C-1 in [Ref.1].
A023	Based on A020, given an undetected ADS-B position error due to position source failure (case 1), the following error distribution is assumed: Slight ~ 99.9%; Significant ~ 0.1%; Large ~ 0% (See OSA-ASSUMP.11 in [Ref.1]	PSC ADS-B-RAD section 10.4.4	The justification of this assumption is made in Annex C Appendix C-1 in [Ref.1]
A024	It is assumed that the likelihood of encountering an aircraft emergency in a given sector is 1.0E-03 per flight hour (See OSA-ASSUMP.22 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	This assumption is based on operational subject matter expertise
A025	It is assumed that an undetected loss of all ADS-B data does not lead to a collision (i.e. another aircraft does not come into close approach with the true position of the problem aircraft) more than 0.1% of the time (See OSA-ASSUMP.61 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	This assumption is based on operational subject matter expertise.
A026	It is assumed that the lack of ATCO assistance actively contributes to the severity of the emergency in 1 out of 10 cases (See OSA-ASSUMP.10 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	This assumption is based on operational subject matter expertise
A027	It is assumed that displayed position errors greater than 40% of the applicable separation minima could lead to a collision (i.e., severity 1) (See OSA-ASSUMP.17 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	The justification of this assumption is made in Annex C Appendix C-1 in [Ref.1]

Ref	Assumption	Source	Validation / Justification
A028	Given that a “significant” ADS-B position error exists, it is assumed that an undetected ADS-B position error does not lead to a large loss of separation more than 90% of the time (See OSA-ASSUMP.18 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	The justification of this assumption is made in Annex C Appendix C-1 in [Ref.1]
A029	Given that a “large” ADS-B position error exists, it is assumed that an undetected ADS-B position error does not lead to a collision more than 1% of the time (See OSA-ASSUMP.19 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	Refer to Annex C Appendix C-1 in [Ref.1] for the derivation of this assumption)
A030	It is assumed that the probability that an altitude error is large (i.e. more than 10,000 feet from the true altitude) and therefore detected is 80% (See OSA-ASSUMP.38 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	This assumption is mathematically derived based on 50,000 feet of airspace in which 10,000 feet is 20% of the total airspace.
A031	Given that an undetected ADS-B altitude error of more than 200 feet exists, it is assumed that the error does not lead to a large loss of separation more than 1% of the time (See OSA-ASSUMP.47 in	PSC ADS-B-RAD section 10.4.4	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A032	It is assumed that duplicate aircraft identity data with active flight plans does not correspond to aircraft in the same sector on the same frequency more than 90% of the time (See OSA-ASSUMP.51 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A033	It is assumed that the probability that the ATCO's use of an incorrect ADS-B ID leads to or fails to prevent a collision is not more than 0.1%.(See OSA-ASSUMP.54 in	PSC ADS-B-RAD section 10.4.4	This assumption is based on ATCO operational expertise, and the specific scenario of concern is as follows: Given that an ATC instruction is issued to aircraft "A," the wrong aircraft "B" follows instruction AND is put on a converging course with another aircraft "C" in proximity to "B." OR aircraft "B" is in proximity of terrain (i.e., at risk for CFIT), AND visibility conditions are limited such that Flight Crew cannot see and avoid terrain. Proximity to another aircraft or terrain is qualitatively defined as within 40% of the separation minima required for the RAD environment.
A034	Given that an undetected ADS-B altitude error of more than 200 feet exists, it is assumed that the error does not lead to controlled flight into terrain or a collision more than 1% of the time (See OSA-ASSUMP.64 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	This assumption is based on operational expert judgment in the frame of RFG.
A035	It is assumed that the ground system ADS-B to radar association function cannot detect ADS-B position errors characterized as "slight" in assumption A020 - OSA-ASSUMP.12 in [Ref.1] (See OSA-ASSUMP.15 in	PSC ADS-B-RAD section 10.4.4	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A036	It is assumed that the probability that an altitude error is more than 500 feet is 97% (See OSA-ASSUMP.41 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	Uniform distribution of the altitude error. The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A037	It is assumed that the probability that an altitude error is more than 200 feet is 98% (See OSA-ASSUMP.46 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	Uniform distribution of the altitude error. The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A038	The probability that the hazard “multiple dispersed position symbols” occurs during a busy period is assumed to be 10%.	PSC ADS-B-RAD section 10.4.4	Conservative assumption The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A039	The probability that an ID error results in an implausible value is 99.5% (See second part of OSA-ASSUMP.49 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	This assumption is based on ATCO operational expertise in the frame of RFG.
A040	It is assumed that the probability of a ground system integrity failure actually corrupts the ID field as opposed to other corruptions is less than 0.1.	PSC ADS-B-RAD section 10.4.4	This assumption is based on ATCO operational expertise in the frame of RFG.

Ref	Assumption	Source	Validation / Justification
A041	It is assumed that the Flight Crew is able to report an emergency to the ATCO, given that the emergency does not entail a radio communication failure or unlawful interference, 99% of the time (See OSA-ASSUMP.21 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4	This assumption is based on operational expertise.
A042	It is assumed that the ATCO will always detect that a loss of ADS position data has occurred when an indication is presented on the ATCO interface for the affected aircraft (See OSA-ASSUMP.06 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4.2.1	This assumption is based on operational expertise in the frame of RFG.
A043	It is assumed that the ATCO detects the ADS-B false target 99% of the time, in an environment with PSR (See OSA-ASSUMP.26 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4.2.1	This assumption is based on ATCO operational expertise in the frame of RFG.
A044	It is assumed that the ATCO will always detect a lack of Flight Crew response when the ATCO attempts to communicate using an "incorrect" aircraft ID (See OSA-ASSUMP.53 in [Ref.1]).	PSC ADS-B-RAD section 10.4.4.2.1	This assumption is based on ATCO operational expertise in the frame of RFG.
A045	The inherent availability of the Primary Surveillance Radar is assumed to be at least 99.7% (see OSA-ASSUMP.32 of [Ref.1]).	PSC ADS-B-RAD section 10.4.4.2.3	This assumption is justified by [Ref.18]
A046	It is assumed that the inherent availability of the Secondary Surveillance Radar is at least 99.9% (see OSA-ASSUMP.33 of [Ref.1]	PSC ADS-B-RAD section 10.4.4.2.3	This assumption is justified by [Ref.18]

Ref	Assumption	Source	Validation / Justification
A047	The probability that an undetected radar fault occurs at the same time as an ADS-B fault is considered to be very small and therefore insignificant (see also OSA-ASSUMP.05 and §3.1.3 of [Ref.1]).	PSC ADS-B-RAD section 10.4.4.2.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A048	A ratio of 6 flight hours per sector hour is used to convert per sector hour probabilities for ground systems and non-aircraft systems to per flight hour probabilities (see §A.4.2.2 of [Ref.1])	PSC ADS-B-RAD section 10.7	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A049	It is assumed that 99% of ADS-B position errors greater than 10NM will be outside the area displayed to the ATCo. (See OSA-ASSUMP.09 in [Ref.1]).	PSC ADS-B-RAD section 10.7.2.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A050	It is assumed that the likelihood of a GPS signal-in-space interference event causing a wide-area loss of horizontal position is 1E-07 per flight hour (OSA-ASSUMP.07 in [Ref.1]).	PSC ADS-B-RAD section 10.7.3	This assumption is based on historical performance.

Ref	Assumption	Source	Validation / Justification
A051	It is assumed that a GPS satellite system integrity failure leading to a horizontal position error is 1.00E-04 per flight hour (OSA-ASSUMP.59 in [Ref.1]).	PSC ADS-B-RAD section 10.7.3	This is based on the failure rate of an individual GPS satellite (refer to RTCA DO-229D) This assumption is based on conservative GPS required performances and not on the current observed performances in operation, which are probably much better.
A052	It is assumed that the (sustained) loss of horizontal position data of sufficient quality (i.e. to support the ATC service) affecting multiple aircraft, due to environmental conditions, is 3.4E-04 per sector hour or less (see OSA-ASSUMP.20 in [Ref.1])	PSC ADS-B-RAD section 10.7.3	This figure has been obtained from the reference system (radar-based) performances. For more detail on the derivation of this value refer to C5.4.5 [Ref.1]. Note that this assumption directly drives the likelihood of 2 hazards (OH-2 and OH-4) as explained in section 10.7.4.
A053	Compared to the failure condition case, the risk of accidents induced by ADS-B-RAD system supporting ATC services, while in failure-free condition, is negligible.	PSC ADS-B-RAD section F.2	The assumption is based on the results obtained from the surveillance separation error (SSE) analysis provided in Annex F of this document.
A054	It is assumed that the number of the ADS-B-RAD system hazards is a reasonable portion of the 2/25/25/73 values for the entire number of ATM hazards.	PSC ADS-B-RAD section F.2	The assumption is based on [Ref.13] method.
A055	The comparative analysis considers only horizontal surveillance separation error, as altitude information is assumed to be of the same quality with ADS-B (pressure-based) as it is for existing radar-based separation (see SSE-ASSUMP.1 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A056	The comparative SSE analysis uses the cross-range radar error distribution at a selected radar reference range for 3 NM and 5 NM separations (i.e., both aircraft situated at the same range from radar). For the approach scenarios, assuming any radar orientation, the maximum of the crossrange or along-range radar errors are used. Acceptable ADS-B performance is then determined by requiring the ADS-B to ADS-B and ADS-B to radar SSE probability values to be no greater than radar to radar at the same apparent separation (see SSE-ASSUMP.2 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A057	The ATC processing system performs coordinate conversion in a way wherein inaccuracies introduced by this conversion process are assumed to be negligible. There is no additional inaccuracy considered to address coordinate conversion in SSE (see SSE-ASSUMP.3 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A058	It is assumed that GNSS is used as the horizontal positioning source, and that the GNSS constellation is sufficient to assure that ADS-B integrity monitoring confirms the integrity of the surveillance position data. This assumes GNSS receivers are approved in accordance with E/TSO-C129 or a higher integrity performance standard as necessary to provide the required position data integrity. The applicability to other horizontal positioning sources should be examined separately (see SSE-ASSUMP.4 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A059	It is assumed that the ADS-B uncompensated latency in the Transmit Airborne Domain is 0.6 seconds (95%) ((see SSE-ASSUMP.2 in [Ref.1]). In the no-fault condition, GNSS sensor position errors are assumed to follow a normal (Gaussian) distribution in each horizontal dimension (x, y), with standard deviation in accordance with the 95% accuracy bound. Consequently, the resultant radial error distribution is represented by a Rayleigh probability density function (see SSE-ASSUMP.6 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A060	In the no-fault condition, GNSS sensor position errors are assumed to follow a normal (Gaussian) distribution in each horizontal dimension (x, y), with standard deviation in accordance with the 95% accuracy bound. Consequently, the resultant radial error distribution is represented by a Rayleigh probability density function (see SSE-ASSUMP.6 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A061	In order to account for the asynchronous arrival of ADS-B reports on the ground, it is assumed that the ground system will time-register nearby ADS-B and radar (or ADS-B and ADS-B) tracks, for example, by using velocity information to extrapolate aircraft positions to a common time. To take account of possible errors from possible aircraft maneuver during the extrapolation, an extrapolation error distribution is introduced (see SSE-ASSUMP.7 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A062	Extrapolation errors from possible aircraft maneuvers are considered in the 3 NM and 5 NM analyses but are not considered in the approach scenarios because aircraft are assumed to be established on ILS approach paths (see SSE-ASSUMP.8 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A063	A conservative value of 30 minutes (6 minutes for the approach scenarios) GPS exposure time is assumed for adjacent aircraft in order to convert GPS fault probability per hour to event probability (see SSE-ASSUMP.9 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A064	In a fault condition, GNSS sensor position errors are assumed to follow a Gaussian distribution with a fault-induced bias error and a fault condition standard deviation equal to HPL/7.5. This assumption is described in detail in [Ref.1] §D.4.2. The undetected fault condition error probability is then calculated by multiplying the probability that the fault event occurs with the missed detect probabilities given in A066 (see SSE-ASSUMP.10 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A065	The SSE analysis assumes horizontal position error biases associated with a GPS fault condition and probability of missed detection for such biases as modeled by a generic RAIM model described in Ref [36] and summarized in §D.4.2. Given a fault had occurred, miss detect probabilities for various Horizontal Position Errors (HPE) are derived. Although a fault bias error at the HPL is the largest error in magnitude, this fault has a very high detection probability. Therefore, two additional fault bias errors within the HPL that have lower detection probabilities are considered, for a total of three: - Probability Missed Detect (HPE = 0.27 x HPL) = 0.99 - Probability Missed Detect (HPE = 0.59 x HPL) = 0.5 - Probability Missed Detect (HPE = 1.00 x HPL) = 0.001 (see SSE-ASSUMP.11 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A066	If nearby separated aircraft are using the same set of satellites, a satellite fault condition would be expected to cause similar positional bias on both aircraft, and the net separation error due to the fault will be zero. However, conservatively, given a fault condition, the SSE analysis assumes a credible worst-case scenario (see §D.4-2) that the nearby separated aircraft do not use the same set of satellites, and that a net separation error towards each other by an amount equal to the HPE results from the fault condition (see SSE-ASSUMP.12 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DNSA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A067	The SSE analysis assumes a probability of 1x10-4 per flight hour per user that a GPS fault occurs based on GPS WAAS MOPS RTCA DO- 229D. (see SSE-ASSUMP.13 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A068	The time-to-alert drift is considered in the SSE analysis as a 5 meters per second drift beyond the containment region (1.00 x HPL) for 10 seconds. Conservatively, the drift is assumed to be in the direction of the adjacent aircraft (see SSE-ASSUMP.14 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A069	Other potential fault mechanisms (such as hardware/software faults onboard) are not considered as part of the SSE analysis (see SSE-ASSUMP.15 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A070	No assumption has been made about time correlation of any errors in the analysis. Although time-correlation of position errors may affect controller use of displayed surveillance data, surveillance separation error probability calculations are the same for errors that are time-correlated and those that are not (see SSE-ASSUMP.16 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.
A071	SSE does not account for any human actions that may result from the display of information (see SSE-ASSUMP.17 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

Ref	Assumption	Source	Validation / Justification
A072	It is assumed that the ATC processing system has a multisensory registration function to detect and compensate for systematic biases between radar and ADS-B. However, some uncompensated radar biases may still remain after this function and therefore it is assumed that the practical performance of this function is limited to leave residual uncorrected radar systematic biases of 0.088 degrees (azimuth) and 60 meters (range) (see SSE-ASSUMP.18 in [Ref.1]).	PSC ADS-B-RAD section G.3	The validity of this assumption has been confirmed through the RFG process that involved lots of industry, operational people (ATCo, pilots), service providers (NATS, DSNA, LFV, etc.), and other organisations as FAA, AirService Australia and EUROCONTROL.

13.2 OUTSTANDING SAFETY ISSUES FOR LOCAL DESIGN

Ref	Safety Issue	Source	Action Required
I001	This PSC corresponds to a specific design in which ADS-B surveillance is the principal surveillance source presented to the Controllers with SSR/Mode-S radar as a back-up (i.e. no fusion of ADS-B and SSR/Mode-S data). The case of fusion of ADS-B and SSR/Mode-S data is therefore out of scope of this document.	PSC ADS-B-RAD section 1.4. and 7.3.2.1	The case of fusion is planned to be addressed in a separate Preliminary Safety Case.
I002	This Preliminary Safety Case is limited to generic aspects, i.e. to a typical ATC service and to the typical design of the ADS-B-RAD system in Typical Operational Environments	PSC ADS-B-RAD section 1.4,	Implementers to review the contents of the PSC in light of the local operational environment etc
I003	This Safety Case is *preliminary* in that it addresses only the design stage of the Application. It does <u>not</u> address implementation issues, although the structure of the Safety Argument presented herein does include a high-level framework for the development of assurance relating to the implementation, transition and in-service stages of the safety lifecycle	PSC ADS-B-RAD section1.4.	Implementers to address other safety-lifecycle stages
I004	This PSC defines a service (ATC separation) taking place in a typical OE supported by an ADS-B-RAD system which is derived by comparison with a Reference radar-based situation.	PSC ADS-B-RAD section 1.4.	It is in particular the responsibility of the implementer to determines the suitability of a local Reference radar based situation for the purposes of supporting their LSC
I005	This document does not supersede all assumptions made in the reference document [Ref.1]	PSC ADS-B-RAD section 7.5	Implementers to review the contents of the ED-161 requirements and assumptions in light of the local operational environment.
I006	All aircraft in the ADS-B-RAD airspace are equipped with	PSC ADS-B-RAD section	Possible partial equipage issues are left open for

Ref	Safety Issue	Source	Action Required
	suitable certified ADS-B and radar transponder equipment and system (§ASSUMP-12 [Ref.1]).	2.2.4	decision at local implementation level (through e.g. mandating airborne equipage or segregating airspace between equipped and certified aircraft and the rest of the traffic, or permitting Air Traffic Controllers to tactically manage a mixed equipage environment). Implementers should assess the impact of their choice regarding the management of the mixed equipage environment when considering their Local Operational Environment.
I007	The latest edition of the PANS-ATM doc 4444 [Ref.3] contains separation minima of 5 NM when using ADS-B ([Ref.3]. At the time of the edition of the ADS-B-RAD Preliminary Safety Case, 3 NM and Approach separation minima when using ADS-B are still under development at ICAO level (Circular).	PSC ADS-B-RAD section 2.2.2	Implementers wishing to implement in their Local ADS-B-RAD Operational Environment separation minima of less than 5 NM should check the status of ICAO documents in order to determine the separation minima to be locally applied.
I008	The ICAO material (Annex 10 and Doc 9871) update to support the removal of the current Mode A geographical filter has not been published at the time of edition of this PSC document.	PSC ADS-B-RAD section 7.3.1.1	Implementers wishing to utilise Mode A code-based procedures where ADS-B is the prime surveillance source should determine the availability and applicability of PANS-ATM identification procedure based on this information and in particular any update of ICAO material (Annex 10 and Doc 9871).
I009	Human factors, as they are closely related to the implementation, are out of the scope of this PSC	PSC ADS-B-RAD section 7.3.2	Implementers to address human factors analysis during the implementation stage.

13.3 LIMITATIONS

13.3.1 Limitations on the ADS-B-RAD System

Ref	Limitation	Source	Implications
L001	This PSC has not assessed the case of "Independent parallel runways with a spacing between centreline less than 1310 meters but not below 1035 meters"	PSC ADS-B-RAD section 2.2.2	Implementers wishing to implement ADS-B-RAD in an environment with “Independent parallel runways with a spacing between centreline less than 1310 meters but not below 1035 meters” should perform their own local safety assessment (and addressing both the success and failure cases).
L002	DO-242 (version 0) does not satisfy ADS-B-RAD requirements	PSC ADS-B-RAD section 8.2	
L003	The assessment performed and requirements obtained are based on agreed performance and characteristics of GPS system.	PSC ADS-B-RAD section 10.7	For alternative position sources a dedicated safety and performance assessment is required to demonstrate compliance with the ED-126/DO-303 requirements[69] and assumptions
L004	This PSC is limited to the application of gradual alternate separation minima in case of loss of ADS-B data where SSR data are displayed. This limitation is based on analyses of current practice in Europe, which found the application of immediate alternate separation minima to be not broadly applied.	PSC ADS-B-RAD section 10.4.4.2.1	Implementers wishing to implement ADS-B-RAD in an environment where controllers have to apply immediate alternate separation minima in case of loss of ADS-B data where SSR data are displayed should perform their own local safety assessment.

[69] As per paragraph 8.4.7. of [Ref.14].

13.3.2 Limitations on the Analysis

Ref	Limitation	Source	Implications
L005	This PSC has not covered radar failures when ADS-B is working correctly.	PSC ADS-B-RAD section 10.3, 10.4.4, 10.6.1	Implementers wishing to implement ADS-B-RAD should perform specific safety assessment on radar failures only.

14 CONCLUSIONS

This Preliminary Safety Case sets out with the aim of showing that the use of ADS-B surveillance together with radar to support Air Traffic Control service is acceptably safe, subject to satisfaction of the Safety Requirements specified herein[70]. In the context of this document, “acceptably safe” is defined principally against the following safety criterion: the comparison with ATC operation supported by a radar-based only system (Reference system).

Two principal Arguments addressed herein are that the service supported by the ADS-B-RAD has been described and is identical to the one supported by the Reference system (argument 1), and that ADS-B-RAD system has been designed to be *acceptably safe (*argument 2*).* In addressing these Arguments, supporting Evidence has been presented to show that:

For Argument 1: the service supported by the ADS-B-RAD has been described and is identical to the one supported by the Reference system

For Argument 2 (Design):

1. The ADS-B-RAD system has been designed to be acceptably safe, more specifically:
   - Appropriate Safety Targets have been set for the ADS-B-RAD system in the corresponding Typical Operational Environments, derived from the Safety Criterion above (comparison with a radar-based only ATC operation):
     a. In absence of failure, ADS-B-RAD system shall support ATC service in preventing accident/incidents as safely as the Reference system does
     b. Relevant target level of safety (compliant with ESARR4) in the non nominal mode of operation (failure case):
        i. ADS-B-RAD system shall not induce more than 1.5e-09 accidents per flight.hour (*9.0e-09 per sector hour*)
        ii. ADS-B-RAD system shall not induce more than 2.0e-07 serious incidents per flight.hour (*1.0e-06 per sector hour*)
        iii. ADS-B-RAD system shall not induce more than 3.0e-06 major incidents per flight.hour (2.0*e-05 per sector hour*)
        iv. ADS-B-RAD system shall not induce more than 1.0e-04 significant incidents per flight.hour (*7.0e-04 per sector hour)*
   - The Logical design satisfies the Safety Targets defined.

[70] The caveat “subject to satisfaction of the Safety Requirements specified herein” is necessary because this is only a Preliminary Safety Case and therefore doesn’t not address implementation issues (except in outline)

a. The ADS-B-RAD Logical Design exhibits all the necessary properties to satisfy the Safety Targets

b. The ADS-B-RAD Logical Design functions correctly and coherently under all normal environmental conditions

c. The ADS-B-RAD Logical Design is robust against external abnormalities

d. All risks from internal ADS-B-RAD Logical Design have been mitigated sufficiently

- The ADS-B-RAD Logical design is realistic.
- The Evidence for the ADS-B-RAD Logical Design is trustworthy

Thus, subject to the caveats presented in section 13 above, and subject to satisfaction of the Safety Requirements specified herein[70], it is concluded overall that the use of ADS-B to provide surveillance information in complement to radar (the ADS-B-RAD system) to support ATC service is *acceptably safe.*

Local issues have not been addressed (except in outline) in this Preliminary Safety Case. However, it has been shown that all the Requirements identified in this PSC are achievable in a generic implementation and significant guidance material has been provided in this document to support the development of local safety cases.

Finally, a SRC Position Paper [Ref.29] has been produced by the Safety Regulation Commission after a Safety Regulatory Review Process that took place for this Preliminary Safety Case for ADS-B-RAD. This SRC Position Paper is the formal output of the review of the PSC. Implementers are encouraged to take account this document, and other guidance information, as support and input to Implementers and States when using this PSC as a basis to develop their Local Safety Case.

15 REFERENCES

[Ref.1] EUROCAE ED-161/RTCA DO-318 "Safety Performance and Interoperability Requirements Document for ADS-B-RAD Application". 3182009

"This standard provides the minimum operational, safety and performance requirements (SPR) and interoperability requirements (INTEROP) for the implementation of the Automatic Dependent Surveillance - Broadcast (ADS-B) "Enhanced Air Traffic Services in Radar-Controlled Areas using ADS-B surveillance" (ADS-B-RAD). This application is fully defined in the Operational Services and Environment Definition (OSED) found in Annex A" of this document.
"This document provides the minimum ADS-B-RAD requirements and allocation of these requirements to both air and ground domains."
"This requirements definition is based on the results of a requirements determination process performed by the "ADS-B Requirements Focus Group" (RFG). The RFG was established through the EUROCONTROL / FAA Memorandum of Cooperation. It operates as a joint EUROCAE/RTCA activity assuming the responsibility for the SPR and INTEROP standard material contained in this document."

[Ref.2] Description of a First Package of GS/AS Applications, CARE/ASAS Ref. CA-02-040(2.2), version 2.2, September 30, 2002

[Ref.3] ICAO PANS ATM - "Procedures for Air Navigation Services - Air Traffic Management", Document 4444, Fifteen edition 2007, including ADS-B procedures in Chapter 8 " ATS Surveillance Services"

[Ref.4] EUROCONTROL Document - "Safety Case development Manual", DAP/SSH/091, Edition 2.2. Nov 2006

[Ref.5] EUROCONTROL Document - "ANS Safety Assessment Methodology (SAM)" v2.1. Nov 2006

[Ref.6] EUROCONTROL Document - Safety Regulatory Requirement 4 (ESARR4), "Risk Assessment and Mitigation in ATM"

[Ref.7] EUROCONTROL Document - Safety Regulatory Requirement 3 (ESARR3), "Safety Management Systems by ATM Service Providers"

[Ref.8] EUROCAE ED-78A / RTCA DO-264 - "Guidelines for approval of the provision and use of Air Traffic Services supported by data communications". December 2000

[Ref.9] ICAO PANS-OPS - "Procedures for Air Navigation Services - Aircraft operations", Document 8168

[Ref.10] ICAO Annex 10 - Aeronautical Telecommunications, Volume IV “Surveillance Radar and Collision Avoidance Systems”, Edition 3

[Ref.11] EUROCONTROL Document - Flight Crew Guidance for Flight Operations in Airspaces where Surveillance is Provided by ADS-B and Radar, Edition 1.3

[Ref.12] Commission Regulation (EC) 2096/2005 of 20 December 2005 laying down common requirements for the provision of air navigation service

[Ref.13] ED-125 – Process for Specifying Risk Classification Sheme and Deriving Safety Objectives in ATM, March 2010,

[Ref.14] EASA Certification Specification (CS) ADS-B out – under development at the time of edition of this PSC

[Ref.15] EUROCAE ED-129 Technical Specification for 1090MHz Extended Squitter Ground Station (draft November 2007)

[Ref.16] RTCA/DO-229D : Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment (dated 13 December 2006)

[Ref.17] ICAO Annex 11 – Air Traffic Services (Air Traffic Control Service, Flight Information Service, Alerting Service) – 13th Edition, July 2001 including the adopted Amendments 41-46

[Ref.18] EUROCONTROL document - SUR.ET1.ST01.1000-STD-01-01, “EUROCONTROL Standard Document for Radar Surveillance in En Route Airspace and Major Terminal Area,” March 1997

[Ref.19] EUROCONTROL document - TLS apportionment method (SAM - FHA V2.0 Chapter 3, Guidance J core), v0.7 30/07/2003

[Ref.20] EUROCONTROL document - Guidance for the Provision of Air Traffic Services Using ADS-B in Radar Airspace (ADS-B-RAD), Edition 1.0, 01/12/08

[Ref.21] EUROCONTROL document - “SAME: Safety Assessment Made Easier”, Part 1, Edition 1.0, 15/01/2010

[Ref.22] EUROCONTROL document - “SAME: Safety Assessment Made Easier”, Part 2 under development at the time of edition of this PSC

[Ref.23] EUROCONTROL Preliminary Safety Case for Enhanced Air Traffic Services in Non-Radar Areas using ADS-B surveillance – version 1.1 dated 12 December 2008

[Ref.24] Commission Regulation (EC) 1315/2007 of 8 November 2008 on safety oversight in air traffic management amending Regulation (EC) N° 2096/2005

[Ref.25] RTCA DO-242A, “Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS B),” (through Change 1) December 13, 2006

[Ref.26] ICAO doc 9854 - “Global ATM Operational Concept”, first edition 2005

[Ref.27] ICAO doc 9689 - “Manual on Airspace Planning Methodology for the Determination of Separation Minima,” First edition (through Amendment 1), ICAO, August 2002

[Ref.28] ED-102A/DO-260B, Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B), December 2009

[Ref.29] EUROCONTROL document: 2009 IRP (Integrated Risk Picture) ECAC Model for the overall traffic and barrier performance.

“The Integrated Risk Picture - IRP - is the output of a "risk model" representing the risks of aviation accidents, with particular emphasis on ATM contributions. In order to ensure that the risk model reflects ATM as it develops in the future, the risk model is founded on an "ATM model", describing the ATM system whose risks are to be modelled. The ATM model represents the ATM system in diagrammatic form, defining the major ATM elements, representing the concept of operations and identifying potential interdependencies due to the use of common information sources. For the baseline risk model to represent the present ATM, the model is quantified using accident and incident data, with corrections for recent trends, as well as statistical results from previous data analysis so as to obtain risks for current ATM that are fully consistent with accident experience. The IRP version used in this document describes the baseline risk picture for 2008. The risk model can also be used in predictive mode by adapting its underlying structure in order to model future ATM concepts.

The Integrated Risk Picture (IRP) is being developed within EUROCONTROL since 2004. This development has closely been co-ordinated with the FAA within the scope of the FAA/EUROCONTROL Action Plan 15 on Safety. This accident/incident model continues to be developped in the framework of SESAR, with the aim of enabling the setting of safety targets for SESAR projects, and allowing an estimation of the impact of SESAR projects on the ATM contribution to safety."

[Ref.30] The SRC Position Paper (Edition 1.0 – Released Issue) is the formal output of the review of the PSC conducted by representatives of National Supervisory Authorities/States within the SRC Coordination Group acting on behalf of the Safety Regulation Commission.

16 GLOSSARY

ACAS	Airborne Collision Avoidance Systems
ADS-B	Automatic Dependent Surveillance - Broadcast
ANSP	Air Navigation Service Provider
ASOR	Allocation of Safety Objectives and Requirements
ATC	Air Traffic Control
ATS	Air Traffic Services
CAP	Close Approach Probability
EASA	European Aviation Safety Agency
ESARR	EUROCONTROL Safety Regulatory Requirement
FC	Flight Crew
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSN	Goal Structuring Notation
HFOM	Horizontal Figure Of Merit
HPL	Horizontal Protection Limit
ICAO	International Civil Aviation Organisation
INS	Inertial Navigation System
LOA	Letter Of Agreement
MSAW	Minimum Safe Altitude Warning
MSSR	Monopulse Secondary Surveillance Radar
NAC	Navigation Integrity Category
NACp	Navigation Integrity Category Position
NIC	Navigation Accuracy Category
NUC	Navigation Uncertainty Category
NUCp	Navigation Uncertainty Category Position
NTZ	Non Transgression Zone
RAD	Non Radar Area
OH	Operational Hazard
OHA	Operational Hazard Assessment
OPA	Operational Performance Assessment
OSA	Operational Safety Assessment
OSED	Operational Service and Environment Definition
PR	(ED-161) Performance Requirement
PRA	Precision Radar Approach

PSC	Preliminary Safety Case
RFG	Requirement Focus Group
SAF	Safety Requirement
SIL	Source Integrity Level (datalink version 2) Surveillance Integrity Level (datalink version 1 and 0)
SPI	Special Position Ident
SPR	Safety and Performance Requirement
SR	(ED-161) Safety Requirement
SRA	Surveillance Radar Approach
SRC	Safety Regulation Commission
SSR	Secondary Surveillance Radar
STCA	Short Term Conflict Alert
SWSSR	Sliding Window Secondary Surveillance Radar
TMA	Terminal Manoeuvering Area
VHF	Very High Frequency

Annex A HAZARD CLASSIFICATION MATRIX

This Matrix is directly obtained from §Table 30 of [Ref.1], the second row “type of effect” has been added in relation with the severity class.

Hazard Class	1 (most severe)	2	3	4	5 (least severe)
Type of Effect	Accidents	Serious Incidents	Major Incidents	Significant Incidents	-
Effect on Operations	Normally with hull loss. Total loss of flight control, mid-air collision, flight into terrain or high speed surface movement collision.	Large reduction in safety margins or aircraft functional capabilities.	Significant reduction in safety margins or aircraft functional capabilities.	Slight reduction in safety margins or aircraft functional capabilities.	No effect on operational capabilities or safety.
Effect on Occupants	Multiple fatalities.	Serious or fatal injury to a small number of passengers or cabin crew.	Physical distress, possibly including injuries.	Physical discomfort.	Inconvenience.
Effect on Air Crew	Fatalities or incapacitation.	Physical distress or excessive workload impairs ability to perform tasks.	Physical discomfort, possibly including injuries or significant increase in workload.	Slight increase in workload.	No effect on flight crew.
Effect on Air Traffic Service	Total loss of separation.	Large reduction in separation or a total loss of Air Traffic Control for a significant period of time.	Significant reduction in separation or significant reduction in Air Traffic Control capability.	Slight reduction in separation or in ATC capability. Significant increase in Air Traffic Controller workload.	Slight increase in Air Traffic Controller workload.
Example of ASAS Operational Effects	• *Mid-air collision* • *Controlled flight into terrain* • *Total loss of flight control* • *High speed surface movement collision (i.e. collision in runway)* • *Leaving a prepared surface at high speed.*	• *Large reduction in separation or safety margins* • *Loss of separation resulting in wake vortex encounter at low altitude.* • *Large reduction in safety margins like abrupt manoeuvre is required to avoid mid-air collision or CFIT (e.g. one or more aircraft deviating from their intended clearance)* • *Large reduction in aircraft functional capabilities* • *Total loss of Air Traffic Control for a significant period of time*	• *Significant reduction in separation or safety margins* • *Loss of separation resulting in wake vortex encounter at high altitude.* • *Low speed surface movement collision (i.e. collision in taxiway)* • *Leaving a prepared surface at low speed* • *Significant reduction in aircraft functional capabilities* • *Significant reduction in Air Traffic Control capability*	• *Slight reduction in separation or safety margins* • *Significant increase in Air Traffic Controller workload* • *Slight increase in flight crew workload*	• *No effect on operations /traffic* • *Slight increase in Air Traffic Controller workload* • *No effect on flight crew*

Annex B ORGANISATIONS INVOLVED IN DEFINITION OF ADS-B-RAD

The organisations involved in the definition of ADS-B-RAD in the framework of the Requirements Focus Group (RFG) are:

Airbus

Airservices Australia

ALPA

AOC Services

BAE SYSTEMS

Boeing

Boeing Air Traffic Management

CNS Support HB

DGAC

DoD

DFS Deutsche Flugsicherung GmbH

EUROCAE

EUROCONTROL

Engility Corporation

FAA

FAA Flight Standards

FAA WJH Technical Centre

Johns Hopkins University

LFV Group

LFV Luftfartsverket

MITRE/CAASD

MLIT Japan

National Air Traffic Services Ltd - LACC

QinetiQ

Project Management Enterprises, Inc

Regulus Group

Rockwell Collins

RTCA

SAIC (FAA)

Systems Enginuity

Thales Air Defence SA

Thales ATM

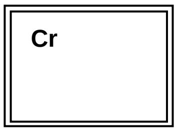
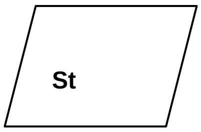
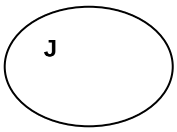
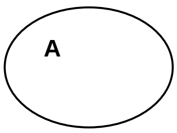
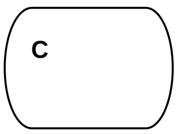
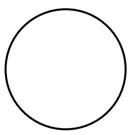
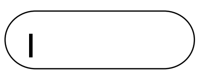
Thales Avionics

Transport Canada

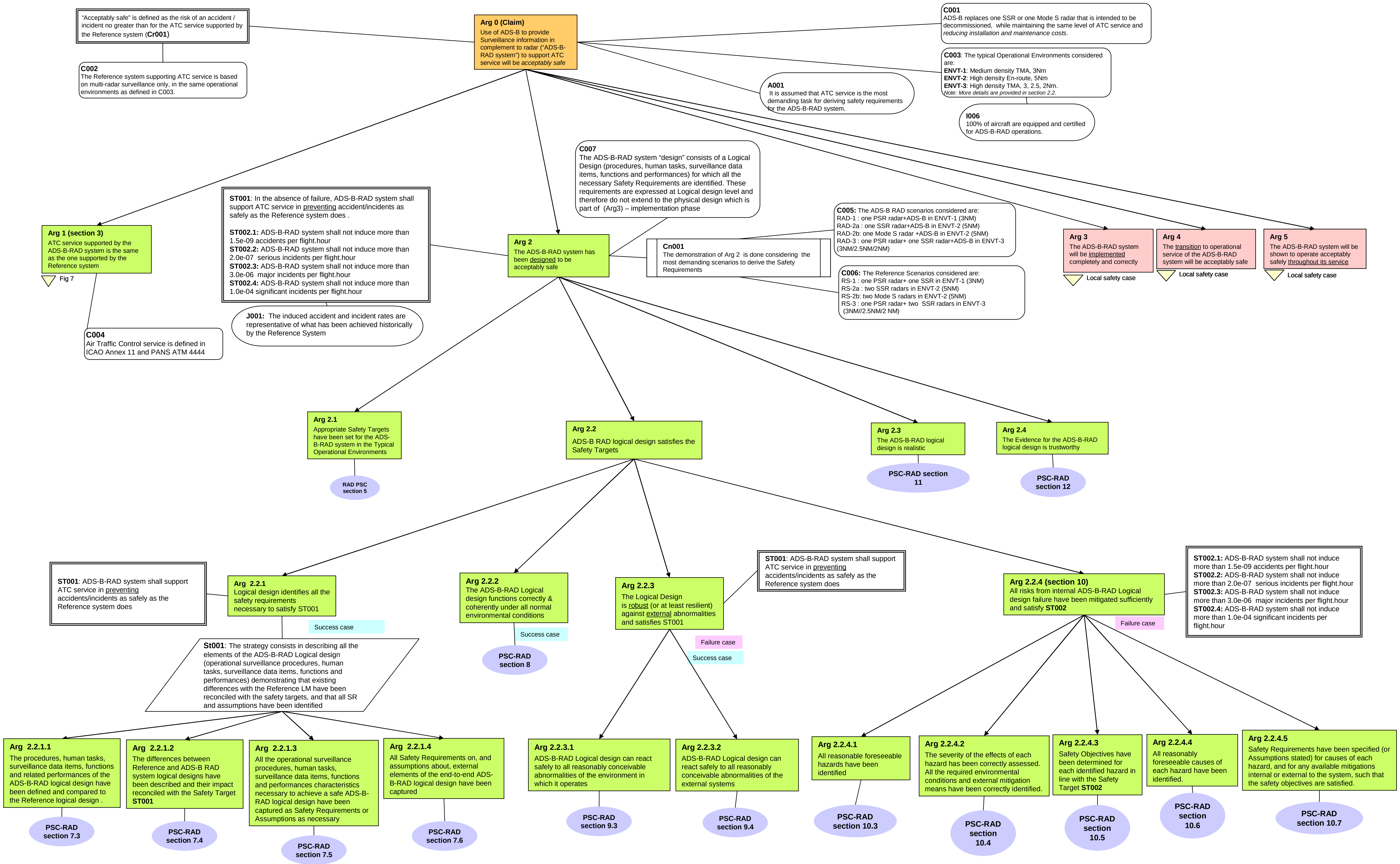
United Airlines

More detail about people from involved in this process can be found in ED-161/DO318 document [Ref.1].

Annex C GOAL STRUCTURING NOTATION LEGEND

	**Goal**	A goal is a requirement or target to be met or shown to be true. In this document, goals are called arguments.
	**Criteria**	Criteria are the means by which satisfaction of particular goals, strategies, choices and solutions can be assessed or checked.
	**Strategy**	A goal or set of goals can be solved by a strategy, which breaks those goals down into a number of sub-goals. The interpretation is that the solution of the sub-goals ensures the solution of the parent goals.
	**Justification**	The various elements of the GSN can all be given justifications for their use. Justifications are most frequently associated with strategies.
	**Assumption**	An assumption is an assertion that some element of the goal structure (e.g. Goal or Strategy) has to rely on, in order for it to be satisfiable. An assumption is some fact that has to be assumed about the environment, system, theories, etc., for the goal structuring element to be valid.
	**Context**	Context provides the inputs or background information that a goal or other goal structuring element requires for it to be understood or satisfied. It will include analysis results, hazard logs, etc. in some senses models and assumptions could be regarded as special cases of context, but are treated as separate entities because of their importance in defining goal structures.
	**Constraint**	To be further developed
	**Solution**	Solutions provide the evidence for satisfaction of goals. They may be individual pieces of analysis, evidence, results of audit reports, references to design material, etc.
	**Issue**	An issue lists any outstanding safety issues that must be resolved before the Claim can be considered to be valid, together with the responsibilities and timescales for clearing them.

Annex D FULL GSN STRUCTURE FOR ADS-B-RAD



Annex E Relationship between ATS, ATC and the Surveillance Services procedures

E.1 Definition of terms

The definitions related to ATS below are extracted from ICAO Annex 11 [Ref.17] and from PANS-ATM [Ref.3]:

Air traffic service*. A generic term meaning variously, flight information service, alerting service, air traffic advisory service, air traffic control service (area control service, approach control service or aerodrome control service).*

Flight information service*. A service provided for the purpose of giving advice and information useful for the safe and efficient conduct of flights.*

Alerting service. *A service provided to notify appropriate organizations regarding aircraft in need of search and rescue aid, and assist such organizations as required.*

Air traffic advisory service*. A service provided within advisory airspace to ensure separation, in so far as practical, between aircraft which are operating on IFR flight plans.*

Air traffic control service. *A service provided for the purpose of:*

a) preventing collisions:

1) between aircraft, and

2) on the manoeuvring area between aircraft and obstructions; and

b) expediting and maintaining an orderly flow of air traffic.”

ATS surveillance service*. A term used to indicate a service provided directly by means of an ATS surveillance system.*

ATS surveillance system*. A generic term meaning variously, ADS-B, PSR, SSR or any comparable ground-based system that enables the identification of aircraft.*

As defined above, ATS is actually a diverse collection of services provided to aircraft in a range of environments. The objective of the ADS-B-RAD system in ED-161/RTCA DO-318 [Ref.1] was to define ADS-B surveillance requirements and within this objective the diversity in ATS scope was reviewed as part of the analysis (see [Ref.1]. A. 4.1.1) and a restricted set of services were selected.

This Annex E aims at clarifying the scope of the ADS-B-RAD system as defined in this PSC.

The objectives and the scope of the ADS-B-RAD system defined in this PSC are directly derived from the application description presented in Annex A of ED-161 ([Ref.1]). In this latter document, the description of ADS-B-RAD system is based on the structure and on the procedures contained in chapter 8 “ATS Surveillance Services” of the PANS ATM Doc 4444. This chapter described the procedures associated to the ATS Surveillance services.

E.2 Relationship between the ATS, ATC and Surveillance Services

ATS Surveillance Services (see definition above) is a support service designed to be primarily applied within the three Air Traffic Control (ATC) services namely Area Control, Approach Control and Aerodrome Control Services. Aerodrome service has not been included in the analysis as an alternative EUROCONTROL CASCADE ADS-B application (ADS-B-APT Airport) contains those operations within its scope.

Air Traffic Services also contains a number of other services apart from ATC: Flight Information, Air Traffic Advisory and Alerting Services. These three other services have not been included in the [Ref.1] ED 161 SPR application description due to the focus of the application being the derivation of ADS-B surveillance requirements to support ATC. The assumption is that if the ADS-B-RAD system can support ATC in the application of area and approach control services (excluding the Aerodrome Control Service), then the ADS-B-RAD system requirements will be sufficient to support the other less demanding services from a surveillance perspective. The following discussion aims at clarifying the scope of the ADS-B-RAD system covered by this PSC.

The description of ATS Surveillance Services procedures in PANS-ATM [Ref.3] Chapter 8 covers its general use for ATS but also breaks it down to focus on the three ATC Services (Area, Approach and Aerodrome) as well as making some reference to the use of surveillance to support FIS. As such the chapter crosses the descriptive boundaries established between the High Level Service of ATS, mid level services such as ATC and FIS and low level service descriptions of Area, Approach and Aerodrome Control Services. All of these are described as ‘services’ but each has a different granularity of description and hierarchy.

The diagram below represents this hierarchical view of the services described in ICAO SARPS. The red squares delimit the “ATS Surveillance Services” as defined in PANS-ATM surveillance services section.

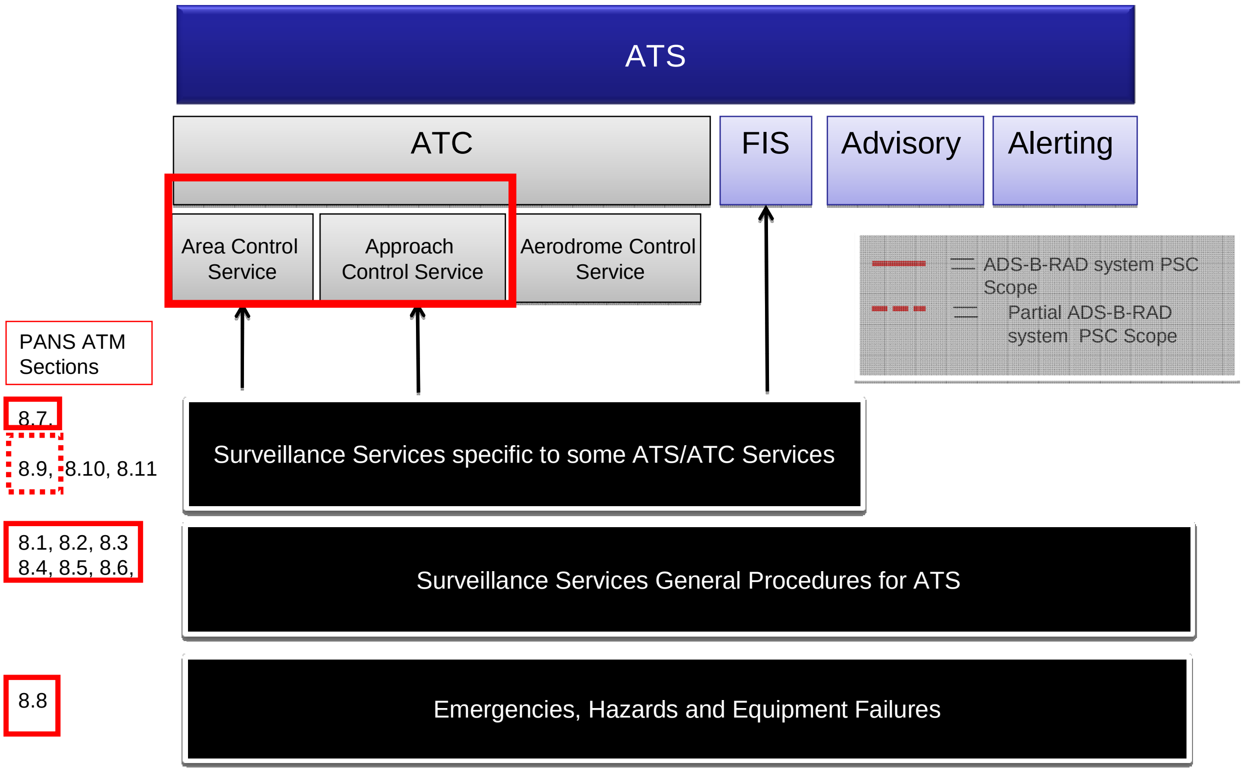


Figure 20: Chapter 8 PANS-ATM ATS Surveillance Services

Procedures considered for the ADS-B-RAD system based on PANS-ATM chapter 8 sections.

Sections 8.1 to 8.6 have been written to describe the procedures to be applied in the support of ATS and do not specify or limit these to any particular service of ATS. The following lists the headings of each section that was analysed based on the expert judgement that these procedures were relevant to be contained within ADS-B-RAD description in support of the objective of the application:

- 8.1: ATS Surveillance System Capability
- 8.2: Situation display
- 8.3: Communications
- 8.4: Provision of ATS Surveillance Services
- 8.5: Use of SSR transponders
- 8.6: General procedures

Note: §8.3 was excluded from the [Ref.1] *Application Description. However it has was covered under the* [Ref.1] *Environment Description as an assumed item.*

Section 8.7 is specifically relevant for surveillance procedures in support of ATC. In so far as ADS-B-RAD system is concerned the Aerodrome Control Service is out of scope hence the following identifies the relevance of each sub-heading of chapter 8.7:

- 8.7.1: Functions
- 8.7.2: Separation Application
- 8.7.3: Separation Minima based on ATS Surveillance Systems
- 8.7.4: Transfer of Control

Section 8.8 describes the surveillance procedures related specifically to the handling of emergencies, hazards and surveillance equipment failures. This chapter does not assign these to any particular Air Traffic Service but are covered by the ADS-B-RAD system.

Section 8.9 described the specific surveillance procedures to be applied in support of the approach control service. These procedures have not been spelled specifically in the [Ref.1] ADS-B-RAD system as although the application does support the approach control service the critical elements of this section (vectoring and approach separation minima) were already covered in previous sections. Independent parallel runways71 operations and the use of approach minima were specific scenarios assessed in the OHA described at [Ref.1] Annex C.

Additionally, references in this section to Surveillance Radar Approaches (SRA) and Precision Radar Approaches (PRA) are also out of scope of the ADS-B-RAD system. For both of these procedures, section 8.9 contains specific requirements on, amongst other things, controller situation displays and were considered to be of a high level of detail, and local variations of these procedures were too great to be included in a typical analysis and were not deemed to add a value to the ADS-B-RAD system requirements.

Given the ADS-B-RAD system has analysed the use of vectoring and separation minima in the approach environment, it has been foreseen that local authorities wishing to support SRA would find sufficient analysis to justify these procedures. However no analysis or anticipated support was provided in regards to PRA and local Authorities wishing to implement these procedures would be required to establish the appropriate requirements supporting cases to justify their implementation.

[71] Some independent parallel runways operations have been excluded – see section 3

GM076. Local authorities wishing to support SRA should develop sufficient analysis to justify these procedures.

GM077. Local authorities wishing to implement PRA should establish the appropriate requirements supporting cases to justify their implementation.

Section 8.10 and 8.11 are out of scope of the ADS-B-RAD system as described above.

E.3 Summary

The ADS-B-RAD system has been specified to support the ATS Surveillance Service within the confines of the ATC services of Area and Approach Control and this annex has provided justification and detail of these considerations and how each ICAO service relates to each other from a hierarchical point of view and which procedures have been considered for the ADS-B-RAD system.

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Annex F DETAILS ON SAFETY TARGET ST002

This annex describes how the safety target ST002 has been determined in [Ref.1], and provides the details of the apportionment of global ATM Safety Targets into ADS-B RAD Safety Targets.

Safety Target ST002 in [Ref.1] has been derived following a two-step approach, based on ED-125 guidelines:

a) The definition of ATM safety targets,

b) The definition of an appropriate portion of these ATM safety targets allocated to ADS-B-RAD.

F.1 ATM Safety Targets Definition

ATM Safety Targets have been obtained based on ESARR4 [Ref.6] value for severity class 1, completed by ED-125 [Ref.13] values for severity classes 2, 3 and 4. These ATM Safety Targets specify the overall (i.e. ATM) maximum quantitative frequency at which an operational effect for a given severity class can be tolerated to occur (see Table 50 below, 3rd column).

An Ambition Factor of 10 has been used for these initial ATM Safety Targets (see §C2.2.2.4 in [Ref.1]) resulting in more demanding values (see in Table 50 below in the far right column).

Severity Class	Types of Effects	ATM Safety Targets per [flight.h]	AF	ATM Safety Targets per [flight.h] with AF
Severity 1	Accidents	1e-08	10	1e-09
Severity 2	Serious incidents	1e-05	10	1e-06
Severity 3	Major incidents	1e-04	10	1e-05
Severity 4	Significant incidents	1e-02	10	1e-03

Table 50: ATM Safety Targets

This Ambition Factor is a safety margin to ensure that the ADS-B-RAD system is “future-proofed” (i.e. against the unknown environmental characteristics in the future) and that subjective expert judgment is given a margin of error. Indeed at each stage of the process, assumptions are made on the variables impacting the safety levels, for example the Environmental Conditions, Mitigation Means (as identified in section 10). Each of these will contain probabilities and quantities impacting on the overall safety requirements.

F.2 ADS-B-RAD Safety Targets Derivation

The second step consists in apportioning the ATM Safety Targets presented above through the ADS-B-RAD system by specifying the overall maximum quantitative frequency of occurrence of effects in case of failure (of the ADS-B-RAD system).

Note that all these ATM safety targets apply in principle to both success and failure approaches, but that the following is assumed for ADS-B-RAD, as supported by next section F.5:

A053. Compared to the failure condition case, the risk of accidents induced by ADS-B-RAD system supporting ATC services, while in failure-free condition, is negligible.

Thus, in [Ref.1], the strategy has been to apportion Safety Target per hazard of the ADS-B-RAD system. This method is adapted from the European guidelines ED-125 [Ref.13], which proposes an estimated number of ATM hazards (Nmax) and their distribution in the various severity classes.

Table 51 below provides the total number of ATM hazards (Nmax=125) and the distribution of these hazards in the various severity classes (Nmax i) as per ED-125 [Ref.13]. These numbers have been extracted from table 5 of ED-125 [Ref.13] for an airspace of complexity category 1 ("this would typically be airspace in the European core area having a complex mix of traffic, very high traffic density and a large number of flight level changes") and this number is applicable for both En-Route and TMA airspaces (i.e. in the three environments ENVT-1, ENVT-2 and ENVT-3).

Severity	ATM ST per [flight.h] with AF	Nmax	ST per individual RAD hazard [flight.h]
Severity 1	1e-09	2	5.0e-10
Severity 2	1e-06	25	4.0e-08
Severity 3	1e-05	25	4.0e-07
Severity 4	1e-03	73	1.4e-05

Table 51: ADS-B RAD Safety Targets per Individual Hazard

The number of ADS-B-RAD hazards per severity class must only take a reasonable portion of the 2/25/25/73 values for entire ATM.

The following methodological safety assumption is defined:

A054. It is assumed that the number of the ADS-B-RAD system hazards is a reasonable portion of the 2/25/25/73 values for the entire number of ATM hazards.

GM078. The impact of a change in the ratio between the numbers of ADS-B-RAD and overall ATM hazards (for each severity) would have to be reviewed by implementers as apportionment of the safety objectives in a local environment will depend on the complexity of their Local Operational Environment and such values will have to be adapted. It is recommended to implementers to use the ED125 document as input for determining the level of granularity at which hazards have to be defined, and for determining the number of ATM hazards to be considered based on the airspace complexity definitions included in ED-125.

Safety Targets per ADS-B-RAD hazard per severity class in Table 51 are obtained by dividing the global ATM Safety Targets (including an ambition factor of 10) by the total number of hazards in each severity class and assuming an even distribution of the risk as shown in the following formula:

$$ST_{RAD} = \frac{ST_{ATM}}{N_{MAX}}$$

F.3 Consolidation of the ADS-B-RAD Safety Targets

Based on these results from [Ref.1], ADS-B-RAD Safety Targets per individual hazard shown above have been consolidated, in the frame of this PSC, into ADS-B-RAD Safety Targets per severity class for each ADS-B-RAD scenario (RAD-1, RAD-2, RAD-3), taking into account the number of ADS-B-RAD hazards per severity class provided in section 10.5, Table 42. These Safety Targets can be expressed per flight hour and sector hour using traffic density defined in section 2.2.1 (i.e. taking 6 flight-hours equivalent to 1 sector hour).

Safety Targets presented in the executive summary, in section 5.2, in section 10.1 and in various GSN figures, have been rounded from those of the following tables, and presented as a unique set applicable to all ADS-B-RAD scenarios / environments.

Severity	RAD-1 scenario (ENVT-1)			
	ST per individual hazard [flight.h]	N° of hazards	ST per severity class [flight.h]	ST per severity class [sector hour]
Severity 1	5.0e-10	**3**	1.5e-09	9.0e-09
Severity 2	4.0e-08	**6**	2.4e-07	1.4e-06
Severity 3	4.0e-07	**5**	2.0e-06	1.2e-05
Severity 4	1.4e-05	**7**	9.6e-05	5.8e-04

Table 52: Consolidated ADS-B-RAD Safety Targets per Severity Class – RAD-1

Severity	RAD-2 scenario (ENVT-2)			
	ST per individual hazard [flight.h]	N° of hazards	ST per severity class [flight.h]	ST per severity class [sector hour]
Severity 1	5.0e-10	**3**	1.5e-09	9.0e-09
Severity 2	4.0e-08	**4**	1.6e-07	9.6e-07
Severity 3	4.0e-07	**7**	2.8e-06	1.7e-05
Severity 4	1.4e-05	**7**	9.6e-05	5.8e-04

Table 53: Consolidated ADS-B-RAD Safety Targets per Severity Class – RAD-2

Severity	RAD-3 scenario (ENVT-3)			
	ST per individual hazard [flight.h]	N° of hazards	ST per severity class [flight.h]	ST per severity class [sector hour]
Severity 1	5.0e-10	**3**	1.5e-09	9.0e-09
Severity 2	4.0e-08	**4**	1.6e-07	9.6e-07
Severity 3	4.0e-07	**7**	2.8e-06	1.7e-05
Severity 4	1.4e-05	**8**	1.1e-04	6.6e-04

Table 54: Consolidated ADS-B-RAD Safety Targets per Severity Class – RAD-3

Note: the numbers of hazards provided in the three tables above include hazards that have sub cases described, such as OH5 and OH6.

<u>Differences between the PSC and [Ref.1] approaches regarding the Safety Targets Calculation</u>:

In both approaches a top-down and bottom-up consolidation process has applied.

During the top-down process, the calculation of the Safety Targets per hazard per severity class is identical in both the PSC and [Ref.1] and is based on ED-125.

During the bottom-up consolidation process:

- In [Ref.1], initial safety objectives have been derived and the number of ADS-B-RAD hazards has been compared against the number of ATM hazards. A grouping of the Severity 1 hazards has been applied to comply with A054 resulting in apportioning the Safety Target for this Severity Class. This apportionment has been only partially performed (only on two hazards rather than on all).
- It has been therefore found more appropriate in this PSC not to perform this grouping of severity 1 hazards and instead to calculate the consolidated Safety Targets per severity class (and not per hazard) and to verify that they take an appropriate portion of the ATM Safety Targets (without the ambition factor) – see Table 55 and Table 57 above. Moreover this allows for comparison and validation with IRP data.

Note: this difference in approach explains why in the fourth column of the tables above, the ST for the severity 1 differs between this PSC and [Ref.1], where in this latter a value of 5e-10 per flight hour has been retained for this Safety Target instead of 1.5e-09.

Finally, Table 55 shows the ratio between these ADS-B RAD Safety Targets and the ATM Safety Targets presented in Table 50 (without ambition factor). This represents the portion of the total ATM safety budget allocated to the surveillance related elements (i.e. the ADS-B RAD system in this case).

Severity (Effects)	ATM ST [flight.h]	% for RAD-1	% for RAD-2	% for RAD-3
Severity 1	1e-08	**15%**	**15%**	**15%**
Severity 2	1e-05	**2%**	**2%**	**2%**
Severity 3	1e-04	**2%**	**3%**	**3%**
Severity 4	1e-02	**1%**	**1%**	**1%**

Table 55: ATM Safety Budget Allocated to the ADS-B RAD System

This ATM safety budget allocated to the ADS-B-RAD system is mainly used to determine the safety objectives established at hazard level (top-down approach). In the following section, an example is provided to illustrate the consolidated bottom-up ADS-B RAD risk i.e. when considering the ADS-B-RAD safety requirements and assumptions and their contributions when calculating the top-event of the fault trees in the SPR (bottom-up).

F.4 Discussion on the Calculation of the ADS-B-RAD Bottom-Up Risk

The following table represents an example of the consolidated bottom-up risk of ADS-B-RAD per severity class. These results have been obtained by adding for each hazard of a given severity class, the product of the top event results by the corresponding Pe (extracted respectively from Table 48 and Table 42).

Severity	Consolidated bottom-up ADS-B-RAD risk per [flight.h]		
	RAD-1	RAD-2	RAD-3
Severity 1	4.7e-10	1.3e-10	1.3e-10
Severity 2	3.7e-07	5.1e-09	5.1e-09
Severity 3	6.8e-07	1.7e-06	1.0e-06
Severity 4	8.5e-06	3.2e-04	1.2e-04

Table 56: Example of Consolidated Bottom-Up ADS-B-RAD Risk per Severity Class

Then, the following table represents the proportion of the consolidated bottom-up ADS-B RAD risk compared to the ATM safety Targets based on the results presented in Table 56 above.

Severity (Effects)	ATM ST [flight.h]	% for RAD-1	% for RAD-2	% for RAD-3
Severity 1	1e-08	**4.7%**	**1.3%**	**1.3%**
Severity 2	1e-05	**3.7%***	**0.1%**	**0.1%**
Severity 3	1e-04	**0.7%**	**1.7%**	**1%**
Severity 4	1e-02	**0.1%**	**3.2%****	**1.2%**

Table 57: Example of Proportion of the Bottom-Up ADS-B RAD Risk Compared to the ATM Safety Budget

*: For the difference between top-down and bottom-up values see explanation note A in section 10.7.4.

**: For the difference between top-down and bottom-up values see explanation note B in section 10.7.4.

In this PSC due to the number of hazards and all scenarios considered, the consolidation has been performed, for simplification, based on the most critical path of each hazard for each scenario.

In reality, the contribution of each hazard in all severity classes and not only the most critical path should be considered during the calculation of the bottom-up ADS-B-RAD risk.

Nevertheless not all hazards have to be taken into account due to the possible dependency between them with respect to their various causes.

GM079. When consolidating the bottom-up local ADS-B-RAD system risk, implementers should consider the contribution of each hazard in all severity classes and not only the most critical path. During this calculation, the selection of appropriate hazards should be carefully done as not all hazards have to be taken into account due to the possible dependency between them with respect to their various causes.

F.5 Justification for Assumption A053

The assumption is based on the results obtained from the surveillance separation error (SSE) analysis provided in Annex G of this document.

In addition, in airspaces where the ATM service and operational environment have remained substantially unchanged, i.e. in airspaces where ADS-B is intended to replace a SSR radar (no change in the separation minima) for a significant period of time, it may be possible to make use of appropriate historical data to reinforce this assumption. In ATM it is usual to set separation standards such the normal operating risks (i.e. the risk in the absence of failure) are reduced to a very low level. Therefore the absence of accidents in historical data could be used to argue qualitatively that the risk is negligible compared with the risk due to service failure [Ref.19].

GM080. In airspaces where ADS-B is intended to replace a SSR radar (no change in the separation minima), implementers could use historical data, to demonstrate that the risk of accident in the absence of failure is negligible in comparison with the risk due to service failure.

Consequently these ATM Safety Targets can be totally apportioned to ADS-B-RAD when in failure case.

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Annex G SUMMARY OF THE ADS-B-RAD SURVEILLANCE SEPARATION ERROR ANALYSIS (SSE)

This annex provides a summary of [Ref.1] Surveillance Separation Error Analysis (SSE) which determines the required values of the ADS-B integrity containment bound quality indicator (NIC) for each of the separation minima applicable to the various ADS-B-RAD environments.

This summary is organised around the following elements:

- SSE Background and relationship with CAP
- SSE derived requirements
- SSE related assumptions
- Guidance material for implementers
- SSE limitation - ADS-B to PSR separation in failure approach

G.1 SSE Approach and Relationship to Previous (ADS-B-NRA) CAP Analysis

The comparative surveillance separation error assessment is based on an extension of ICAO-accepted comparative methodology, described in ICAO Document 9689 [Ref.27] as the Close Approach Probability (CAP). The CAP approach considers the potential measurement errors associated with the separation of two aircraft given a particular surveillance source and assumes all other airspace characteristics remain constant. The ICAO close approach probability (CAP) is defined as the probability that an aircraft pair actually overlap when the apparent distance between them is equal to the radar separation minimum. This comparison method calculates the probability of a separation error resulting in a “Close Approach,” given a displayed apparent separation (separation standard). This original CAP approach has later been refined to additionally consider ADS-B integrity risk, as well as issues related to the asynchronous reception of ADS-B updates and latency. The latest refinement is the Surveillance Separation Error (SSE) probability analysis which decouples the nominal and fault condition ADS-B behaviours and also focuses on general separation errors; it additionally incorporates a RAIM model to determine fault detection probabilities. The ADS-B horizontal position surveillance component of risk (SSE) is then compared with that of a reference radar – the assumption being that the reference radar already achieves safe separation in a similar air traffic environment. Note that both the CAP and SSE comparative methods look at surveillance separation error at a single moment in time, independent of past and future relationship. For a given separation standard, the objective is to ensure that the ADS-B to ADS-B and ADS-B to radar comparative surveillance separation errors are no greater than that of radar to radar at a defined reference range.

The SSE methodology was developed to create a more general comparative analysis; it allows the comparison to be accomplished at all aircraft separations and simply considers the probability that one system has a surveillance error larger than the baseline system. SSE is the probability that separation error for two aircraft towards each other is greater than some error value “E” ($E = S_S\text{-}S_T$ – see figure below). Mathematically, the surveillance separation probability distribution function for two aircraft is obtained by the convolution of the position distribution functions. While the CAP calculation integrates this separation probability function from –Aw to Aw (Aircraft Width – see figure below) to calculate the close approach probability, the SSE probability calculation integrates this same function over all Surveillance Separation (S_S) less than True Separation (S_T), giving the likelihood of a separation greater than E.

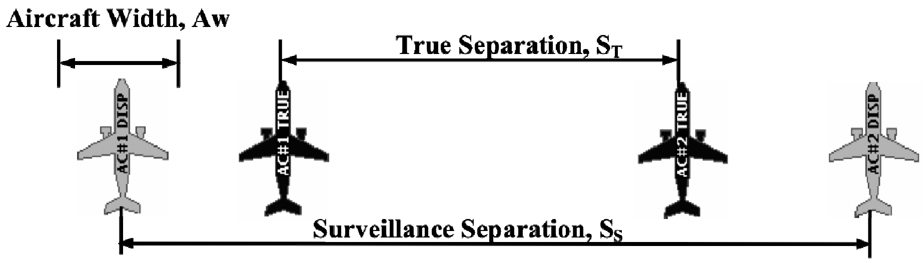

Figure 21: Illustration of Surveillance Separation (S_S) and True Separation (S_T) in the SSE approach

G.2 SSE Derived Requirements

[Ref.1] annex D provides a determination of the required values of the ADS-B integrity containment bound quality indicator (NIC) for each of the separation minima applicable to the various ADS-B-RAD environments. These required values are expressed in this PSC document in the Table 13, in the “Horizontal Position Integrity” row.

Note: Although the integrity containment bounds are established in relation to a faulted horizontal position source condition (i.e., satellite ranging fault for the reference GPS horizontal position source as selected in this document), the corresponding NIC values themselves constitute a nominal performance requirement as they determine the minimum horizontal position measurement integrity quality level required for the nominal operational use of ADS-B data.

The process for deriving these (minimum) integrity quality indicator takes into account a number of elements such as the reference radar characteristics (see [Ref.1] Annex B Appendix B-3.2 and [Ref.1] Annex D.3), the ADS-B error ([Ref.1] Annex D.4), including nominal condition errors ([Ref.1] Annex D.4.1), Fault Condition Error and Time-to-Alert ([Ref.1] Annex D.4.2). The resulting calculations are illustrated by the graphs presented below (extracted from [Ref.1] Annex D) that provide the separation error probability curves for both the reference radar and the ADS-B cases:

Note: NAC values have been derived from the success approach (see Table 13)

Note: SSE is used in the success approach to determine the horizontal position containment bound (Navigation Integrity Category or NIC) per the various separation minima scenarios considered in this document. It is also used in the failure approach as a key input into the establishment of the event trees (through the so-called Probability of effect (Pe) probabilities).

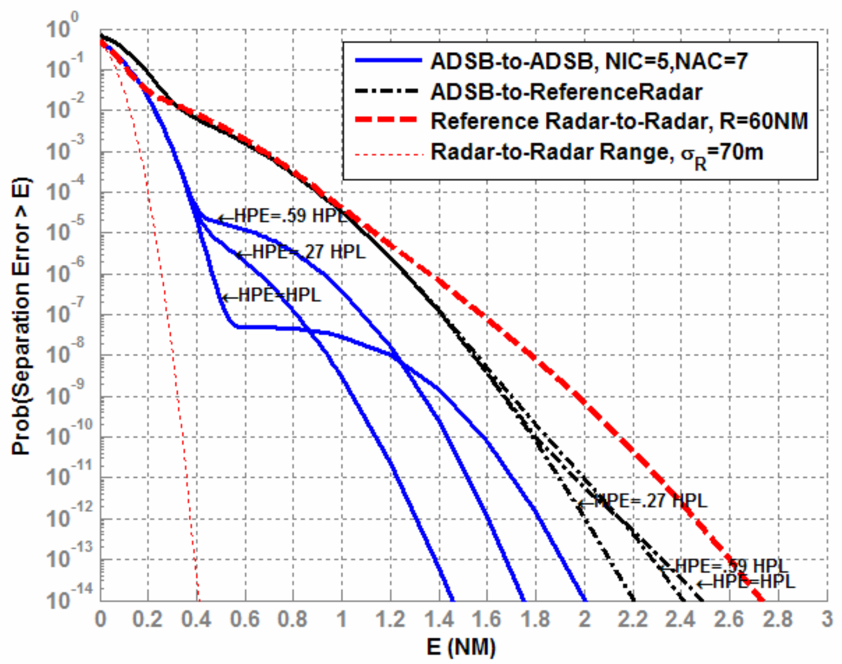

Figure 22: Comparative Separation Error Probability for En-Route 5 NM

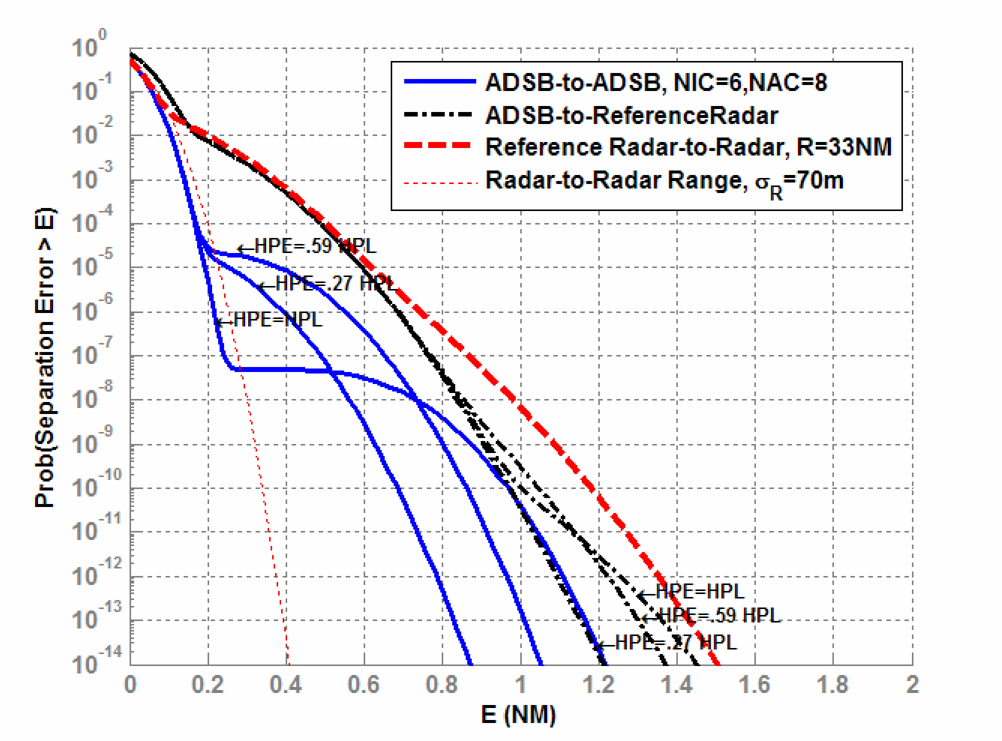

Figure 23: Comparative Separation Error Probability for TMA 3 NM

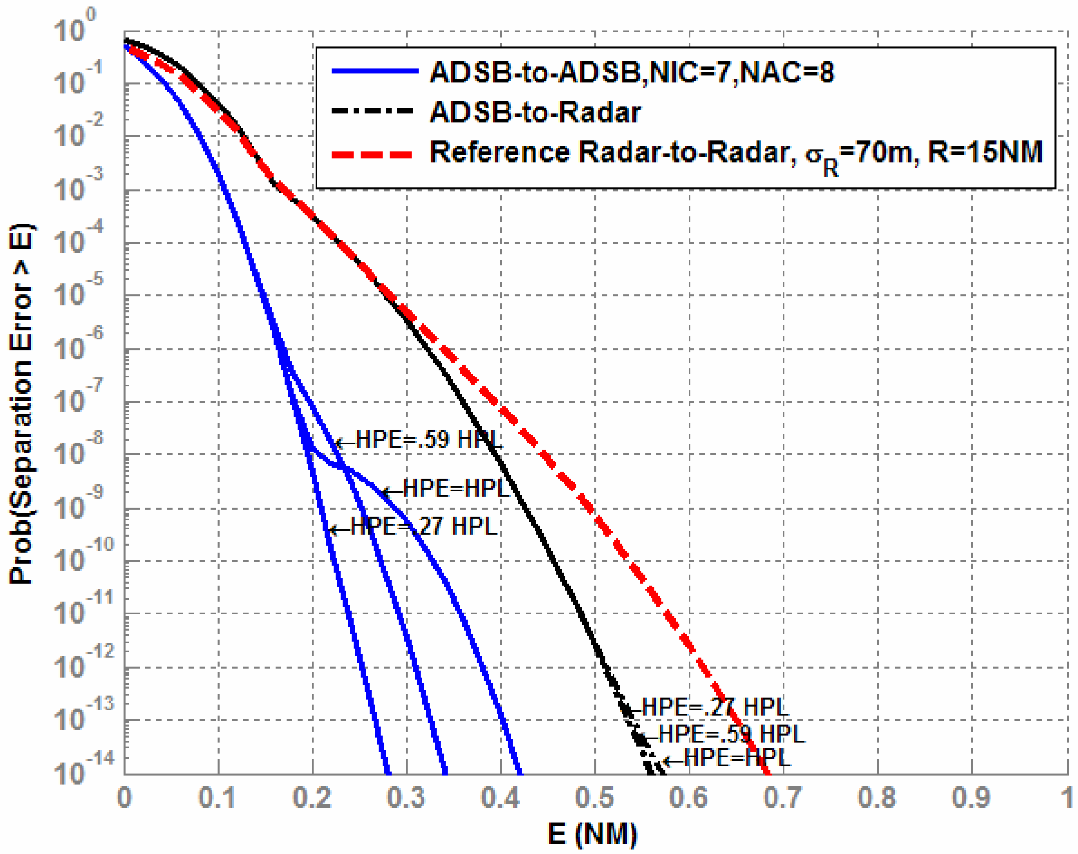

Figure 24: Comparative Separation Error Probability for Approach

G.3 SSE related Assumptions

This section provides all the assumptions made in the SSE analysis of [Ref.1]:

A055. The comparative analysis considers only horizontal surveillance separation error, as altitude information is assumed to be of the same quality with ADS-B (pressure-based) as it is for existing radar-based separation (see SSE-ASSUMP.1 in [Ref.1]).

A056. The comparative SSE analysis uses the cross-range radar error distribution at a selected radar reference range for 3 NM and 5 NM separations (i.e., both aircraft situated at the same range from radar). For the approach scenarios, assuming any radar orientation, the maximum of the crossrange or along-range radar errors are used. Acceptable ADS-B performance is then determined by requiring the ADS-B to ADS-B and ADS-B to radar SSE probability values to be no greater than radar to radar at the same apparent separation (see SSE-ASSUMP.2 in [Ref.1]).

A057. The ATC processing system performs coordinate conversion in a way wherein inaccuracies introduced by this conversion process are assumed to be negligible. There is no additional inaccuracy considered to address coordinate conversion in SSE (see SSE-ASSUMP.3 in [Ref.1]).

A058. It is assumed that GNSS is used as the horizontal positioning source, and that the GNSS constellation is sufficient to assure that ADS-B integrity monitoring confirms the integrity of the surveillance position data. This assumes GNSS receivers are approved in accordance with E/TSO-C129 or a higher integrity performance standard as necessary to provide the required position data integrity. The applicability to other horizontal positioning sources should be examined separately (see SSE-ASSUMP.4 in [Ref.1]).

A059. It is assumed that the ADS-B uncompensated latency in the Transmit Airborne Domain is 0.6 seconds (95%) ((see SSE-ASSUMP.2 in [Ref.1]).

A060. In the no-fault condition, GNSS sensor position errors are assumed to follow a normal (Gaussian) distribution in each horizontal dimension (x, y), with standard deviation in accordance with the 95% accuracy bound. Consequently, the resultant radial error distribution is represented by a Rayleigh probability density function (see SSE-ASSUMP.6 in [Ref.1]).

A061. In order to account for the asynchronous arrival of ADS-B reports on the ground, it is assumed that the ground system will time-register nearby ADS-B and radar (or ADS-B and ADS-B) tracks, for example, by using velocity information to extrapolate aircraft positions to a common time. To take account of possible errors from possible aircraft maneuver during the extrapolation, an extrapolation error distribution is introduced (see SSE-ASSUMP.7 in [Ref.1]).

A062. Extrapolation errors from possible aircraft maneuvers are considered in the 3 NM and 5 NM analyses but are not considered in the approach scenarios because aircraft are assumed to be established on ILS approach paths (see SSE-ASSUMP.8 in [Ref.1]).

A063. A conservative value of 30 minutes (6 minutes for the approach scenarios) GPS exposure time is assumed for adjacent aircraft in order to convert GPS fault probability per hour to event probability (see SSE-ASSUMP.9 in [Ref.1]).

A064. In a fault condition, GNSS sensor position errors are assumed to follow a Gaussian distribution with a fault-induced bias error and a fault condition standard deviation equal to HPL/7.5. This assumption is described in detail in [Ref.1] §D.4.2. The undetected fault condition error probability is then calculated by multiplying the probability that the fault event occurs with the missed detect probabilities given in A066 (see SSE-ASSUMP.10 in [Ref.1]).

A065. The SSE analysis assumes horizontal position error biases associated with a GPS fault condition and probability of missed detection for such biases as modeled by a generic RAIM model described in Ref [36] and summarized in §D.4.2. Given a fault had occurred, miss detect probabilities for various Horizontal Position Errors (HPE) are derived. Although a fault bias error at the HPL is the largest error in magnitude, this fault has a very high detection probability. Therefore, two additional fault bias errors within the HPL that have lower detection probabilities are considered, for a total of three:

- Probability Missed Detect (HPE = 0.27 x HPL) = 0.99
- Probability Missed Detect (HPE = 0.59 x HPL) = 0.5
- Probability Missed Detect (HPE = 1.00 x HPL) = 0.001 (see SSE-ASSUMP.11 in [Ref.1]).

A066. If nearby separated aircraft are using the same set of satellites, a satellite fault condition would be expected to cause similar positional bias on both aircraft, and the net separation error due to the fault will be zero. However, conservatively, given a fault condition, the SSE analysis assumes a credible worst-case scenario (see §D.4-2) that the nearby separated aircraft do not use the same set of satellites, and that a net separation error towards each other by an amount equal to the HPE results from the fault condition (see SSE-ASSUMP.12 in [Ref.1]).

A067. The SSE analysis assumes a probability of 1x10-4 per flight hour per user that a GPS fault occurs based on GPS WAAS MOPS RTCA DO- 229D. (see SSE-ASSUMP.13 in [Ref.1]).

A068. The time-to-alert drift is considered in the SSE analysis as a 5 meters per second drift beyond the containment region (1.00 x HPL) for 10 seconds. Conservatively, the drift is assumed to be in the direction of the adjacent aircraft (see SSE-ASSUMP.14 in [Ref.1]).

A069. Other potential fault mechanisms (such as hardware/software faults onboard) are not considered as part of the SSE analysis (see SSE-ASSUMP.15 in [Ref.1]).

A070. No assumption has been made about time correlation of any errors in the analysis. Although time-correlation of position errors may affect controller use of displayed surveillance data, surveillance separation error probability calculations are the same for errors that are time-correlated and those that are not (see SSE-ASSUMP.16 in [Ref.1]).

A071. SSE does not account for any human actions that may result from the display of information (see SSE-ASSUMP.17 in [Ref.1]).

A072. It is assumed that the ATC processing system has a multisensory registration function to detect and compensate for systematic biases between radar and ADS-B. However, some uncompensated radar biases may still remain after this function and therefore it is assumed that the practical performance of this function is limited to leave residual uncorrected radar systematic biases of 0.088 degrees (azimuth) and 60 meters (range) (see SSE-ASSUMP.18 in [Ref.1]).

G.4 Guidance Material for Implementers

GM081. The comparative methodology by its nature imposes certain limitations that suggest further investigations may be appropriate. For example, some of the analyses in [Ref.1] Annex D are based on an assumption that the tails of the azimuth error distribution for the MSSR can be accurately modelled using a double-Gaussian curve, based on the Eurocontrol surveillance standard and supported by a limited set of US MSSR data (see [Ref.1] Annex B, Appendix B-3). This assumption differs from some previously published reports where the data collected showed that the radar azimuth error distribution could be modelled using a single Gaussian curve. As with any requirements development process, additional data collection and analyses will be performed to confirm that the assumptions made in this standard remain valid. If these data and analyses indicate that assumptions need to be modified, this document will have to be updated accordingly.

GM082. Figure 22, Figure 23 and Figure 24 correspond to certain radar characteristics and in particular the range of applicability (see section 7.3.5.1) for each reference radar case. It is to be noted that [Ref.1] includes an Appendix B-6, which aims at providing guidance on quality indicator values that would result if the radar reference ranges were selected at ranges other than those selected in [Ref.1] Annex B and provided in section 7.3.5.1 of this PSC.

G.5 Limitation of the SSE – ADS-B to PSR Separation in Failure Approach

The SSE was based on a comparative methodology where the horizontal surveillance separation error of two aircraft being detected by an MSSR at the same selected range from the radar head was compared to the SSE of (a) two aircraft being detected by ADS-B surveillance or (b) one aircraft being detected by ADS-B surveillance and the other being detected by an MSSR. Hence the comparison determined the acceptable requirements with which the separation minima may be applied between ADS-B to ADS-B aircraft and ADS-B to MSSR aircraft with the limitation that the ADS-B to PSR aircraft was not included.

Subject to various display technique assumptions (as described in Annex H), in the nominal case (i.e. NAC determination) this omission has no effect on any scenarios. Even for RAD 1 the controller would be separating ADS-B to ADS-B targets and hence the position quality requirements would apply. However in the failure case where ADS-B position information may be removed from the controller display (through loss or degradation of data) the controller may be faced with separating other ADS-B targets with raw PSR targets.

In this event the Safety Assessment at Annex C of [Ref.1] has assessed the impact from a workload perspective where the ATCo is faced with either a loss of ADS-B data (i.e. OH 1 and 2) or faced with a situation where, through a position error being present in the ADS-B surveillance data, the ADS-B and PSR returns become ‘dispersed’ such that it effectively doubles the number of tracks on the display (i.e. OH 9 and 10). However the safety assessment does not provide an indication on the SSE requirements, nor does it provide the likelihood of having an undetected breakdown of separation between two aircraft with one detected by ADS-B and the other by PSR only.

However in the local reference system this scenario is most likely to occur already from time-to-time where aircraft detected by the MSSR are separated from aircraft only being detected by the PSR (particularly in the RAD 1 scenario) and therefore would have already been assessed and accepted (perhaps along with the designation of various locally defined procedures). Hence by comparison, as the ADS-B NIC requirements have been determined using a comparative analysis to MSSR the same local acceptance of this occurrence would apply.

GM083. Local authorities should review their position on separation minima currently allowed between PSR only returns and MSSR returns and assess the impact on the target environment scenario.

Annex H DISPLAY TECHNIQUES FOR PSR TARGETS

§A.5.3.2 in [Ref.1] contains a discussion on the high-level display techniques allowed for by ICAO (PANS-ATM 8.2.3) particularly when multiple surveillance sources are present to detect aircraft in the same sector. ADS-B-RAD does not foresee the SSR/Mode S data and ADS-B data being presented at the same time for the same aircraft during nominal operations (see below for failure modes) as this would represent an unacceptably difficult situation for the controller in managing the traffic. However PSR data represents a different case as depending on the local environment different techniques apply.

The presentation of PSR data is most common in and surrounding complex Terminal Areas but may also exist in En route or smaller terminal areas. In so far as ADS-B-RAD is concerned, two scenarios relate to the Terminal Area (RAD1 and RAD3) where a PSR is present.

The technique used to present PSR position data may either be through the presentation of a combined symbol or through the presentation of individual symbols. In the former the controller sees effectively one symbol that contains an indicator that the aircraft is being detected by both surveillance sources. Whereas in the later the controller sees the individual symbols

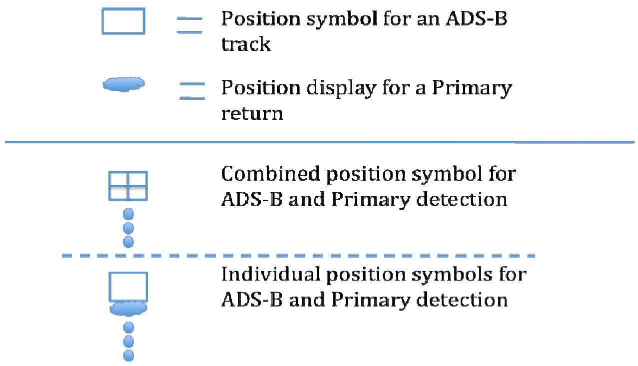

Figure A-1: Example Illustration of a 'Combined Position' Symbols versus Individual Symbology.

In the ADS-B-RAD system, for the nominal case the local decision to display the PSR has no effect on the requirements however in the failure mode case there may be an effect in so far as workload and separation minima applied.

ADS-B-RAD display technique for PSR in the failure case

The safety assessment performed in [Ref.1] has analysed the case where the 'dispersed' position symbols are presented on the controller display where, for example, the ground system has not been able to determine if the positions from different surveillance sources belong to the same aircraft (where in fact they are from the same aircraft). If the local implementation display technique chooses individual position symbols for PSR and ADS-B then this hazard does not come into effect as the symbols are already dispersed. However if the combined technique is chosen then this hazard is relevant and the associated requirements apply which have been derived primarily on the impacts the hazard has on the controllers workload.

GM084. Local authorities should review their display technique in regards to PSR data and consider the requirements in ADS-B-RAD associated with OH9 and OH10 where necessary.

Separation Minima

As indicated in Annex F , the ADS-B-RAD analysis did not provide a justification for separation minima between ADS-B surveillance and PSR surveillance. In the RAD1 scenario there may be failure modes where the controller is presented with a PSR only return (i.e. where no ADS-B surveillance is available due to a failure in the system) for ‘Aircraft A’ and an ADS-B return for ‘Aircraft B’.

Where Aircraft B is also being detected by PSR then the ATCo may separate from the centres of the two PSR returns (as per the various section described in ICAO PANS ATM Chapter 8 such as 8.3.2, 8.7.2.3 and 8.7.3.2). However should aircraft B not, for some reason, be detected by the PSR then local procedures, as would apply in the reference design in so far as separation methods between PSR and SSR/Mode S returns, are required be promulgated to assist the controller.

GM085. Local authorities should review current procedures related to the separation of PSR and SSR/Mode S surveillance sources and assess the applicability for those procedures applying to the ADS-B-RAD system design.

The safety assessment performed in [Ref.1] has analysed the case where the ‘dispersed’ position symbols are presented on the controller display where, for example, the ground system has not been able to determine if the positions from different surveillance sources belong to the same aircraft (where in fact they are form the same aircraft). If the local implementation display technique chooses individual position symbols for PSR and ADS-B then this hazard does not come into effect as the symbols are already dispersed. However if the combined technique is chosen then this hazard is relevant and the associated requirements apply which have been derived primarily on the impacts the hazard has on the contr4ollers workload.

GM086. Local authorities should review their display technique in regards to PSR data and consider the requirements in ADS-B-RAD associated with OH9 and OH10 where necessary.

Annex I HUMAN TASKS IN ADS-B-RAD

In relation to the description of Argument 2 (System Design) an ADS-B-RAD logical design has been developed which includes the interface between the Flight Crew/ATCo and the ADS-B-RAD system (interfaces G2 [ATCO] and C1 [FC]).

In comparison to the Reference logical design it would appear that (a) this interface is located in the same logical position, (b) displays the same operational surveillance data items and (c) presents the surveillance data in the same manner. Hence it could be concluded that between the two designs, from a nominal operational perspective (i.e. failure modes are covered though safety analysis at Annex C of [Ref.1]) there are no discernable Human performance differences in regards to surveillance procedures.

<u>Flight Crew – interface C1</u>

The only possible change with surveillance procedures related to the C1 interface regards the entry of aircraft identification The following Safety Requirements have been identified for this topic:

SAF001: Flight crew shall apply PANS-OPS Doc 8168 [Ref.9] procedures.

SAF002: Flight Crew shall set, check and modify the Mode A code and Aircraft Identification throughout all phases of flight as instructed by ATC or as appropriate (SPR5 [Ref.1]).

SAF003: Flight Crew interface shall enable the Flight Crew to set, check and modify Mode A code and Aircraft Identification throughout all phases of flight (SPR5 [Ref.1])

SAF004: Flight Crew interface shall enable the Flight Crew to select the appropriate Emergency/SPI indication.

As this PSC assumes the same identification data (and hence procedures) that is used in the reference system is also used in the ADS-B-RAD system (see section 7.3.1.1) it can be concluded that the human performance related to these requirements would not change.

However should the implementation decide to change procedures (i.e. from Mode A codes to Aircraft Identification in the RAD-2a scenario) it could be argued that either (a) the flight crews are already experienced at entering Aircraft ID in nearby regions that support Mode S procedures or (b) the human performance difference between Aircraft Id and Mode A interaction is not different. However this argument remains the responsibility of the implementing authority.

Some design limitations to ensure comparability with reference case

In support of the claim that the C1 interface is the same between the reference and ADS-B-RAD designs, a number of requirements have been created to ensure that the implementation of ADS-B-RAD airborne systems do not introduce complexities in the cockpit.

SAF009: The aircraft installation shall use the same source for transmission of pressure altitude from both the SSR/ Mode S transponder and “ADS-B Aircraft” function (see ENV-ASSUMP.15 of [Ref.1]).

SAF010: The aircraft installation shall use the same sources for transmission of aircraft identity, emergency codes and special position identification (SPI), from both the SSR/Mode S transponder and “ADS-B Aircraft” function (see ENV-ASSUMP.16 of [Ref.1]).

The result of the these two safety requirements is essentially a physical limitation that ensure the ADS-B-RAD system contains only one entry point for identity data (including emergency and SPI/IDENT) as would also be the case in the reference design.

Controller – Interface G2

Given that the ADS-B-RAD system introduces a new surveillance source as compared to the reference design, it was paramount in the design process that interface G2 remained unaffected to ensure the ATC service and human performance factors where not negatively impacted. To this end a number of Safety Requirements were created as paraphrased below:

SAF021: For providing ATC services, controllers shall apply the same procedures as in the Reference system and these procedures are consistent with PANS ATM Doc4444 [Ref.3] procedures.

SAF026: The ADS-B-RAD ATC Processing and Display function shall provide the following list of ADS-B-derived surveillance data items to the controller (OR 1 [Ref.1]):

- Aircraft identification
- Mode A Code[72]
- Horizontal Position
- Vertical Position (Pressure-Altitude)
- Ground Speed
- Emergency indication

Special Position Identification (SPI)

The list of data items on display is the same as for reference and presented in a similar manner to reference logical design.

[72] It is planned that the ICAO DOC PANS ATM and Doc 9871 will be modified accordingly (i.e. to suppress the geographic Mode A Code filtering).

SAF027: The ADS-B-RAD ATC Processing and Display function shall present clear information so that the ATCo is able to determine which ‘part’ of the horizontal position symbol is to be used for applying separation standards (i.e. centre or the edges)(ENVT-ASSUMP.29-2 [Ref.1]) (as it would be in the reference design)

SAF025: ADS-B-derived data items shall be the principal information presented to the controller.

This requirement above ensure that nominally only one track is displayed regardless if the aircraft is being detected by multiple surveillance sources (excludes PSR returns which are covered under Annex H)

SAF028: The ADS-B-RAD ATC Processing and Display function shall display the horizontal position information with a constant refresh cycle (same as in the Reference radar-based system) and time synchronized (ENV-ASSUMP-18 [Ref.1]).

A002: It is assumed that there is no change in design of airspace between the reference and ADS-B-RAD systems (OSED ENV-ASSUMP 6 in [Ref.1]).

The result of these requirements (and assumptions) is that from a nominal perspective the design of interface G2 in regards to surveillance data is identical to that of the reference interface and as such has no negative impacts on human performance.

Annex J COMPARISON BETWEEN ADS-B-RAD AND REFERENCE CASES FOR COORDINATION AND TRANSFER.

This annex analyses and compares the various methods of coordination and transfer between ADS-B-RAD and Reference systems and concludes that no difference exists.

From an adjacent sector to ADS-B-RAD

TRANSFERRING SECTOR		**RECEIVING SECTOR**	**Difference between receiving sector supported by Reference system or by ADS-B-RAD**	
Transferring sector surveillance type	Methods used for transfer of identification		w.r.t transfer of identification?	w.r.t. separation?
Procedural	Not applicable (i.e. R/T)	ADS-B-RAD	**No difference**, whatever is performed when supported by the Reference system can be performed by ADS-B-RAD	**No difference**, aircraft transferred in conformance with procedural based minima (e.g. 10 minutes longitudinally/vertical) as per agreed LOA's.
Surveillance based	Mode A code based			**No difference,** transferring and receiving sector would be able to establish an LOA to enable the inter-sector transfer of aircraft separated by surveillance based minima such as 5Nm or other defined agreed distance
	Aircraft Identification			**No difference**, as above

<table>
<tr><th colspan="2">From ADS-B-RAD to an adjacent sector</th><th></th><th colspan="2"></th></tr>
<tr><th colspan="2">TRANSFERRING SECTOR</th><th>RECEIVING SECTOR</th><th colspan="2">Difference between transferring sector supported by Reference system or by ADS-B-RAD</th></tr>
<tr><th>Transferring sector surveillance type</th><th>Methods used for transfer of identification</th><th></th><th>w.r.t transfer of identification?</th><th>w.r.t. separation?</th></tr>
<tr><td rowspan="3">ADS-B-RAD</td><td>Not applicable (i.e. R/T)</td><td>Procedural</td><td rowspan="3">No difference, whatever is performed when supported by the Reference system can be performed by ADS-B-RAD</td><td>No difference, aircraft transferred in conformance with procedural based minima (e.g. 10 minutes longitudinally /vertical) as per agreed LOA's.</td></tr>
<tr><td>Mode A code based</td><td rowspan="2">Surveillance based</td><td>No difference, transferring and receiving sector would be able to establish an LOA to enable the inter-sector transfer of aircraft separated by surveillance based minima such as 5Nm or other defined agreed distance</td></tr>
<tr><td>Aircraft Identification</td><td>No difference, as above</td></tr>
</table>

Annex K REQUIREMENTS TRACEABILITY (AND ADAPTATION) TO [REF.1]

K.1 SPR Requirements

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
SPR 1	SAF012	SPR 1: The Aircraft Domain shall transmit a minimum data set that includes the data items listed below, (SPR 27 §3.4.1). • i. Aircraft Horizontal Position Information • ii. Aircraft Pressure Altitude • iii. Aircraft Position Quality Indicators • iv. Aircraft Identity • v. Emergency Indicators • vi. Special Position Identification (SPI) report SAF012: The Transmitting Aircraft domain shall transmit a minimum data set that includes the data items listed below (SPR 1, IR 1, IR 3, IR 4, IR 6, IR 7, IR 9, IR 16 in [Ref.1]): • Aircraft identification • Mode A code (see note 1 below). • ICAO 24 bit aircraft address • Horizontal Position information (Longitude, Latitude) • Horizontal Position Quality Indicators (see note 2 below) • Pressure Altitude • Special Position Indication (SPI) report • Emergency Indication	In the PSC, SPR 1 has been modified to better explicit the data items that compose the 'aircraft identity'. Editorial modifications have also been made.	No
SPR 2	SAF013	SPR 2: The position integrity quality indicator (NIC) shall be broadcast in every ADS-B position message, (PR 7 §B.4.2.2). SAF013: The position and related position integrity quality indicator (NIC) shall always be broadcast in the same ADS-B message (SPR 2 [Ref.1]).	In the PSC, SPR 2 has been modified to ease readability and understanding of the requirement and to be consistent with the definition of the ADS-B message.	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
SPR 3	SAF006	SPR 3: The “GNSS onboard horizontal position” source function shall provide a horizontal position integrity monitoring capability and horizontal position integrity and accuracy quality indicators (i.e., the integrity containment region and the 95% horizontal accuracy bound), (ER 6 §D.2.2). SAF006: The “GNSS onboard receive function” shall provide a horizontal position integrity monitoring capability and shall provide horizontal position integrity (HPL) and accuracy (HFOM) quality indicators (i.e., the integrity containment region and the 95% horizontal accuracy bound) (SPR 3 [Ref.1]).	The terms HPL and HFOM have been included to SPR 3 to specify the type of quality indicators at the output of the function.	No
SPR 4	Merged into SAF012 as a note	SPR 4: Unless requested otherwise by local ANSPs, aircraft ADS-B systems shall transmit the Mode A code (OR 6 §A.7). Note 1 of SAF012: it has been foreseen the possibility to inhibit Mode A code transmission by ADS-B (see SPR 4 [Ref.1]). However this is out of the scope of the PSC (see also GM018).	The reason why is explained in the note.	No
SPR 5	SAF002 SAF003	SPR 5: Pilots shall have the ability to set, check and modify Mode A code and Aircraft Identification throughout all phases of flight as instructed by ATC (OR 11 §A.7). SAF002: Flight Crew shall set, check and modify the Mode A code and Aircraft Identification throughout all phases of flight as instructed by ATC or as appropriate (SPR5 [Ref.1]). SAF003: Flight Crew interface shall enable the Flight Crew to set, check and modify Mode A code and Aircraft Identification throughout all phases of flight (SPR5 [Ref.1])	SPR 5 has been splitted in two SAF to make distinction between the procedure and the flight crew interface.	No
SPR 6	SAF022	SPR 6: To be eligible to receive 5 NM separation minima as part of the air traffic control services in the ADS-B-RAD En Route airspace, the Aircraft Domain shall provide data to the Ground Domain that meets the respective requirements in Table 1.	Extract of section 7.3.5.2 of the PSC: “Horizontal position accuracy and integrity values part of table Table 14 above are the minimum values necessary for an aircraft to be eligible for the separation minima considered in this document.	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
		SAF022 Separation minima of 5NM shall only be applied by ATCo to ADS-B eligible aircraft in en-route, with SSR radar available as back-up (See SPR 6 in [Ref.1]).	The management of the aircraft eligilibility is the ground responsibility to decide on wich separation minima will be applied based and therefore corresponding eligilibility requirements will be allocated to the ground domain in section 7.5.2.3."	
SPR 7	SAF023 SAF024	SPR 7: To be eligible to receive 3 NM and applicable approach separation minima as part of the air traffic control services in the ADS-B-RAD terminal airspace, the Aircraft Domain shall provide data to the Ground Domain that meets the respective requirements in Table 1. SAF023 Separation minima of 3NM shall only be applied by ATCo to ADS-B eligible aircraft in TMA, with PSR radar available (See SPR 7 in [Ref.1]).. SAF024 Separation minima of 2.5NM and 2NM shall only be applied by ATCo to ADS-B eligible aircraft respectively for succeeding aircraft on same final and for succeeding aircraft on adjacent ILS/MLS, with SSR radar available as back-up and PSR radar available (See SPR 7 in [Ref.1]).	See explanation provided above	No
SPR 8	SAF034	SPR 8: For 5 NM separation, the 95% accuracy of the measured horizontal position shall be less than 308 meters (NACP = 7). SAF034: In En-route, an aircraft is eligible for receiving 5Nm separation minima when its horizontal position quality indicators are NACp=7 or more and NICp=5 or more and with a minimum SIL of 3 (per flight hour) (SPR 8, SPR 15 in [Ref.1]). Note: : NACp = 7 means a 95% accuracy of horizontal position less than 308 meters and NICp=5 means a maximum 1.0 NM integrity containment radius)	Same requirement but SAF039 includes SPR 8 and SPR 15.	No
SPR 9	SAF035	SPR 9: For 3 NM separation, the 95% accuracy of the measured horizontal position shall be less than 171 meters (NACP= 8). SAF035: In TMA, an aircraft is eligible for receiving 3Nm separation minima when its horizontal position quality indicators are NACp=8 or more and NICp=6	Same requirement but SAF040 includes SPR 9 and SPR 16.	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
		or more and with a minimum SIL of 3 (per flight hour) (SPR 9, SPR 16 [Ref.1]). Note: NACp = 8 means a 95% accuracy of horizontal position less than 171 meters and NICp=6 means a maximum 0.6 NM integrity containment radius).		
SPR 10	SAF036	SPR 10: For 2 ½ NM separation in-trail on approach, the 95% accuracy of the measured horizontal position shall be less than 171 meters (NACP= 8). SAF036: An aircraft is eligible for receiving 2.5Nm separation minima in-trail on final approach, when its horizontal position quality indicators are NACp=8 or more and NICp=7 or more and with a minimum SIL of 3 (per flight hour) (SPR 10, SPR 17 [Ref.1]). Note: NACp = 8 means a 95% accuracy of horizontal position less than 171 meters and NICp=7 means a maximum 0.2 NM integrity containment radius).	Same requirement but SAF041 includes SPR 10 and SPR 17.	No
SPR 11	SAF037	SPR 11: For 2 NM dependent parallel approach separation, the 95% accuracy of the measured horizontal position shall be less than 171 meters (NACP= 8). SAF037: An aircraft is eligible for receiving 2Nm separation minima on final approach for dependent parallel runways operations, when its horizontal position quality indicators are NACp=8 or more and NICp=7 or more and with a minimum SIL of 3 (per flight hour) (SPR 11, SPR 18 [Ref.1]). Note: NACp = 8 means a 95% accuracy of horizontal position less than 171 meters and NICp=7 means a maximum 0.2 NM integrity containment radius)	Same requirement but SAF042 includes SPR 11 and SPR 18.	No
SPR 12	SAF038	SPR 12: For independent parallel approach separation, the 95% accuracy of the measured horizontal position shall be less than 121 meters (NACP= 8). SAF038: An aircraft is eligible for independent parallel approach operation, when its horizontal position quality indicators are NACp=8 or more and NICp=7 or more and with a minimum SIL of 3 (per flight hour) (SPR 12, SPR 19 [Ref.1]). Note: NACp = 8 means a 95% accuracy of horizontal position less than 121 meters and NICp=7 means a maximum 0.2 NM integrity containment radius)	Same requirement but SAF043 includes SPR 12 and SPR 19.	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
		Note: see more explanation on the process used in annex B - PR14 of [Ref.1])		
SPR 13	SAF007	No	No	-
SPR 14	SAF008	Yes	It has been clarified that the probabilitiy is “per position source failure event”.	No
SPR 15	SAF034	SPR 15: For 5 NM separation, the value of the horizontal position containment radius shall be less than or equal to 1 NM (NIC greater than or equal to 5). SAF034: In En-route, an aircraft is eligible for receiving 5Nm separation minima when its horizontal position quality indicators are NACp=7 or more and NICp=5 or more and with a minimum SIL of 3 (per flight hour) (SPR 8, SPR 15 in [Ref.1]). Note: : NACp = 7 means a 95% accuracy of horizontal position less than 308 meters and NICp=5 means a maximum 1.0 NM integrity containment radius)	Same requirement but SAF039 includes SPR 8 and SPR 15.	No
SPR 16	SAF035	SPR 16: For 3 NM separation, the value of the horizontal position containment radius shall be less than or equal to 0.6 NM (NIC greater than or equal to 6). SAF035: In TMA, an aircraft is eligible for receiving 3Nm separation minima when its horizontal position quality indicators are NACp=8 or more and NICp=6 or more and with a minimum SIL of 3 (per flight hour) (SPR 9, SPR 16 [Ref.1]). Note: NACp = 8 means a 95% accuracy of horizontal position less than 171 meters and NICp=6 means a maximum 0.6 NM integrity containment radius).	Same requirement but SAF040 includes SPR 9 and SPR 16.	No
SPR 17	SAF036	SPR 17: For 2 ½ NM separation in-trail on approach, the value of the horizontal position containment radius shall be less than or equal to 0.2 NM (NIC greater than or equal to 7). SAF036: An aircraft is eligible for receiving 2.5Nm separation minima in-trail on final approach, when its horizontal position quality indicators are NACp=8 or more and NICp=7 or more and with a minimum SIL of 3 (per flight hour) (SPR 10, SPR 17 [Ref.1]).	Same requirement but SAF041 includes SPR 10 and SPR 17.	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
		Note: NACp = 8 means a 95% accuracy of horizontal position less than 171 meters and NICp=7 means a maximum 0.2 NM integrity containment radius).		
SPR 18	SAF037	SPR 18: For 2 NM dependent parallel approach separation, the value of the horizontal position containment radius shall be less than or equal to 0.2 NM (NIC greater than or equal to 7). SAF037: An aircraft is eligible for receiving 2Nm separation minima on final approach for dependent parallel runways operations, when its horizontal position quality indicators are NACp=8 or more and NICp=7 or more and with a minimum SIL of 3 (per flight hour) (SPR 11, SPR 18 [Ref.1]). Note: NACp = 8 means a 95% accuracy of horizontal position less than 171 meters and NICp=7 means a maximum 0.2 NM integrity containment radius)	Same requirement but SAF042 includes SPR 11 and SPR 18.	No
SPR 19	SAF038	SPR 19: For independent parallel approach separation, the value of the horizontal position containment radius shall be less than or equal to 0.2 NM (NIC greater than or equal to 7). SAF038: An aircraft is eligible for independent parallel approach operation, when its horizontal position quality indicators are NACp=8 or more and NICp=7 or more and with a minimum SIL of 3 (per flight hour) (SPR 12, SPR 19 [Ref.1]). Note: NACp = 8 means a 95% accuracy of horizontal position less than 121 meters and NICp=7 means a maximum 0.2 NM integrity containment radius) Note: see more explanation on the process used in annex B - PR14 of [Ref.1])	Same requirement but SAF043 includes SPR 12 and SPR 19.	No
SPR 20	SAF093 SAF096	SPR 20: The continuity of the ADS-B Aircraft Domain shall be 0.9998 per flight hour. SAF093: The likelihood of a GNSS on-board Receive function system continuity failure shall be 2E-04 or less per flight hour. (SR 06, SPR 20 in [Ref.1]) SAF096: The likelihood of an Aircraft ADS-B function system continuity failure shall be 2.0E-04 or less per flight hour. (SR 08, SPR 20 in [Ref.1])	SPR 20 is derived from a performance requirement, based on typical values of SSR transponders, which should correspond to the ADS-B Function only (SAF096).	Yes

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
SPR 21	SAF092	No	No	-
SPR 22	SAF095	No	No	-
SPR 23	SAF014	No	No	-
SPR 24	SAF015	No	No	-
SPR 25	SAF016	No	No	-
SPR 26	SAF043	No	No	-
SPR 27	SAF044	No	Same except that as for previous SPR 1 the term 'aircraft identity ' has been decomposed into:aircraft identification, Mode A code and 24-bit address.	-
SPR 28	SAF099	SPR 28: When direct recognition procedures are used by the ATCO for identification, the ADS-B Ground Domain shall contain a function to ensure the aircraft identity data that is broadcast is retained and correctly associated with the position information for display, (OR 5 §A.5.6.2.4, §A.7). SAF099 The likelihood of an ADS Ground Domain (Ground ADS-B receive function, Ground ADS-B Surveillance processing function and the ADS-B-to-radar association function) system integrity failure shall be 2.0E-05 or less per sector hour. (SPR 33 in [Ref.1])	SPR 28 overtaken by SAF099 (SPR 33 - SR 07) that corresponds to Ground ATC Processing integrity failure basic cause for hazards related to incorrect Id	No
SPR 29	SAF045	SPR 29: The "Ground ADS-B Receive" function shall provide in each ADS-B surveillance report a time of applicability (Interface E2) of the position information, (PR 30 §B.4.5). SAF045: Each type of ADS-B Surveillance data (i.e. position, identity and/or Emergency/SPI data) provided in ADS-B report(s) shall have a time of	In the PSC, SPR 29 is covered by SAF045 to ease readability and understanding of the requirement. Moreover the PSC is limited to the functional notion of ADS-B reports and does not include the detailed notion of surveillance report	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
		applicability (SPR 29 [Ref.1]).		
SPR 30	SAF045	SPR 30: If the time of applicability within each ADS-B surveillance report is not applicable for all data items of that report (interface E2), the “Ground ADS-B Receive” function shall provide separate times of applicability for the specific data items that differ, (PR 31 §B.4.5). SAF045 See above	SPR 30 is covered by SAF045 where each individual data item shall have its time of applicability (PSC is limited to the functional notion of ADS-B reports and does not include the detailed notion of surveillance report).	No
SPR 31	SAF030	SAF030: The ADS-B-RAD ATC Processing and Display function shall extrapolate the ADS-B position data, based on time-registering the asynchronously received updates, to a common display time. SPR 31: The “Ground ADS-B Surveillance Processing” function shall time register the asynchronously received ADS-B position updates from ADS-B-equipped aircraft (OPA-ASSUMP.07 §B.2.2).	Clarification	No
SPR 32	SAF078 SAF083 SAF086	SAF078 In case of loss or degradation of ADS-B horizontal position quality below the required threshold for a single or multiple aircraft after the notification to the controller (as per SAF077), the ADS-B-RAD ATC Processing and Display function shall automatically provide the corresponding SSR radar data item to the controller. (SPR 32 in [Ref.1]) SAF083 The Ground ADS-B receive function and the ADS-B-RAD ATC processing and Display function shall detect a loss of ADS-B-reported altitude and provide the corresponding SSR-reported altitude to the controller with a probability of at least 99%. (SPR 32, SPR 41, ASSUMP 46 in [Ref.1]) SAF086 The Ground ADS-B receive function and the ADS-B-RAD ATC processing and Display function shall detect a loss of ADS-B aircraft identity and provide the same SSR aircraft identity to the controller with a probability of at least 99.99% (SPR 32, See ASSUMP 41 in [Ref.1]). 2 requirements instead of one requirement in [Ref.1] , one per data item. A note below each requirement explains that there is no need for re-verification of altitude or re-identification.	To ease readability and understanding of the requirements	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
SPR 33	SAF099	SPR 33 The likelihood of an ADS-B Ground Domain system integrity failure shall be 2E-05 or less per hour. SAF099 The likelihood of an ADS Ground domain (Ground ADS-B receive function, Ground ADS-B Surveillance processing function and the ADS-B to radar association function) system integrity failure shall be 2.0E-05 or less per sector hour. (SPR 33 in [Ref.1])	It has been clarified which sub-functions are included in the ADS-B Ground Domain	No
SPR 34	SAF098	No	No	-
SPR 35	SAF047	SPR 35: The 95% latency for ADS-B surveillance reports (measured between points D and E2 – output of the “Ground ADS-B Receive” function) shall be no greater than 0.5 seconds, excluding communication latency to the ATC processing system. SAF047: The 95% latency for ADS-B Reports shall be no greater than 0.5s, excluding communication latency to the ATC processing system (SPR 35 [Ref.1])	Editorial modifications.	No
SPR 36	SAF046	The only difference is that in the PSC, the term “ADS-B report” is used instead of “ADS-B surveillance report”	Correction made	No
SPR 37	SAF056	No	No	-
SPR 38	SAF057	SPR 38: The ADS-B Ground Domain (including data link) shall not degrade altitude resolution to worse than 100 feet. SAF057 The ADS-B Ground Domain shall not degrade altitude resolution to worse than 100 ft (SPR 38 [Ref.1]).	In the PSC it is clearly defined that the ADS-B Ground Domain includes the ADS-B data link	No
SPR 39	SAF058	No	No	-
SPR 40	SAF077	SPR 40: The probability that the ADS-B Ground Domain detects a loss of ADS-B position, and provides an indication of such to the existing ATC Processing System shall be at least 99.99%.	To ease readability of the requirement and to cover the ADS-B-RAD ATC	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
		SAF077 The Ground ADS-B receive function and the ADS-B-RAD ATC Processing and Display function shall detect a loss or degradation of ADS-B horizontal position quality below the required threshold for a specific or multiple aircraft and provide an indication of such to the controller with a probability of at least 99.99% (SPR 40, ASSUMP 44 in [Ref.1]) The requirement in the PSC has merged SPR 40 and ASSUMP 44 and covers the detection of the failure, the notification to the controller and the performance of the functions.	Processing and Display function in the PSC as part of the system under assessment.	
SPR 41	SAF083	SPR 41: The probability that the ADS-B Ground Domain detects a loss of ADS-B-reported altitude, and provides an indication of such to the existin ATC Processing System shall be at least 99%. SAF083 The Ground ADS-B receive function and the ADS-B-RAD ATC processing and Display function shall detect a loss of ADS-B-reported altitude and provide the corresponding SSR-reported altitude to the controller with a probability of at least 99%. (SPR 32, SPR 41, ASSUMP 46 in [Ref.1]) The requirement in the PSC has merged SPR 41 and ASSUMP 46 and covers the detection of the failure, the notification to the controller and the performance of the functions.	To ease readability of the requirement and to cover the ADS-B-RAD ATC Processing and Display function in the PSC as part of the system under assessment.	No
SPR 42	SAF085	SPR 42: The probability that the “ADS-B to Radar Association” function detects an inconsistency between an ADS-B- and radar-reported emergency code, and provides an indication of such to the existing ATC Processing System shall be at least 99%. SAF085 The ADS-B-RAD ATC Processing and Display function shall detect an inconsistency between ADS-B- and radar-reported emergency codes, and provide an indication of such to the controller with a probability of at least 99%. (SPR 42, ASSUMP 37 in [Ref.1]) The requirement in the PSC has merged SPR 42 and ASSUMP 37 and covers the detection of the failure, the notification to the controller and the performance of the functions.	To ease readability of the requirement and to cover the ADS-B-RAD ATC Processing and Display function in the PSC as part of the system under assessment.	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
SPR 43	SAF090	SPR 43: The probability that the “ADS-B to Radar Association” function detects an inconsistency between ADS-B and SSR aircraft identity data (i.e., Mode A or aircraft identification), and provides an indication of such to the existing ATC Processing System shall be at least 99%. SAF090 The ADS-B-RAD ATC Processing and Display function shall detect of an inconsistency between radar an ADS-B Identity data (i.e. Mode A or aircraft identification) and provide separate system tracks to the controller for each source, with a probability of least 99%. (SPR 43, ASSUMP 38 in [Ref.1]) The requirement in the PSC has merged SPR 43 and ASSUMP 38 and covers the detection of the failure, the notification to the controller and the performance of the functions.	To ease readability of the requirement and to cover the ADS-B-RAD ATC Processing and Display function in the PSC as part of the system under assessment.	No
SPR 44	SAF084	SPR 44: The probability that the “ADS-B to Radar Association” function detects an inconsistency between ADS-B and SSR aircraft pressure altitude data, and provides an indication of such to the existing ATC Processing System shall be at least 99%. SAF084 The ADS-B–RAD ATC Processing and Display function shall detect an inconsistency of more than 500 ft between radar and ADS-B pressure altitude, and provide an indication of such to the controller with a probability of at least 99%. (SPR 48, SPR 44, ASSUMP 48 in [Ref.1]) The requirement in the PSC has merged SPR 44 and ASSUMP 48 and covers the detection of the failure, the notification to the controller and the performance of the functions.	To ease readability of the requirement and to cover the ADS-B-RAD ATC Processing and Display function in the PSC as part of the system under assessment.	No
SPR 45	SAF091	SPR 45: The probability that the ADS-B Ground Domain detects duplicate ADS-B Aircraft Identities (i.e., discrete Mode A or aircraft identification) within the same sector), and provides an indication of such to the existing ATC Processing System shall be at least 99%. SAF091 The ADS-B-RAD ATC processing and Display function shall detect duplicate ADS-B Aircraft Identities (i.e. discrete Mode A or aircraft ID) within the same sector and provide an indication of such to the controller with a probability	To ease readability of the requirement and to cover the ADS-B-RAD ATC Processing and Display function in the PSC as part of the system under assessment.	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
		of at least 99%. (SPR 45, ASSUMP 39 in [Ref.1]) The requirement in the PSC has merged SPR 45 and ASSUMP 39 and covers the detection of the failure, the notification to the controller and the performance of the functions.		
SPR 46	SAF081	SPR 46: The probability that the “ADS-B to Radar Association” function detects a large ADS-B position error, and provides an indication of such to the existing ATC Processing System shall be at least 99%, where a large error is at least 40% of the separation minima for the ADS-B-RAD environment. SAF081 The ADS-B–RAD ATC Processing and Display function shall detect a “large” difference in horizontal position information between ADS-B and radar and provide separate system tracks to the controller for each source, with a probability of at least 99% (SPR 46 and ASSUMP 43 in [Ref.1]). The requirement in the PSC has merged SPR 46 and ASSUMP 43 and covers the detection of the failure, the notification to the controller and the performance of the functions.	To ease readability of the requirement and to cover the ADS-B-RAD ATC Processing and Display function in the PSC as part of the system under assessment.	No
SPR 47	SAF082	SPR 47: The probability that the “ADS-B to Radar Association” function detects a significant ADS-B horizontal position error, and provides an indication of such to the existing ATC Processing System, shall be at least 90%, where a significant error is at least equal to the NIC boundary but less than 40% of the separation minima for the ADS-B-RAD environment. SAF082 The ADS-B–RAD ATC Processing and Display function shall detect a “significant” difference in horizontal position information between ADS-B and radar and provide separate system tracks to the controller for each source, with a probability of at least 90% (SPR 47 and ASSUMP 43 in [Ref.1]) The requirement in the PSC has merged SPR 47 and ASSUMP 43 and covers the detection of the failure, the notification to the controller and the performance of the functions	To ease readability of the requirement and to cover the ADS-B-RAD ATC Processing and Display function in the PSC as part of the system under assessment.	No
SPR 48	SAF084	SPR 48: The probability that the “ADS-B to Radar Association” function detects an error of more than 500 ft between ADS-B and SSR pressure altitudes shall be	To ease readability of the requirement and to cover the ADS-B-RAD ATC	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
		at least 99%. SAF084 The ADS-B–RAD ATC Processing and Display function shall detect an inconsistency of more than 500 ft between radar and ADS-B pressure altitude, and provide an indication of such to the controller with a probability of at least 99%. (SPR 48, SPR 44, ASSUMP 48 in [Ref.1]) The requirement in the PSC has merged SPR 44 and SPR 48, which were found to be equivalent.	Processing and Display function in the PSC as part of the system under assessment.	
SPR 49	SAF048	SPR 49: The probability of providing a Surveillance Report containing newly received ADS-B Position data of sufficient quality associated with any aircraft in En Route airspace within 8 seconds shall be 97%. SAF048 For supporting 5NM separation minima in En-Route: The time interval for Reports containing newly received ADS-B Position data of sufficient quality associated with any single aircraft shall be no longer than 8s with a probability of 97% (SPR 49 [Ref.1]).	To ease readability of the requirement and to be consistent with the definition of the ADS-B report.	No
SPR 50	SAF049	SPR 50 : The time interval between a change of Mode A code provided by the ADS-B aircraft domain and an ADS-B surveillance report containing the new Mode A code at interface E2 shall be no longer than 8 seconds (95%) En Route SAF049 For supporting 5NM separation minima in En-Route: The time interval between a change of identity (aircraft identification or Mode A code) at ADS-B aircraft domain level and the reception of an ADS-B report containing the new Mode A code at interface E2 shall be no longer than 8s with a probability of 95% (SPR 50 [Ref.1]).	The requirement in the PSC is now applicable to the Aircraft Identification, primary means of identification in scenario RAD-2b (as it would be in the reference ce system).	No
SPR 51	SAF050	No	No	No
SPR 52	SAF051	No	No	No
SPR 53	SAF052	SPR 53: The probability of providing a Surveillance Report containing newly received ADS-B Position data of sufficient quality associated with any aircraft in TMA airspace within 5 seconds shall be 97%.	To ease readability of the requirement and to be consistent with the definition of the ADS-B report.	No

SPR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
		SAF052 For supporting 3, 2.5, 2NM separation minima in TMA, the time interval for Reports containing any newly received ADS-B Position data of sufficient quality associated with any single aircraft shall be less than 5s with a probability of 97% (SPR 53 [Ref.1]).		
SPR 54	SAF053	SPR 54: The time interval between a change of Mode A code provided by the ADS-B aircraft domain and an ADS-B surveillance report containing the new Mode A code at point E2 shall be no longer than 5 seconds (95%) TMA SAF053: For supporting 3, 2.5, 2NM separation minima in TMA, the time interval between a change of identity (aircraft identification or Mode A code) at ADS-B aircraft domain level and the reception of an ADS-B report containing the new Mode A code at interface E2 shall be no longer than 5s with a probability of 95% (SPR 54 [Ref.1]).	The requirement in the PSC is now applicable to the Aircraft Identification, primary means of identification in scenario RAD-2b (as it would be in the reference ce system).	No
SPR 55	SAF054	No	No	No
SPR 56	SAF055	No	No	No

K.2 Interoperability Requirements

IR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
IR 1	SAF012	IR 1: The Aircraft Domain shall provide ADS-B messages containing at least the elements specified in SPR 1, enabling the “Ground ADS-B Receive” function to format the required ADS-B Surveillance reports for the ADS-B-RAD application (SPR 1 §3.3.1).	This requirement was considered to be already covered in SAF012	No
IR 2	SAF069	No	No	-
IR 3	SAF012	IR 3 : The Aircraft Domain shall provide the unique ICAO 24-bit aircraft address within each ADS-B Message	SAF012 already includes this data item to be transmitted to the Ground Domain.	No
IR 4	SAF012	IR 4 : The Aircraft Domain shall provide an ADS-B message containing the aircraft identification.	SAF012 already includes this data item to be transmitted to the Ground Domain.	No
IR 5	SAF063	No	No	-
IR 6	SAF012	IR 6 : Unless requested otherwise by local ANSPs, the Aircraft Domain shall transmit an ADS-B Message containing the Mode A code.	SAF012 already includes this data item to be transmitted to the Ground Domain.	No
IR 7	SAF012	IR 7 : The Aircraft Domain shall transmit horizontal position information (i.e., latitude and longitude).	SAF012 already includes this data item to be transmitted to the Ground Domain.	Np
IR 8	SAF064	No	No	-

IR in [Ref.1]	Related SAF	Difference identified	Rationale	Severity of the Change
IR 9	SAF012	IR 9: The Aircraft Domain shall transmit pressure altitude.	SAF012 already includes this data item to be transmitted to the Ground Domain.	No
IR 10	SAF065	No	No	-
IR 11	SAF066	No	No	-
IR 12	SAF067	No	No	-
IR 13	SAF066	IR 13: A distinction between NUCP and NIC, NACP, and SIL airborne implementations shall be provided by the Aircraft Domain (e.g., a datalink-specific defined version number) SAF066: The indicators of horizontal position quality transmitted by the Transmitting Aircraft Domain shall be in accordance with the respective version number (version 1 or 2) of the data link protocol in use transmitted (see IR 11, IR 13 in [Ref.1]).	IR 13 has been modified as in Europe "version 1" (DO-242A) and Version 2 (version 2" (ED-102A/DO-260B are applicable. NUCp will not be used in that perspective, and Annex E of [Ref.1] is also not applicable.	Yes
IR 14	SAF012	IR 1: The Aircraft Domain shall provide ADS-B messages containing at least the elements specified in SPR 1, enabling the "Ground ADS-B Receive" function to format the required ADS-B Surveillance reports for the ADS-B-RAD application (SPR 1 §3.3.1).	This requirement was considered to be already covered in SAF012	No
IR 15	SAF068	No	No	-
IR 16	SAF012	IR 16 : The Aircraft Domain shall send an indicator when the special position identification (SPI) is set.	SAF012 already includes some this data item to be transmitted to the Ground Domain.	No
IR 17	No	No	Deleted as optional	No
IR 18	No	No	Deleted as optional	No

K.3 New Safety Requirements Compared to ED-161 [Ref.1] SPR Requirements

SAF #	Traceability to ED-161 [Ref.1] SPR requirements	Category
SAF001	-	Procedure
SAF002	SPR5	-
SAF003	SPR5	-
SAF004	-	Procedure
SAF005	-	Assumption in [Ref.1]
SAF006	SPR3	-
SAF007	SPR13	-
SAF008	SPR14	-
SAF009	-	Assumption in [Ref.1]
SAF010	-	Assumption in [Ref.1]
SAF011	-	Functional clarification
SAF012	SPR1, SPR4, IR1, IR3, IR4, IR6, IR7, IR9, IR14, IR16	-
SAF013	SPR2	-
SAF014	SPR23	-
SAF015	SPR24	-
SAF016	SPR25	-
SAF017	-	Performance requirement in [Ref.1]
SAF018	-	Performance requirement in [Ref.1]
SAF019	-	Performance requirement in [Ref.1]
SAF020	-	coverage
SAF021	-	Procedure
SAF022	SPR6	-
SAF023	SPR7	-
SAF024	SPR7	-
SAF025	-	Procedure
SAF026	-	Functional clarification
SAF027	-	Functional clarification
SAF028	-	Functional clarification
SAF029	-	Functional clarification
SAF030	SPR31	-
SAF031		Functional clarification
SAF032	-	Functional clarification
SAF033	-	Functional clarification
SAF034	SPR8, SPR15	-
SAF035	SPR9, SPR16	-
SAF036	SPR10, SPR17	-
SAF037	SPR11, SPR18	-
SAF038	SPR12, SPR19	-
SAF039	-	Assumption in [Ref.1]
SAF040	-	Functional clarification
SAF041	-	Functional clarification
SAF042	-	Functional clarification
SAF043	SPR26	-

SAF #	Traceability to ED-161 [Ref.1] SPR requirements	Category
SAF044	SPR27	-
SAF045	SPR29, SPR30	-
SAF046	SPR36	-
SAF047	SPR35	-
SAF048	SPR49	-
SAF049	SPR50	-
SAF050	SPR51	-
SAF051	SPR52	-
SAF052	SPR53	-
SAF053	SPR54	-
SAF054	SPR55	-
SAF055	SPR56	-
SAF056	SPR37	-
SAF057	SPR38	-
SAF058	SPR39	-
SAF059	-	Assumption in [Ref.1]
SAF060	-	Assumption in [Ref.1]
SAF061	-	Assumption in [Ref.1]
SAF062	-	Assumption in [Ref.1]
SAF063	IR5	-
SAF064	IR8	-
SAF065	IR10	-
SAF066	IR11, IR13	-
SAF067	IR12	-
SAF068	IR15	-
SAF069	IR2	-
SAF070	-	Procedure
SAF071	-	Procedure
SAF072	-	Assumption in [Ref.1]
SAF073	-	Assumption in [Ref.1]
SAF074	-	Procedure
SAF075	-	Assumption in [Ref.1]
SAF076	-	Assumption in [Ref.1]
SAF077	SPR40	-
SAF078	SPR32	-
SAF079	-	Functional clarification
SAF080	-	Functional clarification
SAF081	SPR46	-
SAF082	SPR47	-
SAF083	SPR41, SPR32	-
SAF084	SPR44, SPR48	-
SAF085	SPR42	-
SAF086	SPR32	-
SAF087	-	Assumption in [Ref.1]
SAF088	-	Assumption in [Ref.1]
SAF089	-	Assumption in [Ref.1]
SAF090	SPR43	-
SAF091	SPR45	-

SAF #	Traceability to ED-161 [Ref.1] SPR requirements	Category
SAF092	SPR21	-
SAF093	SPR20	-
SAF094	-	Assumption in REF1
SAF095	SPR22	-
SAF096	SPR20	-
SAF097	-	Assumption in [Ref.1]
SAF098	SPR34	-
SAF099	SPR33	-