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SAFETY, PERFORMANCE AND INTEROPERABILITY REQUIREMENTS DOCUMENT FOR ADS-B-NRA APPLICATION

ED-126 V1.0

December 2005

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Table of Contents

CHAPTER 1. INTRODUCTION 10
1.1 Purpose of this document 10
1.1.1 ADS-B-NRA 10
1.1.2 Approval Material 10
1.1.3 EUROCAE ED78A/RTCA DO-264 10
1.2 Scope of the document 11
1.2.1 ADS-B-NRA context 11
1.2.2 Approval Material 12
1.2.3 Use of ED78A/DO-264 13
1.3 Structure of this document 14
1.3.1 Document Organisation 14
1.3.2 Document traceability 15
1.4 References 15
1.4.1 ICAO 15
1.4.2 EUROCONTROL 16
1.4.3 FAA 16
1.4.4 EUROCAE/RTCA 16
1.4.5 Miscellaneous 16
CHAPTER 2. ASSUMPTIONS 17
2.1 OSED assumptions 17
2.2 OPA assumptions 17
2.3 OSA Assumptions 17
2.3.1 Operational experts assumptions 17
2.3.2 Environmental conditions (EC) 17
2.3.3 External Mitigation Means (EMM) 17
2.3.4 Internal Mitigation Means (IMM) 17
2.3.5 Safety assumptions 18
2.4 Interoperability Assumptions 18
2.5 Assumed Airborne & Ground generic functional Architecture 18
CHAPTER 3. Safety & Performance Requirements (SPR) 20
3.1 Aircraft – Safety and Performance Requirements/Recommendations 20
3.1.1 General requirements 20
3.1.2 ADS-B message 20
3.1.3 Aircraft identification, mode A code, SPI & 24 bit aircraft address 20
3.1.4 Horizontal position 21
3.1.5 Altitude 22
3.1.6 Altitude Resolution 22
3.1.7 Quality indicator (QI) 22
3.1.8 Emergency 23
3.2 Aircraft Operator – Safety and Performance Requirements/Recommendations 24
3.2.1 General human factor assumption 24

3.2.2 General requirements ... 24
3.2.3 Aircraft identification, Mode A code, SPI & 24 bit aircraft address ... 24
3.2.4 Altitude ... 24
3.3 ATS Provider – Safety and Performance Requirements/Recommendations ... 26
3.3.1 Ground processing system assumption ... 26
3.3.2 General human factor assumption ... 26
3.3.3 General requirements ... 26
3.3.4 ADS-B reports ... 27
3.3.5 Aircraft identification/mode A code, SPI & 24 bit aircraft address ... 28
3.3.6 Horizontal position ... 29
3.3.7 Quality indicator (QI) ... 29
3.3.8 Emergency ... 30
CHAPTER 4. INTEROPERABILITY REQUIREMENTS ... 31
4.1 Purpose of Interoperability Requirements ... 31
4.2 Presentation of the Interoperability Requirements in this Document ... 31
4.2.1 Organisation of the Annexes for Interoperability Requirements ... 31
Annex A OSED ... 32
A.1 Environment Description ... 32
A.2 Application Description ... 37
A.2.1 Introduction ... 37
A.2.2 Context ... 38
A.2.3 Objective ... 38
A.2.4 Procedure description ... 39
A.2.5 Airspace Characteristics and Operational Environment ... 43
A.2.6 ADS-B-NRA Control Phases ... 44
A.2.7 Abnormal Modes ... 45
A.2.8 Requirements ... 46
A.2.9 References ... 48
Appendix A.1 An example of a mixed operations environment at Kiruna ... 50
Appendix A.2 An example of a mixed operations environment in Australia ... 51
Appendix A.3 Phase Diagrams ... 53
Appendix A.4 Definition of ADS-B surveillance terms ... 60
Annex B OPA ... 62
B.1 Introduction ... 62
B.1.1 Purpose ... 62
B.1.2 The CNS/ATM system ... 62
B.1.3 Glossary of terms ... 62
B.2 ADS-B-NRA OPA Approach ... 63
B.2.1 Scope of the ADS-B-NRA OPA ... 63
B.2.2 Comparative approach and reference radar ... 63
B.3 Required data items at the input of the “ATC Processing System” ... 64
B.3.1 List of required surveillance data items ... 64

B.4 Definition of the performance parameters ... 66
B.4.1 Update interval and update probability ... 66
B.4.2 Accuracy ... 68
B.4.3 Integrity ... 68
B.4.4 Reliability ... 71
B.4.5 Other Surveillance parameter definitions ... 72
B.5 Performance requirements at the input of the “ATC Processing System” ... 74
B.5.1 References for Performance Values ... 74
B.5.2 Update interval and update probability Requirements ... 75
B.5.3 Accuracy Requirements ... 76
B.5.4 Integrity Requirements ... 77
B.5.5 Reliability Requirements ... 79
B.5.6 Other Parameter Requirements ... 81
B.6 ADS-B Requirement Breakdown between transmit aircraft domain and Ground domain ... 82
B.6.1 ADS-B Update interval and update probability Requirements ... 83
B.6.2 ADS-B Accuracy Requirements ... 86
B.6.3 ADS-B Integrity Requirements ... 87
B.6.4 ADS-B Reliability Requirements ... 90
B.6.5 ADS-B Other Requirements ... 92
B.7 Additional material – Radar Errors for Comparison ... 95
B.7.1 Classes of Radar Errors ... 95
B.7.2 Radar Measurent Errors ... 95
B.7.3 Radar Error Models ... 96
B.7.4 Specification of Radar Plan Position Errors ... 97
B.7.5 Radar error distributions ... 98
B.7.6 Reconciliation between radar models ... 99
B.8 Additional material – Comparison of Surveillance Risk ... 100
B.8.1 Surveillance Risk ... 100
B.8.2 CAP method ... 100
B.8.3 CAP for radar reference baseline ... 100
B.8.4 Comparative Assessment Approach for ADS-B ... 103
B.9 Additional material – Time Stamping and Latency of Surveillance Data ... 105
B.9.1 Introduction ... 105
B.9.2 Radar Time Characteristics ... 105
B.9.3 ADS-B Time Characteristics ... 106
Annex C OSA ... 107
C.1 Introduction ... 107
C.1.1 Annex Objectives ... 107
C.1.2 OSA purpose and scope ... 107
C.1.3 References ... 107
C.1.4 Definition of Safety terms ... 107
C.2 Safety Assessment Approach ... 108

C.2.1 OHA Process ... 109
C.2.2 ASOR Process ... 116
C.2.3 Role of actors in OSA process ... 120
C.2.4 Process and results Mapping ... 121
C.3 Major OSED Outputs ... 122
C.3.1 NRA Modelling ... 122
C.3.2 Identification of Environmental Conditions ... 122
C.4 Operational Hazard Assessment (OHA) ... 123
C.4.1 Operational Hazards identification ... 123
C.4.2 Assessment of Operational Hazards ... 124
C.4.3 Safety Objectives assignment ... 127
C.4.4 Link to Close Approach Probability calculation ... 128
C.5 Allocation of Safety Objectives and Requirements (ASOR) ... 130
C.5.1 Identification of Basic Causes ... 130
C.5.2 Safety Objectives allocation ... 133
C.5.3 Safety requirements derived from basic causes ... 135
C.5.4 OSA Results ... 141
Annex D Fault Trees ... 147
Annex E Summary from ADS-B-NRA expert analysis ... 159
E.1 SCOPE ... 159
E.2 External Mitigation Means: ... 160
E.3 Internal Mitigation means: ... 161
E.4 Important Notes: ... 161
E.5 Participation: ... 163
Annex F Automatic Dependent Surveillance—Broadcast Surveillance Requirements to Support Air Traffic Control Separation Standards (Summary) - S. R. Jones, MITRE/CAASD ... 164
F.1 Introduction ... 164
F.2 Reference System Radar Baseline ... 165
F.2.1 Terminal area 3 NM separation baseline ... 165
F.2.2 En route 5 NM separation baseline ... 166
F.3 Comparative Assessment for ADS-B ... 166
F.3.1 Comparative risk assessment ... 167
F.3.2 Comparison of Acceptable ADS-B Accuracies with SWSSR and MSSR Accuracies ... 170
F.4 Summary ... 171
F.5 List of References ... 172
Annex G Mapping between integrity and NUC/NIC/NAC ... 173
G.1 NUCp, NIC, NACp Relationships and Summary of Separation Requirements ... 173
G.2 Minimum ADS-B requirements based on SSR comparative risk assessment ... 174
Annex H Analysis of NUCp use risk ... 175
H.1 Introduction ... 175
H.2 Further mitigations ... 177
H.3 Other considerations ... 177

Annex I INTEROPERABILITY STANDARD 178
I.1 Introduction 178
I.1.1 Purpose 178
I.1.2 Scope 178
I.1.3 Relationship to other documents 179
I.1.4 How to use this document 179
I.1.5 References 183
I.2 Description and General Requirements for ADS-B-NRA 183
I.2.1 Main Components 183
I.2.2 Functions of the ADS-B-NRA application 184
I.2.3 General requirements for ADS-B-NRA 184
I.3 Requirements for the ADS-B-NRA application specific information 186
I.3.1 Identity 186
I.3.2 Position 187
I.3.3 Emergency/SPI indicators 190
I.3.4 Ground Velocity 191
I.3.5 Other Ground Domain specific Requirements for the ADS-B-NRA application 191
Annex J ADS-B-NRA Interoperability Requirements for 1090 MHz Extended Squitter 192
J.1 General Information on 1090 MHz Extended Squitter ADS-B 193
J.1.1 Broadcast Message Characteristics 193
J.1.2 Formal definition 194
J.1.3 Set of parameters 195
J.1.4 Aircraft identification 197
J.1.5 Special Position identification (SPI) 197
J.1.6 Horizontal (Airborne) position (latitude and longitude) 197
J.1.7 Quality of information 198
J.1.8 Emergency indicators 198
J.1.9 Barometric altitude/geometric height 199
J.1.10 Geometric height difference from barometric altitude 199
J.1.11 Ground velocity 199
J.1.12 Version Indicator (Distinction between ICAO Annex 10, Amendment 79, ... 199
J.1.13 VOL III and DO-260A avionics implementations) 199
Appendix A Acronyms 200
Appendix B Guidance material on ATC processing system for new implementation 201

Table of Tables

Table 1 OSED - ADS-B-NRA Control Phases 45
Table 2 OPA Glossary of terms 63
Table 3 OPA Required data Items at the input of the ATC processing system 64
Table 4 OPA - Update interval and update probability parameters definition 67
Table 5 OPA - Accuracy Parameter Definitions 68

Table 6 OPA - Integrity Parameter Definitions 70
Table 7 OPA - Reliability Parameter Definitions..... 71
Table 8 OPA - Other parameter Definitions 73
Table 9 OPA - Update interval and update probability Requirements 75
Table 10 OPA - Accuracy performance Requirements 76
Table 11 OPA - Integrity performance Requirements 78
Table 12 OPA - Reliability performance Requirements 80
Table 13 OPA - Other performance Requirements 81
Table 14 OPA - Ground and Airborne ADS-B Requirements for update interval and Update probability85
Table 15 OPA - Ground and Airborne ADS-B Requirements for Accuracy 86
Table 16 OPA - Ground and Airborne ADS-B Requirements for Integrity 89
Table 17 OPA - Ground and Airborne ADS-B Requirements for Reliability..... 91
Table 18 OPA - Other Ground and Airborne ADS-B Requirements 94
Table 19 OPA - Radar Model Parameters 97
Table 20 OPA - Single plot error threshold distances for L= 10^{-7} to 10^{-3} per plot 98
Table 21 OPA- Error thresholds for En-route scaled in proportion to TMA operational range 99
Table 22: OSA - Definition of Safety terms 108
Table 23 : OSA - ED78A/DO264 Hazard Classification Matrix 112
Table 24: OSA - Risk Classification Scheme 114
Table 25 OSA – Number of ATM Hazards per Severity Class..... 114
Table 26: OSA - Units - Translation into Per ATSU hour 116
Table 27: OSA - Roles of OSA Actors..... 121
Table 28 : OSA – Navigation table 121
Table 29: OSA - List of ADS-B-NRA Operational Hazards – From Modelling 123
Table 30: OSA - List of ADS-B-NRA Operational Hazards – From Expert Analysis..... 124
Table 31: OSA - ADS-B-NRA Operational Hazard Assessment..... 125
Table 32: OSA - ADS-B-NRA External Mitigation Means List..... 126
Table 33: OSA - ADS-B-NRA Safety Objectives identified 128
Table 34: OSA - ADS-B-NRA Basic Causes - From Functional Architecture 132
Table 35: OSA - Safety Objective Compliance Matrix 133
Table 36: OSA - ADS-B-NRA Internal Mitigation Means List..... 134
Table 37: OSA - ADS-B-NRA Safety Requirements 140
Table 3-38. ADS-B Surveillance Requirements for 3 NM Separation Standard at a CAP = 3 x 10^{-12})169
Table 3-39. ADS-B Surveillance Requirements for 5 NM Separation Standard at a CAP = 3 x 10^{-12})169

Table of Figures

Figure 1 Method of Derivation of Safety and performance Requirements..... 13
Figure 2 Traceability scheme 15
Figure 3 ADS-B-NRA architecture, “points of measure” and NRA scope (shaded)..... 19
Figure 4 ADS-B-NRA Surveillance Environment Illustration 43

Figure 5 : OSED – High-level Phase diagram 54
Figure 6 : OSED – Phase 1 ADS-B Data Acquisition 55
Figure 7 : OSED – Phase 2 Initiation of ADS-B Based Services 56
Figure 8 OSED – Phase 3 Provision of ADS-B Based Services 57
Figure 9 OSED – Phase 4 Alerting 58
Figure 10 OSED – Phase 5 Termination of ADS-B Based Services 59
Figure 11 : OPA - Radar Measurent Errors 96
Figure 12: OPA – Position Error Distributions 97
Figure 13: OSA process overview 109
Figure 14: OSA - OHA Steps 110
Figure 15: OSA - Probability per hazard-effect pair scheme 113
Figure 16: OSA - ASOR Steps 117
Figure 17: OSA - *Example of Fault Tree structure* 118
Figure 3-18. CAP Evaluation Approach for ADS-B Risk Assessment 168

CHAPTER 1.

INTRODUCTION

1.1 PURPOSE OF THIS DOCUMENT

This standard provides the safety, performance and interoperability requirements (SPR and INTEROP) for the implementation of the Automatic Dependent Surveillance – Broadcast (ADS-B) application "Enhanced Air Traffic Services in Non-Radar Areas using ADS-B surveillance" (ADS-B-NRA). The requirements have been developed following the provisions of EUROCAE ED78A/RTCA DO-264, as further explained in this document. The intention is that this standard will support approval of those elements of the CNS/ATM system that are used for ADS-B-NRA.

1.1.1 ADS-B-NRA

The ADS-B-NRA application is designed to support and enhance in En-route and TMA airspaces the following Air Traffic Services (as defined in ICAO Annex 11[1] [1]):

- Air Traffic Control service
- Flight Information Service
- Alerting service

The introduction of ADS-B will provide in NRA (Non Radar Areas) enhancements to these services (compared to current capabilities) in a similar way as through the introduction of secondary surveillance radar (SSR), especially when (and where) many aircraft become ADS-B equipped. In particular, the Air Traffic Control Service will be enhanced by providing controllers with improved situational awareness of aircraft positions and the possibility of applying separation minima much smaller than what is presently used with current procedures (Procedural Separation).

1.1.2 Approval Material

This standard is intended to support the approval of the ADS-B element of the CNS/ATM system. This standard is to be used, when appropriate, with other SPR standards, as evidence of a coordinated requirements determination process, as defined in ED78A/DO-264. These standards provide the basis for qualifying the operational, safety, and performance aspects of an ADS-B element of the CNS/ATM system as well as being a basis for the certification of the airborne components.

Information on adapting an SPR standard to a local implementation can be found in paragraph 1.3.3 of /ED78A/DO-264 [13]. Guidelines for qualifying a CNS/ATM system element to an SPR standard can be found in sections 5 and 6 of ED78A/DO-264 [13].

1.1.3 EUROCAE ED78A/RTCA DO-264

This document was developed in accordance with the criteria for SPR standards set forth in ED78A/DO-264, "Guidelines for Approval of the Provision and Use of Air Traffic Services Supported by Data Communications" [13].

This document includes minimum requirements based on the results of a coordinated requirements determination process. The coordinated process included an:

- Operational Services and Environment Definition (OSED) providing operational requirements ("OR") - Annex A
- Operational Performance Assessment (OPA) providing Performance Requirements ("PR") - Annex B

[1] Terminology used in this standard is consistent with ICAO use.

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- Operational Safety Assessment (OSA) providing Safety Requirements ("SR") - Annex C
- INTEROP providing Interoperability requirements ("IR") - Annex I

These requirements are necessary to provide adequate assurance that the elements of the CNS/ATM system, when operating together, and under the assumptions made in this document, will perform their intended function in an acceptably safe manner. Main assumptions used are provided in CHAPTER 2 of this document.

1.2 SCOPE OF THE DOCUMENT

1.2.1 ADS-B-NRA context

1.2.1.1 Package I and the context of the ADS-B-NRA application

ADS-B-NRA is one of the applications originally defined as a first package of ground and airborne surveillance applications enabled by ADS-B and collectively called "Package I"[2].

The applications within Package I fall into two categories.

ADS-B Package I Ground Based Surveillance Applications which are:

- ADS-B-NRA Enhanced ATS in non-radar areas using ADS-B Surveillance
- ADS-B-RAD Enhancing ATS in radar areas using ADS-B surveillance
- ADS-B-APT Airport surface surveillance
- ADS-B-ADD Aircraft derived data for ATC tools

ADS-B Package I Airborne based Surveillance Applications which are:

- ATSA-SURF Enhanced traffic situational awareness on the airport surface
- ATSA-VSA Enhanced visual separation on approach
- ATSA-ITP In-trail procedure in oceanic airspace
- ATSAAIRB Enhanced traffic situational awareness during flight operations
- ASPA-S&M Enhanced sequencing and merging operations

The packaging approach is pragmatic and aims at the early implementation of these applications on a world-wide basis. The current document is the first of several documents that are expected to be published to cover all Package I applications.

Separate publication of the SPR and INTEROP documents for each application will allow States, ANS providers and airspace users to select, from the set of applications, those that are the best suited to their operations and their needs and then to carry out implementation.

1.2.1.2 The ADS-B-NRA application

The ADS-B-NRA application will provide enhanced Air Traffic Services in areas where radar surveillance currently does not exist (areas where ADS-B and radar are both used are covered by the ADS-B RAD application).

Examples are remote, off-shore, oil rig and small island environments, which, due to traffic levels, location, or equipment cost can not justify the installation of radar. Another example are areas where existing radar is to be de-commissioned and the replacement costs are not justified.

The ADS-B-NRA application is designed to enhance the following ICAO Air Traffic Services (refer to PANS-ATM doc 4444):

a. Air Traffic Control Service and Flight Information Service principally for:

- Air traffic control separation services

[2] Some of the original application acronyms have been modified in the course of the RFG work.

- Transfer of responsibility for control
- Air traffic control clearances
- Flight information services

b. Alerting services, principally for

- Notification of rescue co-ordination centres
- Plotting of aircraft in a state of emergency

Note that Air Traffic Services also include the provision of Air Traffic Advisory Services in advisory airspace (including traffic avoidance advice).

The introduction of ADS-B will provide enhancements to these services (compared to current capabilities) similar to what would occur by the introduction of SSR radar, especially when and where many aircraft become ADS-B equipped. The eventual goal in many regions will be to have all aircraft equipped.

In particular, the Air Traffic Control Service will be enhanced by providing controllers with improved situational awareness of aircraft positions and the possibility of applying separation minima much smaller than those presently used with procedural separation. The Alerting Service will be enhanced by more accurate information on the latest position of aircraft.

Hence, it is expected that this application will provide benefits to capacity, efficiency and safety in a similar way to what would be achieved by use of SSR radar where it is not in use today.

1.2.1.3 ADS-B

"ADS-B is a means by which aircraft, aerodrome vehicles and other objects can automatically transmit and/or receive data such as identification, position and additional data as appropriate in a broadcast mode via a data-link". [6]

ADS-B is *automatic* because no external stimulus is required; it is *dependent* because it relies on on-board navigation sources and on-board broadcast transmission systems to provide surveillance information to other users. The aircraft originating the broadcast may or may not have knowledge of which users are receiving its broadcast; any user, either aircraft or ground based, within range of this broadcast, may choose to receive and process the ADS-B surveillance information.

1.2.2 Approval Material

The minimum operational, safety, performance and interoperability requirements to implement ADS-B-NRA are provided in this document. The requirements have been allocated to the following "domains": ANSP, Airframe manufacturers and Aircraft Operators. However, it is important to understand that safe implementation can be achieved only when all of those requirements are applied all together.

NOTE 1: *Requirements that provide for protection against intentional behaviour causing harm are beyond the scope of this document.*

NOTE 2: *Requirements related to the recording of data communications for accident or incident investigation purposes are beyond the scope of this document.*

1.2.2.1 Airborne

Airborne requirements defined in this document either apply at system level, therefore applicable to airframe manufacturers, or apply at flight crew level and therefore are applicable at Aircraft Operators level.

1.2.2.2 Ground

The application, the assumptions and the analysis processes as set out in this document are intended to be at a level such that they can form the basis for specific local implementations.

ATS providers wishing to implement the ADS-B-NRA application in their own airspace, who feel additional analysis beyond this document is required, might use similar processes. It is therefore suggested that material presented in this document should be reused to the extent possible. It is however the responsibility of any ATS provider using this document and wishing to implement ADS-B-NRA to ensure that the various conditions or assumptions mentioned in this document (primarily in section 2) are applicable for the local target environment. This is in particular true for

a) the local environment characteristics

b) the characteristic of a local reference radar supporting 5 NM

c) the identification of hazards and their severity class in the local environment

NOTE 1: *This standard is intended to provide the basis for demonstrating that an implemented system can meet the relevant operational, safety, and performance requirements for services performed within the operational limitations defined herein. This standard is not intended to constrain the use of an implementation only to the services and operational limits defined herein. In cases where ATS service providers intend to support expanded operations or wish to define new services, additional operational, safety and performance requirements may need to be established.*

1.2.3 Use of ED78A/DO-264

As part of the coordinated requirements determination process, requirements from the OSED (in particular for the 5 NM separation service) were analyzed:

a) through the OPA process to derive the performance requirements by comparison using performance of a reference radar;

b) Through the OSA process to derive the safety requirements by comparison with “radar services” hazards.

Figure 1 below summarises the process by which the Safety and Performance requirements have been derived.

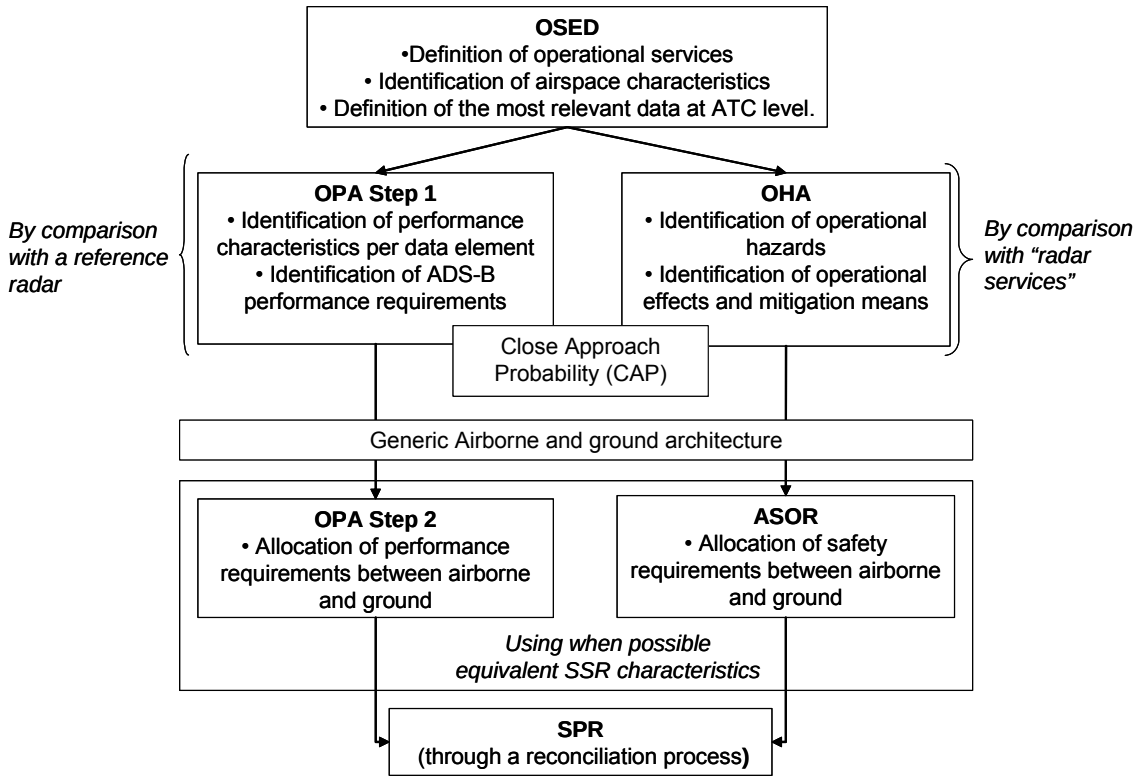

Figure 1 Method of Derivation of Safety and performance Requirements

The Operational Service and Environment Definition (OSED) defines the ADS-B-NRA Application, assuming a typical (generic) environment where this application may be implemented.

The first step of the OPA takes into account typical radar performance characteristics and the first step of the OSA takes into account typical "radar services". This is done in order to derive by comparison ADS-B safety and performance requirements.

The second step consists in defining a generic ADS-B architecture (generic enough to be applicable for any environment) and in apportioning the ADS-B requirements between the airborne and ground domains.

The most demanding requirements between OPA and OSA are retained.

This document defines and allocates the set of minimum requirements for the operational, safety, performance and interoperability aspects for implementations of the ADS-B-NRA application.

NOTE: *EUROCAE ED-78A/ Based on RTCA DO-264, SPR and INTEROP standards provide recommendations intended for government organizations, conferences of governments, or agencies having statutory jurisdiction over the use and provision of data link services. These recommendations are for use by such government organizations to enunciate official policy related to such matters in aeronautical information publications (AIPs), notices to airmen (NOTAMs), airplane flight manuals (AFMs), and operator specifications*

1.3 STRUCTURE OF THIS DOCUMENT

1.3.1 Document Organisation

Section 1 (the current section) provides an introduction to the SPR and INTEROP for the ADS-B-NRA application.

Section 2 identifies assumptions that have been made in developing this document. These consist of environmental and application assumptions, a high level functional architecture for the complete end-to-end system in which ADS-B-NRA is conceived to operate, as well as assumptions needed for the safety, performance and interoperability analyses.

Section 3 provides Safety and Performance Requirements applicable to the ADS-B-NRA application. For convenience, these are organised into sections for each of the domains involved: aircraft, aircraft operator and ATS provider.

Section 4 introduces the Interoperability Requirements applicable to the ADS-B-NRA application. It refers to Annex I, which provides the technology independent Interoperability Requirements. Annex I itself refers also to Annex J, which contains the specific 1090 MHz Extended Squitter ADS-B requirements.

Annex A is the Operational Service and Environment Definition (OSED) for ADS-B-NRA developed by RFG. This consists of the summary tabular presentation of the Environment Definition as well as the detailed Application Description. The Application Description contains the Phase tables that give a diagrammatic (flow chart) description of the steps of the fundamental procedures applied and which are used as part of the analysis process.

Annex B is the Operational Performance Assessment (OPA) developed by the RFG. Appendices to this Annex explain topics of major significance in the OPA: the nature of radar errors; surveillance risk; and time stamping and latency of surveillance data.

Annex C is the Operational Safety Assessment (OSA) developed by the RFG. This Annex begins by explaining in some detail the steps of the process that has been developed by the RFG based on ED78A/DO-264. The latter part of the Annex presents the detailed tables of results of the Safety Assessment.

Annex D provides the fault trees that have been developed by RFG for the most critical Operational Hazards. These are complementary to the material of Annex C.

Annex E is the summary of the expert analysis conducted by Air Traffic Controllers in order to identify the Operational Hazards and to assess their severity. This is also detailed material that is complementary to Annex C.

Annex F explains the analytic basis behind the calculation of the requirements placed on ADS-B in order to support ATC separation standards, based on a comparison with a representative radar. This is complementary to Appendix A of Annex B.

Annex G provides the mapping between integrity and NIC/NAC/NUC values, which is necessary because GNSS equipment providing integrity information both in NUC format, and NIC/NAC format may be used for ADS-B position reports.

Annex H provides a specific analysis of the NUPp use risk, complementary to Annex G.

Annex I provides the technology independent interoperability requirements (INTEROP) standard, together with recommendations, needed to assure that the elements of the CNS/ATM system employed for ADS-B-NRA will correctly work together to carry out their intended function.

Annex J is complementary to Annex I and provides specific 1090 MHz Extended Squitter Technology ADS-B-NRA interoperability requirements.

Annex K contains a list of abbreviations and acronyms used within this document.

Annex L provides some requirements at the ATC ground processing system level for new implementations. This brings together the applicable safety requirements set out earlier in the document as they may be specified for new equipment procurements.

Annex M provides a list of participants who have contributed to the development of this SPR standard.

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1.3.2 Document traceability

Safety and Performance requirements provided in Chapter 3 are identified as SPR#. Those requirements can be derived from several sources:

- From OPA: the applicable performance requirement(s) are then indicated as PR#
- From OSA: the applicable safety requirement(s) are then indicated as SR#
- Note: the most demanding requirements between OPA and OSA are retained.
- From OSED: the applicable operational requirements are identified as OR#

For the INTEROP: the applicable interoperability requirements are identified as IR#. Interoperability recommendations are identified as IRec#.

The following Figure 2 shows the traceability scheme

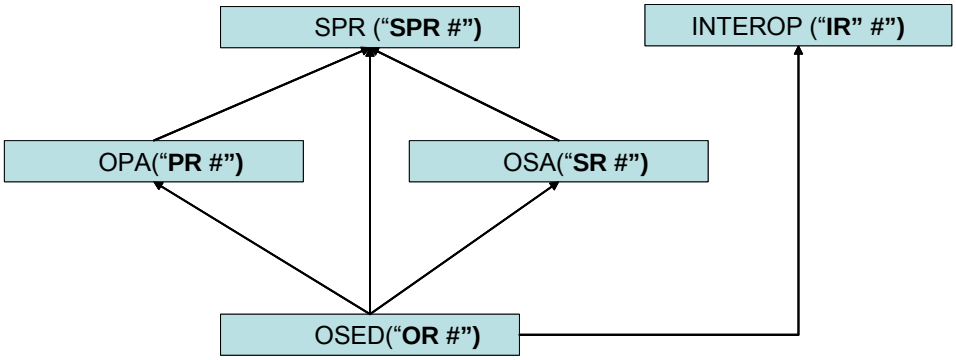

Figure 2 Traceability scheme

1.4 REFERENCES

This SPR standard considers material from the International Civil Aviation Organization (ICAO) material, EUROCONTROL, the FAA, EUROCAE and RTCA, the Requirements Focus Group (which is a working body established by EUROCONTROL, FAA EUROCAE and RTCA specifically for the development of ADS-B Package I requirements) and other sources, as listed below. The relevance of the references is also indicated. Additional references, specific to a particular Annex, are listed within the Annex itself.

1.4.1 ICAO

[1] "Air Traffic Services", ICAO, Annex 11 to the convention on International Civil Aviation, Thirteenth edition, July 2001.

[2] "Air Traffic Management", ICAO, Procedures for Air Navigation Services, Document 4444, Fourteenth edition.

OPLINKP proposal to update Doc 4444 to Amendment 4 to be formally published 2006-2007

[3] Annex 2, Rules of the Air

[4] Annex 10, Aeronautical Telecommunications - Volume II (Communications Procedures including those with PANS status)

[5] Annex 11, Air Traffic Services

Annexes 2, 10 and 11 include Standards and Recommended Practices (SARPs) for the provision and use of ATS. Unless explicitly stated, this SPR standard assumes the provision and use of ATS are implemented in accordance with these SARPs.

[6] Doc 4444, Procedures for Air Navigation Services - Air Traffic Management (PANS-ATM)

[7] Doc 8400, ABC - ICAO Abbreviations and Codes,

Doc 4444 and Doc 8400 are complementary to the SARPs and include the ICAO procedures for the provision and use of ATS. This SPR standard uses these documents to align service descriptions with ICAO procedures for ATS communication.

[8] Annex 15, Aeronautical Information Services

Annex 15 provides SARPs relating to the publication in AIPs of lists of significant differences between local procedures and the related ICAO procedures. When local procedures are different from ICAO procedures, this SPR standard provides the means to assess the impact of those differences on the services and publish appropriate procedures and other relevant information in the AIP.

[9] ICAO Annex 6, Operation of Aircraft, Part I - International Commercial Air Transport – Aeroplanes,

Annex 6 includes SARPs for aircraft operations that are relevant to this SPR standard, including flight crew training and recording of data link communications.

[10] "SASP Report of Project Team 13 – ADS-B" (SASP WG/WHL/8-SD Appendix E).

The Separation and Airspace Safety Panel (SASP) completed in November 2005 its "Assessment of ADS-B Surveillance to Support Air Traffic Services and State Implementation Roadmap". This document presents the assessment undertaken by SASP on the use of ADS-B surveillance by the Air Traffic Services to provide radar like services. This assessment has concluded that ADS-B can be used to provide a 5 nautical mile separation minima, subject to certain conditions being satisfied.

1.4.2 EUROCONTROL

[11] Eurocontrol Standard Document for Radar Surveillance in En-Route Airspace and Major Terminal Areas.

1.4.3 FAA

[12] December 13, 1999, "Mosaic Display Target Accuracy Study," ARCON Final Report for FAA under Contract DTFA01-97-C-00046.

1.4.4 EUROCAE/RTCA

[13] EUROCAE ED78A / RTCA DO264: Guidelines for Approval of the Provision and Use of air Traffic Services Supported by Data Communications, March 2002.

[14] "Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation" RTCA/DO-283A. October 28, 2003.

[15] ED 120

1.4.5 Miscellaneous

[16] Stanley R. Jones, "Automatic Dependent Surveillance – Broadcast Surveillance Requirements to Support Air Traffic Control Separation Standards," MITRE Technical Report MTR 05W0000008, August 2005

[17] S. Nagaoka and O. Amai, 1991, "Estimation Accuracy of Close Approach Probability for Establishing a Radar Separation Minimum," Journal of the Institute of Navigation, Vol. 44, No. 1.

CHAPTER 2.

ASSUMPTIONS

This section includes the main assumptions that have been extracted from OSED, OPA, OSA and INTEROP and reference [16] (to be added).

The objective of this section is to allow involved Organisations to assess the applicability of this SPR to their specific environment.

This section provides in addition the assumed generic ground and airborne functional architecture.

2.1 OSED ASSUMPTIONS

ADS-B-NRA application assumes implementation of the procedures proposed in the PANS-ATM ADS-B amendment (November 2005 - [2]) (ASSUMP 1 :)

2.2 OPA ASSUMPTIONS

Reference radar for comparison is capable of supporting safe ATC separation services, with the required separation minima (5NM) as sole means of surveillance. .ASSUMP 3 :).

It is assumed that separation task is the most demanding ATS for deriving ADS-B requirements (ASSUMP 2 :)

The comparisons of surveillance quality of ADS-B and radar is conducted at the input of the "ATC Processing System" and ADS-B requirements are therefore expressed at ADS-B Surveillance report level. It is assumed, based on existing experience, that current ATC processing systems achieve adequate levels of performance (availability, continuity, integrity…) for implementation of the ADS-B-NRA application. Functions required to process ADS-B are largely equivalent to those required to process radar. Therefore, no specific new quantitative requirements on existing ATC processing systems are imposed. (ASSUMP 4 :)

2.3 OSA ASSUMPTIONS

2.3.1 Operational experts assumptions

In order to assess the severity of the various operational hazards that can affect the ADSB-NRA application, an expert analysis was conducted with Air Traffic Controllers. The objectives of the analysis were to identify Operational Hazards (OH) that can affect ADSB-NRA, and to assess the severity of each OH by comparison with similar operations in a radar environment. The full OSA analysis is provided in Annex E

2.3.2 Environmental conditions (EC)

The following External mitigation means have been used in the safety assessment in order to mitigate the occurrence of operational safety hazards and are requirements.

EC-1: Direct Controller Pilot Communications (VHF) **shall** be available.

EC-2: ATCo **shall** be able to apply alternate separation (could simply be a vertical standard)

EC-3: System segregation of route structure (e.g. SID/STAR separation, one way routes, hemispherical levels) **shall** exist. Although difficult to measure these can have a significant impact on the hazard if implemented into the environment concerned.

EC-4: Traffic density is medium/low, i.e. the same kind of environment in which a single radar coverage would enable the provision of a 5NM separation service.

2.3.3 External Mitigation Means (EMM)

EMM-1 Fall-back procedures from Radar environment applies to ADS-B-NRA when necessary.

2.3.4 Internal Mitigation Means (IMM)

IMM1. Ground monitoring detects loss of track information leading to system generated alert provided to controller (controller monitoring assumed not to detect this scenario)

IMM2. Ground monitoring detects hazard leading to system generated alert provided to controller if it relates to satellite error resulting in multiple position error

IMM3. ATCo monitoring will detect the hazard if it relates to a frozen screen (current radar system mitigation)

IMM4. Ground monitoring detects large single jumps in one AC position that is outside the probable position

IMM5. ATCo monitoring will detect aircraft deviation from track (current radar system mitigation)

IMM6. ATCo monitoring will detect the loss of all tracks on the CWP (current radar system mitigation)

IMM7. Gnd-Pro checks of QI for display and separation purpose

IMM8. ATCo correlates ADS-B information with FP

IMM9. Site monitoring detects hazard related to corruption of ADS-B messages received by Ground ADS-B Station

2.3.5 Safety assumptions

ASSUMP 5 :An undetected common mode GPS integrity failure affecting all AC in the sector (QI lower than real one) is supposed to be no greater than 2E-04 per hour.

ASSUMP 6 :An undetected common mode GPS integrity failure affecting all AC in the sector (QI higher than real one) is supposed to be no greater than 2E-04 per hour.

ASSUMP 7 :A common mode GPS failure affecting all AC in the sector (no position) 2E-04 per hour.

ASSUMP 8 :It is assumed that ATCo rarely fails to perform sector transfer coordination (probability used in the fault trees 1E-02).

ASSUMP 9 :It is assumed that FC very rarely fails to contact ATCo when entering the new airspace (probability used in the fault trees 1E-03).

2.4 INTEROPERABILITY ASSUMPTIONS

It has been assumed that current ADS-B transceivers developed in accordance with either ED-102/DO-260 or DO-260A can support the ADS-B-NRA application.

2.5 ASSUMED AIRBORNE & GROUND GENERIC FUNCTIONAL ARCHITECTURE

Figure 3 below presents the generic ADS-B architecture considered by the RFG for all Package I applications. For the ADSB-NRA application, only an airborne ADS-B transmission capability (or "ADS-B out") implementation is required (shaded). The figure also provides various measurement points where Safety and Performance requirements will be specified (e.g., D, E2).

The minimum surveillance infrastructure includes:

- On the ground: an ADS-B Ground Data Acquisition function, ADS-B ground processing functions, and display of ADS-B data
- Airborne: functions that support ADS-B transmissions

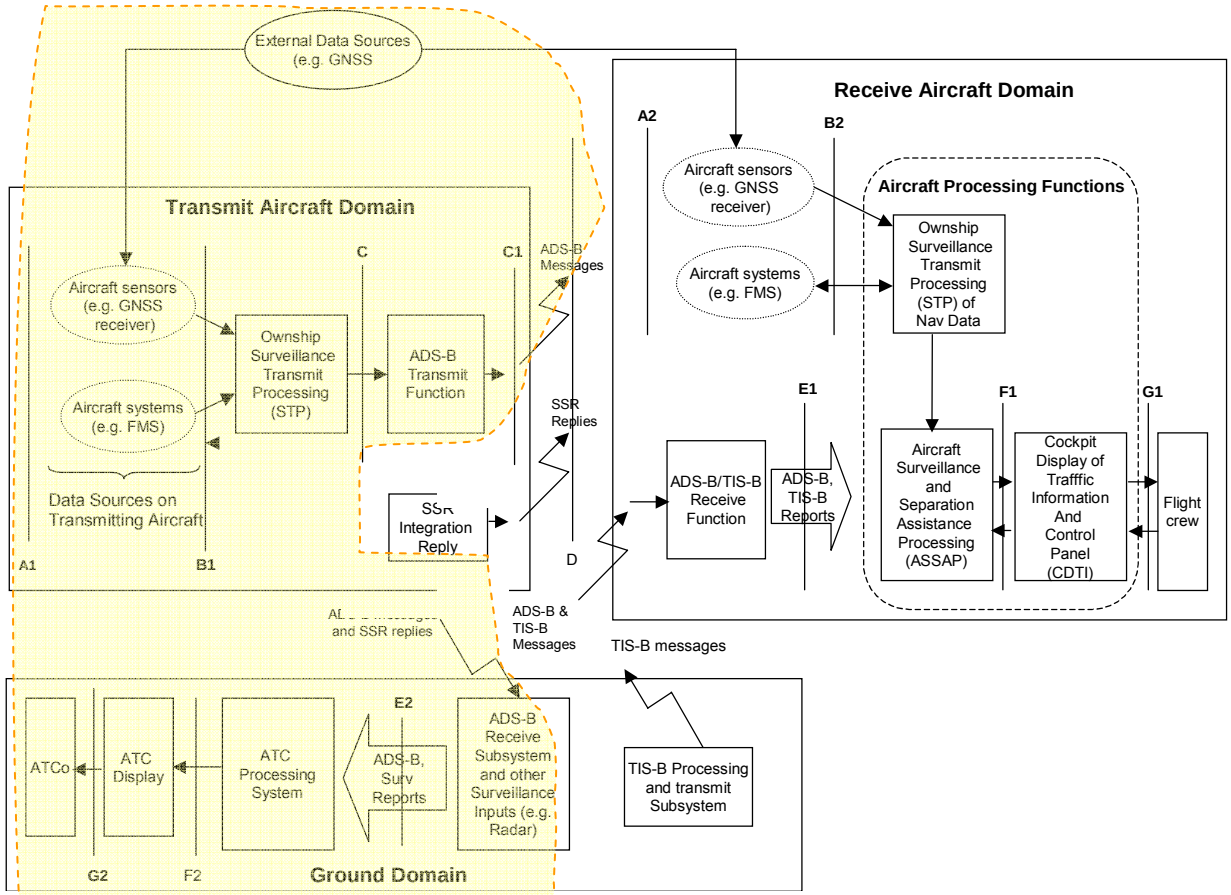

Figure 3 ADS-B-NRA architecture, "points of measure" and NRA scope (shaded)

NOTE: *pilot interface corresponds to B1.*

CHAPTER 3.

SAFETY & PERFORMANCE REQUIREMENTS (SPR)

Note 1: *"Points of measures" (E1, E2, C1, etc.) used in the SPR requirements relate to interfaces describe in Figure 3*

Note 2: *Annex I provides the list of the required data items and should therefore be refered to regarding the applicability of the following Safety and Performace Requirements (SPR)*

3.1 AIRCRAFT – SAFETY AND PERFORMANCE REQUIREMENTS/RECOMMENDATIONS

3.1.1 General requirements

SPR 1 : for civil commercial aircraft, the airborne availability shall be ≥10000 h MTBF (as good as SSR transponder) (PR 33 :)

SPR 2 : for general aviation, the airborne availability shall be ≥3000 h MTBF (as good as SSR transponder) (PR 34 :)

3.1.2 ADS-B message

3.1.2.1 Continuity

SPR 3 : The likelihood that aircraft fails to transmit ADS-B messages shall be less than 3E-05 per fh.(SR 18 :)

SPR 4 : the continuity of the airborne system ABS-B out function shall be as good as for current SSR transponding function. Requirement to be discussed (PR 35 :)

SPR 5 : the continuity of the airborne system positioning function shall be as good as for current SSR transponding function. Requirement to be discussed (PR 36 :)[3]

3.1.3 Aircraft identification, mode A code, SPI & 24 bit aircraft address

3.1.3.1 Update interval and probability

Note: The update interval and probability are provided by the link as required by the Interop.

3.1.3.2 Latency

SPR 6 : The latency (measured between points B1 and C1) of aircraft identification shall be no greater than in the current implementation for SSR (PR 46 :)

SPR 7 : The latency (measured between points B1 and C1) of mode A code shall be no greater than in the current implementation for SSR (PR 48 :)

SPR 8 : The latency (measured between points B1 and C1) of SPI shall no be greater than in the current implementation for SSR (PR 50 :)

3.1.3.3 Integrity

SPR 9 : The likelihood that an A/C-Av transmits an incorrect aircraft identification (or mode A) shall be less than 1E-3 per fh.(SR 12 :)

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[3] Those PR 35 and 36 shall be ignored in the frame of the reconcialation with SR18as less demanding.

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SPR 10 : The probability that the airborne domain degrades the aircraft identification information (i.e. different to identity source) shall be no worse than in current SSR case(PR 23 :)

SPR 11 : The probability that the airborne domain degrades the mode A code information (i.e. different to identity source) shall be no worse than in current SSR case (PR 25 :)[4]

SPR 12 : The probability that the airborne domain degrades the 24 bit aircraft address information (i.e. different to identity source) shall be no worse than in current SSR case (PR 27 :)

SPR 13 : The probability that the airborne domain degrades the SPI information (i.e. different to identity source) shall be no worse than in current SSR case of mode A (PR 29 :)

SPR 14 : In the airborne system, Identity source integrity shall be no worse than for SSR case (PR 21 :)

3.1.4 Horizontal position

3.1.4.1 Update interval and probability

Note: The update interval and probability are provided by the link as required by the Interop.

3.1.4.2 Latency

Note: It is assumed that the on-board latency in position and time accuracy of position information between B1 and C may be extrapolated to the time of transmission. Any residual latency appears as an error in the determination of the time of applicability and degrades along-track accuracy

SPR 15 : Any airborne horizontal position latency shall be compensated for at the time of transmission, in order that the residual time stamping error is less than 0.2 seconds (PR 40 :)

3.1.4.3 Accuracy

Minimum ADS-B surveillance requirements for 5 NM separations are:

SPR 16 : For TMA, the 95% accuracy of the horizontal position shall be less than 304 m (PR 8 :)

SPR 17 : For En-route, the 95% accuracy of the horizontal position shall be less than 911 m (PR 9 :)

SPR 18 : For TMA the tail error distribution shall be better than ($<10^{-3}$ > 0.52NM, $<10^{-5}$> 0.71NM, $<10^{-7}$> 0.85NM) (PR 10 :)[5]

SPR 19 : For En-route the tail error distribution shall be better than ($<10^{-3}$> 2.37NM, $<10^{-5}$> 3.19NM, $<10^{-7}$> 3.84NM) (PR 11 :)

3.1.4.4 Reliability

SPR 20 : The likelihood that the avionics data source does not provide position shall be less than 1E-05 per fh.(SR 21 :)

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[4] Those PR 23 and 25 shall be ignored in the frame of the reconcialation with SPR11as less demanding.

[5] Refer to Figure 12.

3.1.4.5 Integrity

SPR 21 : The likelihood that the integrity of the maximum 2.0 NM containment radius is exceeded without detection shall be less than 1E-5 per flight hour.(SR 1 :)[6]

SPR 22 : The probability of an undetected integrity failure affecting position shall be less than 1E-5 per fh.(SR 13 :).

3.1.5 Altitude

3.1.5.1 Update interval and probability

Note : The update interval and probability are provided by the link as required by the Interop.

3.1.5.2 Accuracy

SPR 23 : Altimeter accuracy shall be no worse than for SSR case Avionic standard (PR 12 :)

3.1.5.3 Latency

SPR 24 : The maximum age for barometric altitude (measured between B1 and C1) shall be no greater than in the current SSR case (PR 44 :)

3.1.5.4 Continuity

SPR 25 : The probability that an A/C-Av does not continue to transmit messages containing altitude shall be less than 1E-3 per fh. (SR 17 :)

3.1.5.5 Integrity

SPR 26 : The likelihood that an A/C-Av transmits an incorrect altitude shall be less than 1E-03 per fh. (SR 16 :)

SPR 27 : in the airborne system, Altimeter source integrity shall be no worse than for SSR case Avionic standard (PR 18 :)

SPR 28 : in the airborne system, probability of incorrect height information (i.e. different to altimeter source) shall be no worse than for the current SSR case (PR 20 :)[7]

3.1.6 Altitude Resolution

SPR 29 : The resolution of the Barometric altitude shall be ≤100 ft (PR 14 :)

3.1.7 Quality indicator (QI)

3.1.7.1 Update interval and probability

Note : The update interval and probability are provided by the link as required by the Interop.

3.1.7.2 Latency

SPR 30 : Any airborne quality indicator latency shall be compensated for at the time of transmission, in order that the residual time stamping error is less than 0.2 seconds(PR 42 :)

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[6] *2.0 NM is not the ICAO SASP considered value for 5Nm separation – To be aligned*

[7] Those 2 PR 18 and 20 shall be ignored in the frame of the reconcialation with SR16 as less demanding.

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3.1.7.3 Time to alert

SPR 31 : The time to alert regarding a change of the quality indicator shall be <10s in TMA (PR 16 :)

SPR 32 : The time to alert regarding a change of the quality indicator shall be <20s in En-route (PR 17 :)

3.1.7.4 Integrity

SPR 33 : The likelihood that aircraft transmits incorrect quality indicator (QI higher that real level) shall be less than 1E-05 per fh. (SR 15 :)

Note: Higher means that the transmitted QI is degraded compared to the real one (too pessimistic value) and does not allow the aircraft to benefit from the service it may expect.

SPR 34 : The likelihood that aircraft transmits incorrect quality indicator (QI lower that real level) shall be no greater than 3E-05 per fh. (SR 14 :)

Note: Lower means that the transmitted QI is better than the real one (too optimistic value) and that inadequate service (e.g. separation) may be proposed to this a/c.

SPR 35 : The probability of an incorrect QI being transmitted by the avionics source shall be less than 1E-5 per fh. (QI lower than real one) (SR 20 :).

3.1.8 Emergency

3.1.8.1 Update interval and probability

Note: The update interval and probability are provided by the link as required by the Interop.

3.1.8.2 Latency

SPR 36 : The latency (measured between points B1 and C1) of Emergency shall be no greater than in the current implementation for SSR Emergency (PR 52 :)

3.1.8.3 Integrity

SPR 37 : The likelihood that the aircraft transmits an incorrect emergency indicator shall be no greater than … (should be a requirement coming from the osa for airborne side)[8]

SPR 38 : The probability that the airborne domain degrades the Emergency information (i.e. different to identity source) shall be no worse than in current SSR case (PR 31 :)

[8] This will map to the safety requirements based on the hazard where the system replaces an emergency indicator with an incorrect one

3.2 AIRCRAFT OPERATOR – SAFETY AND PERFORMANCE REQUIREMENTS/RECOMMENDATIONS

3.2.1 General human factor assumption

ATCo and FC are assumed to follow normal operating procedures, as described in the OSED (Annex G).

In particular:

- ATCo will perform sector transfer coordination
- FC will contact ATCo when entering the new airspace

3.2.2 General requirements

SPR 39 : Requirements as developed in "Air Traffic Management", ICAO, PANS-ATM, Document 4444, Fourteenth edition (proposal to update Amendment 4 to include ADS-B procedures in Chapter 8 'Surveillance Services'; yet to be approval by the ANC) shall be met by ADS-B-NRA.(OR 2 :)

SPR 40 : FC shall notify ATCo of ADS-B transmitter failure once detected (SR 19 :)

SPR 41 : It is expected that the aircrew shall interface to the ADS-B transponder in the same way to a SSR (or Mode S) transponder. (OR 3 :)

3.2.3 Aircraft identification, Mode A code, SPI & 24 bit aircraft address

It is assumed that the flight crew follows the procedures listed in the OSED (Annex A) regarding correct aircraft identification entry.

In addition, the following procedures are proposed based on PANS-ATM. However, it is proposed to delete them and to keep only OR2 at this stage.

SPR ? Whenever it is observed on the situation display that the aircraft identification transmitted by an ADS-B equipped aircraft is different from that expected from the aircraft, the pilot shall be requested to confirm aircraft identification (SR ?(OR2)

SPR ? When, after a pilot has been instructed to operate the aircraft's ADS-B transmitter on an assigned aircraft identification or to effect a call sign change, it is observed that the aircraft identification shown on the situation display is different from that assigned to the aircraft, the pilot shall be requested to re-enter the assigned aircraft identification. (SR? (OR2)

SPR ? Whenever it is observed that the aircraft identification (TBC operational identity & spi) of an aircraft as shown on the display is different from that assigned to the aircraft, and the application of the procedure described in 0has not resolved this discrepancy or is not warranted by circumstances (e.g. unlawful interference), the pilot shall be requested to confirm that the correct aircraft identification has been selected. (SR ?(OR2)

SPR ? If the discrepancy continues to exist, following confirmation by the pilot that the correct aircraft identification (has been set on the ADS-B identification (feature, the following actions shall be taken by the controller:
a) inform the pilot of the persistent discrepancy;
b) where possible, correct the label showing the aircraft identification on the situation display; and
c) notify the erroneous aircraft identification transmitted by the aircraft to the next control position and any other interested unit using ADS-B for identification purposes. (SR ?(OR2)

3.2.4 Altitude

SPR ? Verification of pressure altitude-derived level information displayed to the controller shall be effected at least once by each suitable equipped ATC unit on initial contact with the aircraft concerned or, if not feasible, as soon as possible thereafter. The verification shall be effected by simultaneous comparison with altimeter-derived level information

received from the same aircraft by radiotelephony. The pilot of the aircraft whose pressure-altitude-derived level information is within the approved tolerance value need not be advised of such verification. Geometric height information shall not be used to determine if altitude differences exist. (SR ?)

SPR ? If the displayed level information is not within the approved tolerance value or when a discrepancy in excess of the approved tolerance value is detected subsequent to verification, the pilot shall be advised accordingly and requested to check the pressure setting and confirm the aircraft's level. (SR ?)

SPR ? If following confirmation of the correct pressure setting the discrepancy continues to exist, the following action should be taken according to circumstances:
a) request the pilot to stop ADS-B altitude data transmission, provided this does not cause the loss of position and operational & SPI – TBC identity information and notify the next control positions or ATC unit concerned with the aircraft of the action taken; or
b) inform the pilot of the discrepancy and request that the relevant operation continue in order to prevent loss of position and identify information of the aircraft and, when authorized by the appropriate ATS authority, override the label-displayed level information with the reported level. Notify the next control position or ATC unit concerned with the aircraft of the action taken. (SR ?)

SPR 42 : When altitude information being transmitted through ADS-B is verified as being inaccurate there shall be a function (either airborne or ground) to enable manual filtering of this data item (either prior to or at the CWP). (OR 7 :)

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3.3 ATS PROVIDER – SAFETY AND PERFORMANCE REQUIREMENTS/RECOMMENDATIONS

3.3.1 Ground processing system assumption

It is assumed, based on existing experience, that current ATC processing systems achieve adequate levels of performance (availability, continuity, integrity…) for implementation of the ADS-B-NRA application. Functions required to process ADS-B are largely equivalent to those required to process radar. Therefore, no specific new quantitative requirements on existing ATC processing systems are imposed.

For new ATC processing systems, the guidance in Annex B should be used.

3.3.2 General human factor assumption

ATCo and FC are assumed to follow normal operating procedures, as described in the OSED (Annex G).

In particular:

- ATCo will perform sector transfer coordination
- FC will contact ATCo when entering the new airspace

SPR 43 : Requirements as developed in "Air Traffic Management", ICAO, PANS-ATM, Document 4444, Fourteenth edition (proposal to update Amendment 4 to include ADS-B procedures in Chapter 8 'Surveillance Services'; yet to be approval by the ANC) shall be met by ADS-B-NRA.(OR 2 :)

3.3.3 General requirements

SPR 44 : The probability that ground monitoring fails to inform controller of the loss of traffic information for one aircraft shall be no greater than 0.001. (SR 42 :)

SPR 45 : Where various datalinks are used by the system to transmit and receive ADS-B data these shall be transparent to the controllers. (OR 6 :)

SPR 46 : Surveillance information shall be presented to the controller in a clear and concise manner in a similar way to radar (e.g. Surveillance tracks refresh rate).(OR 10 :)

SPR 47 : The following list of surveillance parameters shall be provided to the controller
-Identity
-Position
-Indication of the quality of ADS information (in particular, to indicate whether it is good enough for certain separation purposes).
-Emergency indicator(s) (as a minimum "general emergency" but may also include "communications failure" and "unlawful interference").
-Special Position Identifier (SPI)
-Barometric Altitude
-Ground Velocity (OR 1 :)

SPR 48 : A/C not transmitting a quality indicator shall remain under procedural control. (traceability to OSED be added)[9]

SPR 49 : The ATCo shall be able to identify and correlate ADS-B a/c to Flight Plan information.(SR 47 :)

[9] This assumes an implementation decision. The SPR should merely state that these aircraft are assumed to not be in the application (i.e. equivalent to not ADS-B out equipped)

SPR 50 : The probability that ground monitoring fails to inform controller of a satellite error resulting in multiple position error shall be no greater than 0.001.(SR 43 :)

SPR 51 : The number of AC controlled in the sector by the same controller has to be determined taking into account that controller has to be able to detect error in the positioning source resulting in unexpected changes to multiple aircraft tracks on the CWP.(SR 44 :)

SPR 52 : The number of AC controlled in the sector by the same controller has to be determined taking into account that controller has to be able to detect the ADS-B track loss for one aircraft.(SR 23 :)

SPR 53 : The probability that ground monitoring fails to detect large single jumps in one aircraft position that is outside the probable position shall be no greater than 0.001.(SR 45 :)[10,11]

SPR 54 : The ADS-B ground system **shall** monitor all ground functions (e.g., the ADS-B receive sub-function) and shall indicate the function's health (i.e., either failed or operational). (traceability to OSED to be added)

SPR 55 : The ADS-B system shall indicate to ATCO's whenever the surveillance quality of particular aircraft or the surveillance system as a whole falls below limits that are acceptable for the various functions of ATC (e.g. Enroute or TMA). (OR 8 :)

SPR 56 : The number of AC controlled in the sector by the same controller has to be determined taking into account that controller has to be able to detect aircraft deviation from track displayed on the CWP.(SR 46 :) [12]

SPR 57 : The probability that ground monitoring fails to inform controller about the position corruption of ADS-B messages received on the ground station shall be no greater than 0.001.(SR 48 :)

3.3.4 ADS-B reports

3.3.4.1 ADS-B report: Time of applicability

SPR 58 : each ADS-B report shall contain a time of applicability (PR 37 :)

SPR 59 : The time of applicability within each ADS-B report shall be valid for all data items of the report (PR 38 :)

3.3.4.2 Update interval

SPR 60 : The update interval for report containing at least the time of applicability, the position, the barometric height, the quality indicators and the ICAO 24 bit aircraft address (measured at point E2) shall be no longer than 10s (En-route) and 5s (TMA) (PR 1 :)

SPR 61 : The update interval for report containing at least the aircraft identification/ mode A code and the & 24 bit aircraft address (measured at point E2) shall be no longer than 20s (En-route) and 10s (TMA) (PR 2 :)

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[10] This relates to an existing radar feature which references detected position within the expected range and if its outside of that it coasts the radar track. This should be duplicated in ADS-B

[11] to be discussed as this req has no specified quantities, i.e. what are the bounds of the probable position? Where does the need for this requirement come from? (e.g. such tests are not done on radar positions). It ought to be covered by the position integrity requirements (involving Stan's results, containment bounds etc).

[12] Amendments also made to the SR42. The point was that it needs to be clear that the ATCO can only detect it if the deviation is shown on the CWP display

SPR 62 : The update interval for report containing at least the Emergency or SPI information and the 24 bit aircraft address (measured at point E2) shall be no longer than 10s (En-route) and 5s (TMA) (PR 3 :)

Note 1: These figures are for aircraft first coming into coverage of ADS-B and subsequently for any Aircraft identification/ Mode A code or SPI change whilst in coverage.

Note 2: The update interval is to be met considering the combination of both ground system, airborne system, and link characteristics.

Note3: The update interval is to be met considering the combination of ground system, airborne system, and link characteristics.

3.3.4.3 Update probability

SPR 63 : The update probability for report containing at least the time of applicability, the position, the barometric height, the quality indicators and the ICAO 24 bit aircraft address (measured at point E2) shall be greater than 0.95 (En-route or TMA) (PR 4 :)

SPR 64 : The update probability for report containing at least the aircraft identification/mode A code & 24 bit aircraft address (measured at point E2) shall be greater than 0.95 (PR 5 :)

SPR 65 : The update probability for report containing at least the Emergency or SPI information and the 24 bit aircraft address (measured at point E2) shall be greater than 0.95 (PR 6 :)

Note: The update probability is to be met considering the combination of both ground system, airborne system, and link characteristics.

3.3.4.4 Reliability

SPR 66 : The ADS-B system shall be at least as reliable and available as for today's SSR system (ground and airborne components included) (OR 5 :)

SPR 67 : The continuity risk of the ground ADS-B receivers shall be less than 1E-4 per hour.(SR 28 :) [13]

SPR 68 : The ground shall not create any significant numbers of false reports Link errors causing false ADS surveillance reports < 0.001 per report (PR 32 :)

3.3.4.5 Capacity/Total load

SPR 69 : The ground shall have capacity to handle the reports from the maximum load of aircraft in the environment as described in annex G1. Link must support transmission and reception of ADS-B from the numbers of aircraft required in the environment.(PR 54 :)

3.3.5 Aircraft identification/mode A code, SPI & 24 bit aircraft address

3.3.5.1 Latency

SPR 70 : The maximum age for the aircraft identification (measured between points C1 and E2) shall be 2s (PR 45 :)

SPR 71 : The maximum age for the mode A code (measured between points C1 and E2) shall be 2s (PR 47 :)

[13] Those PR 32 and OR 5 shall be ignored in the frame of the reconcialation with SR28 as less demanding

SPR 72 : The maximum age for the SPI (measured between points C1 and E2) shall be 2s (PR 49 :)

3.3.5.2 Integrity

SPR 73 : The probability that the ground domain (between C1 and E2) degrades the aircraft identification shall be less than 0.001 (per ADS-B report) (PR 22 :)

SPR 74 : The probability that the ground domain (between C1 and E2) degrades the mode A code shall be less than 0.001 (per ADS-B report) (PR 24 :)

SPR 75 : The probability that the ground (between C1 and E2) degrades the 24 bit address (i.e. different from identity source) shall be less than < 0.001 (per ADS-B report (PR 26 :)

SPR 76 : The probability that the ground domain (between C1 and E2) degrades the SPI information shall be less than 0.001 (per ADS-B report)(PR 28 :)

3.3.6 Horizontal position

3.3.6.1 Latency

SPR 77 : The maximum age for horizontal position (measured between points C1 and E2) shall be less than 2s (PR 39 :)

SPR 78 : The ground, in conjunction with the link, shall provide the time of applicability of the information to within 0.2s. (PR 53 :)

3.3.6.2 Accuracy

SPR 79 : The ground (including link) shall not degrade the airborne horizontal position accuracy (PR 7 :)

3.3.6.3 Integrity

SPR 80 : The likelihood that ground system corrupts ADS-B position for all messages received shall be no greater than 1E-04 per hour.(SR 25 :)

SPR 81 : The probability that ground monitoring fails to inform controller of a satellite error resulting in multiple position error shall be no greater than 0.001.(SR 43 :)

3.3.6.4 Latency

SPR 82 : The maximum age for barometric altitude (measured between points C1 and E2) shall be less than 2s (PR 43 :)

3.3.6.5 Integrity

SPR 83 : The ground vertical position integrity error shall be less than 0.001 per ADS-B report containing this data item (PR 19 :)

3.3.6.6 Resolution

SPR 84 : The ground (including link) shall not degrade altitude resolution to worse than 100ft (PR 13 :)

3.3.7 Quality indicator (QI)

3.3.7.1 Latency

SPR 85 : The maximum age for quality indicators(measured between points C1 and E2) shall be less than 2s (PR 41 :)

3.3.7.2 Integrity

SPR 86 : The likelihood that Ground ADS-B Receive subsystem corrupts ADS-B messages for all the a/c (incorrect QI - lower than real level) shall be less than 1E-4 per hour.(SR 26 :)

SPR 87 : The likelihood that Ground ADS-B Receive subsystem corrupts QI (higher than real one) for all the aircraft in its region shall be less than 1E-4 per hour.(SR 27 :)

SPR 88 : The ground shall not significantly degrade the integrity of the quality indicators, i.e. a) the undetected error rates in the ground-ground transmission of ADS-B surveillance reports should be no worse than in current transmission of radar surveillance reports and b) the undetected errors in the transmission of ADS-B messages by the air-ground link shall not be more than xxx rate per message and cause corruption in ADS-B position information.. TBD (PR 15 :) (XXX value to be discussed)

3.3.8 Emergency

SPR 89 : Indication that an aircraft is transmitting an emergency and /or urgency mode shall be displayed to the controller in a clear and expeditious manner. (OR 15 :)

3.3.8.1 Latency

SPR 90 : The maximum age for the Emergency indicator (measured between C1 and E2) shall be less than 2s(PR 51 :)

3.3.8.2 Integrity

SPR 91 : Place holder - Should be a safety requirement from OSA

SPR 92 : The probability that the ground domain (between C1 and E2) degrades the Emergency information shall be less than 0.001 (per ADS-B report (PR 30 :)

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CHAPTER 4.

INTEROPERABILITY REQUIREMENTS

4.1 PURPOSE OF INTEROPERABILITY REQUIREMENTS

The purpose is to define the set of requirements for the interoperability (INTEROP) aspects of the ADS-B-NRA application. These specifications are intended for use in conjunction with the consistent safety and performance requirements derived and defined elsewhere within this document, other INTEROP standards, and the guidelines described in ED-78A/DO-264 for each approval type associated with the elements of the CNS/ATM system.

NOTE 1: *Such an INTEROP standard is not intended to contain detailed requirements on avionics and/or ground equipment. These requirements can be found in specialised documents (e.g.: MOPS and Interface Control documents).*

4.2 PRESENTATION OF THE INTEROPERABILITY REQUIREMENTS IN THIS DOCUMENT

It is assumed that the INTEROP requirements may mainly be used for the purpose of providing the hard- and software specifications of implementations serving the described application whilst the other parts may be more addressed to certification and/or authorisation institutions.

Consequently, the Interoperability specifications are presented as a ‚self-supporting part' which can be extracted without loosing completeness in Annexes.

4.2.1 Organisation of the Annexes for Interoperability Requirements

Annex I contains the technology independent Interoperability Requirements.

Therein the:

Section 1 provides an introduction to the Interoperability Requirements Standard for ADS-B-NRA (INTEROP ADS-B-NRA),

Section 2 describes ADS-B-NRA in terms of its main components and functions, and

Section 3 defines the air and ground interoperability requirements for the ADS-B-NRA application.

Annex J provides the interoperability specifications for the ADS-B-NRA application utilizing the 1090 MHz Mode-S extended squitter technology.

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Annex A OSED

A.1 ENVIRONMENT DESCRIPTION

***"E-IIIa":* Environment Description for ADS-B-NRA in Controlled Airspace**	**CURRENT ENVIRONMENT**	**Reference[14] Environment**	**TARGET (Proposed) ENVIRONMENT**
	Low-Density Continental		
	Non-Radar	**Single Radar Coverage**	**ADS-B sole means of surveillance**
	TMA and En-Route		
Operational and Airspace Characteristics			
Class of airspace	A, B, C, D, E		
Air Traffic Services:	ATC, FIS, Alerting	Improved ATC, FIS, Alerting	No change to reference environment
• ATC/Type of control	Procedural	Radar based	ADS-B based
• Separation method [Separation Minima]	Procedural + Visual[15] [Non Radar Separation Minima as described in doc 4444 chapter 5]	Radar based[16] [Separation Minima same as described in doc 4444 chapter 8 (radar services)]	ADS-B-based[3] [Separation Minima same as described in doc 4444 chapter 8 (surveillance services)[17] as if radar would be available]
• ATC/Vectoring	No	Same as described in doc 4444 chapter 8 (radar services)	Same as described in doc 4444 chapter 8 (surveillance services)[4] same as if radar would be available
• FIS	Yes	Yes (improved)	No change to reference environment
• Alerting	Yes	Yes (improved)	No change to reference environment
• Air Traffic Advisory	no	Yes	No change to reference environment
ATCo workload	Varied	Less than current environment[18]	No change to reference environment
Impact of weather on operations	Increases complexity	Less impact than current environment [19]	No change to reference environment

[14] The 'reference' environment relates to a fictitious set of characteristics, performances and capabilities described in this document that are necessary to support the comparative assessment method chosen by the RFG to define Safety and Performance requirements, in particular for the use of 5nm separation in ADS-B-NRA.

[15]: As defined for the airspace classes in section 5.2.1. of doc 4444

[16] : procedural and visual separation may still be applied for non equipped aircraft(outside the scope of the ADS-B-NRA application)

[17] The term 'Surveillance Services' is taken from the proposed amendment to Edition 14 (Amendment 4) PANS-ATM Doc 4444 by the first meeting of the Oplink Panel (OPLINKP/1: 12-23 September 2005)

[18] : no need for voice position reports management

[19] : due to the possibility to tactically redirect more efficiently the aircraft

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***"E-IIIa":* Environment Description for ADS-B-NRA in Controlled Airspace**		**CURRENT ENVIRONMENT**	**Reference[14] Environment**	**TARGET (Proposed) ENVIRONMENT**
		Low-Density Continental		
		Non-Radar	**Single Radar Coverage**	**ADS-B sole means of surveillance**
		TMA and En-Route		
Flexible Use of Airspace		No	Yes[20]	No change to reference environment
Airspace structure (+ complexity)		Generally low complexity	Medium complexity	No change to reference environment
Route configuration and complexity		- Limited reciprocal tracks, - Limited altitude transitions, - RVSM (en-route),	- SIDs & STARs (TMA) - Single runway (TMA) - RNAV operations, - Limited crossing tracks,	No change to reference environment
Generic Airspace Traffic Characteristics				
En-route	Average flights per hour	15	25	No change to reference environment
	Traffic numbers in sector	8 Aircraft maximum instantaneous count	15 Aircraft maximum instantaneous count	No change to reference environment
TMA	Average flights per hour	3	6	No change to reference environment
	Traffic numbers in sector	4 Aircraft maximum instantaneous count	7 Aircraft maximum instantaneous count	No change to reference environment
Aircraft mix		- Wide range of a/c bodies & performances; Mix IFR/VFR, except in airspace class A	- Mix of Regular Public Transport and General Aviation traffic	No change to reference environment
CNS Infrastructure: Capabilities and Performances				
ATS Communication (Controller/Controller)		Capabilities and Performances required to support Controller/Controller coordination (Inter Sector communications) as described in ICAO Annex 11 (chapter 6) and doc 4444 (chapter 10)		
ATS Communication (Pilot/Controller)		Capabilities and Performances required to support the above Air Traffic Services, in particular the procedural separation. See also ICAO Annex 11, chapter 6.	Capabilities and Performances required to support the above Air Traffic Services, in particular radar based separation. See also ICAO Annex 11, chapter 6	Capabilities and Performances required to support the above Air Traffic Services, in particular ADS-B based separation as for radar based separation
Navigation		none[21]	navigation capability required as for radar services	No change to reference environment
Surveillance		Capabilities and Performances required to support Pilot/Controller communication for transmission of position report (as described in doc 4444 section	Capabilities and Performances required to support the above Air Traffic Services. Including in particular the following capabilities:	Capabilities and Performances required to support the above Air Traffic Services. Including in particular the following capabilities:

[20] : provided that the ground/ground Civil/Military coordination exists

[21] : procedural control is possible where no CNS infrastructure is present (e.g. visual tracking standards)

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***"E-IIIa":* Environment Description for ADS-B-NRA in Controlled Airspace**	**CURRENT ENVIRONMENT**	**Reference[14] Environment**	**TARGET (Proposed) ENVIRONMENT**
	Low-Density Continental		
	Non-Radar	**Single Radar Coverage**	**ADS-B sole means of surveillance**
	TMA and En-Route		
	4.11)	Ground: SSR, SDPD, CWP, Airborne: radar transponder	Ground: ADS-B GS, SDPD, CWP, Airborne: "ADS-B out" for all aircraft.
ATS TOOLS	Flight Plan update using aircraft position report	Flight Plan update using aircraft track; Surveillance based tools may be enabled (e.g. MSAW, AIW, STCA)	No Change to reference system

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***"E-IIIb":* Environment Description for ADS-B-NRA in Uncontrolled Airspace**	**CURRENT ENVIRONMENT**	**Reference Environment**	**TARGET ENVIRONMENT**
	Low-Density Continental		
	Non-Radar	**Single Radar Coverage**	**ADS-B sole means of surveillance**
Operational and Airspace Characteristics			
Class of airspace	F, G		
Air Traffic Services:	FIS, Alerting	FIS & Alerting (improved from current environment)	No change to reference environment
• ATC/Type of control	n.a.	n.a.	n.a.
• ATC/Separation	n.a.	n.a.	n.a.
• ATC/Vectoring	n.a.	n.a.	n.a.
• FIS	Yes	Yes (improved from current environment)	No change to reference environment
• Alerting	Yes	Yes (improved from current environment)	No change to reference environment
• Air Traffic Advisory [Separation Minima]	IFR/IFR when practicable in Class F [Non Radar Separation Minima as described in doc 4444 chapter 5]	IFR/IFR when practicable in class F[Separation Minima as described in doc 4444 chapter 8 (radar services)	IFR/IFR when practicable in class F[Separation Minima as described in doc 4444 chapter 8 (radar services) is if for radar
ATCo workload	low[22]		
Weather constraints	Varied		
Flexible Use of Airspace	No		
Airspace structure (+ complexity)	low complexity[23]		
Route configuration and complexity	low complexity		
Traffic Characteristics			
Sector Traffic density as a maximum instantaneous count	10 Aircraft	10 Aircraft	No change to reference environment
Aircraft mix	- Predominantly Light and Medium Category aircraft; High Mix of IFR/VFR		
CNS Infrastructure & Tools: Capabilities and Performances (in this part are initial elements to be updated from the SPR work)			
ATS Communication (Controller/Controller)	Capabilities and Performances required to support Controller/Controller coordination (Inter Sector communications) as described in ICAO Annex 11 (chapter 6) and doc 4444 (chapter 10)		

[22] : ATCo could provide more service due to information available (e.g. Air Traffic Advisory) however workload will remain the same

[23] : but with potential in target environment to enhance structure to handle more traffic

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***"E-IIIb":* Environment Description for ADS-B-NRA in Uncontrolled Airspace**	**CURRENT ENVIRONMENT**	**Reference Environment**	**TARGET ENVIRONMENT**
	Low-Density Continental		
	Non-Radar	**Single Radar Coverage**	**ADS-B sole means of surveillance**
ATS Communication (Controller/Controller)	Capabilities and Performances required to support the above Air Traffic Services. See also ICAO Annex 11, chapter 6.		
Navigation	n.a. (minimum navigation is by visual flight rules)		
Surveillance	Capabilities and Performances required to support Pilot/Controller communication for transmission of position report (as described in doc 4444 section 4.11)	Capabilities and Performances required to support the above Air Traffic Services. Including in particular the following capabilities: Ground: SSR, SDPD[24], CWP Airborne: a percentage of radar transponder equipped aircraft.	Capabilities and Performances required to support the above Air Traffic Services. Including in particular the following capabilities: Ground: ADS-B GS, SDPD[25], CWP Airborne: a percentage of "ADS-B out" aircraft.
ATS Tools	none	Surveillance based tools may be enabled (e.g, MSAW, AIW)	Surveillance based tools may be enabled (e.g, MSAW, AIW)

[24] : SDPD system required for ADS-B processing may be very simple and could be limited to the reception, format conversion and distribution of ADS-B to CWP
[25] : SDPD system required for ADS-B processing may be very simple and could be limited to the reception, format conversion and distribution of ADS-B to CWP

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A.2 APPLICATION DESCRIPTION

A.2.1 INTRODUCTION

The ADS-B-NRA application will provide enhanced Air Traffic Services in areas where radar surveillance currently does not exist (note that radar area cases are covered by the ADS-B-RAD application)

Examples are remote, off-shore, oil rig and small island environments, which, due to the level of traffic, location or the cost of the equipment, could not justify the installation of radar. Also it will include areas where existing radar is to be de-commissioned and the replacement costs are not justified.

The ADS-B-NRA application is designed to enhance the following ICAO Air Traffic Services [Ref 1, chapters 3 to 5].

- Air Traffic Control Service and Flight Information Service principally for the following functions:
- Operation of air traffic control service (Ref 2 chapter 3.3).
- Separation minima (Ref 2 chapter 3.4)
- Transfer of responsibility for control (Ref 2 chapter 3.6)
- Air traffic control clearances (Ref 2 chapter 3.7)
- Scope of flight information service (Ref 2 chapter 4.2)
- Alerting Service, principally for the following functions:
- Notification of rescue co-ordination centres (Ref 2 chapter 5.2)
- Plotting of aircraft in a state of emergency (Ref 2 chapter 5.4)
- Air Traffic Advisory Services

The introduction of ADS-B will provide enhancements to these services (compared to current capabilities) in a similar way as would occur by the introduction of SSR radar, especially when (and where) many aircraft become ADS-B equipped. [The target state in many regions will be to have all aircraft equipped].

In particular, the Air Traffic Control Service will be enhanced by providing controllers with improved situational awareness of aircraft positions and the possibility of applying separation minima much smaller than what is presently used with current procedures. The Alerting Service will be enhanced by more accurate information on the latest position of aircraft. Furthermore, ADS-B is able to broadcast emergency status information which will be displayed to the controller independently from any radio communications.

Hence, it is expected that this application will provide benefits to capacity, efficiency and safety in a similar way as could be achieved by the introduction of SSR radar.

Currently, air traffic management procedures in non-radar airspace are in accordance with those defined in ICAO Procedures for Air Navigation Services, Air Traffic Management [Ref 2 = PANS-ATM Document 4444], but of course excluding those procedures that specifically require radar surveillance. Hence, the intention of the ADS-B-NRA application is to allow the procedures using radar surveillance to be enabled by ADS-B, assuming that the quality of service of ADS-B surveillance is similar to (or better than) SSR radar and that appropriate air-ground communications coverage is available.

ASSUMP 1 : ADS-B-NRA application assumes implementation of the procedures proposed in the PANS-ATM ADS-B amendment (November 2005 - [2])

The approach to procedures taken in this document is to assume that proposed PANS-ATM procedures (as per Ref 2) will be essentially unchanged when approved by the ANC. Where there are some particular differences between ADS-B and radar that may affect the procedures, then these are indicated.

Whilst the role of the controller and pilot remain unchanged, there may be impact on their workloads because of new control procedures and the provision of enhanced services. On the other hand, there may be some reduction in workload due to, inter alia, a simplification of the separation standards expected to be used within the target ADS-B environment as well as reduced need for voice position reports, since the aircraft parameters will be broadcast and received automatically via ADS-B. The flight crews may interface with the ADS-B transmitter in a similar way to that of a SSR transponder.

This application is not complex. It is very mature. The challenge is the demonstration and validation of the separation service using surveillance minima (e.g. 5nm) with the target architecture (Safety Case) based on the assumption that it will produce the most stringent requirements.

A.2.2 CONTEXT

Currently, air traffic services within non-radar airspace are based upon procedural methods. Because the knowledge of the position of the aircraft is not as accurate as that provided in radar-controlled airspace, the separation standards and traffic information parameters are typically much larger. Furthermore, the provision of alerting information is limited to that which can be supplied by voice transmissions, and there are no traffic advisory services available.

The ADS-B-NRA environment is described in Annex B of the general Operational Services and Environment Definition [Reference 3], but some aspects of this are further highlighted below.

Target application:

- Will apply to airspace classes (A to G) where radar surveillance currently does not exist (note that radar areas cases are covered by ADS-B-RAD).
- Will apply to aircraft (in the general sense, e.g. including helicopters). Ground vehicles are not covered.
- Will include en-route, arrival and departure phases of flight.

Minimum surveillance infrastructure:

- Ground: ADS-B Ground Data Acquisition, SDPD (Surveillance Data Processing & Distribution), CWP (Controller Working Position).
- Airborne: “ADS-B out”

Note that the SDPD system required for ADS-B processing may be very simple and could be limited to the reception, format conversion and distribution of ADS-B information to the CWP.

The provision of surveillance services to aircraft in a particular NRA will also depend upon the availability and coverage of appropriate air-ground communications. In particular, VHF coverage is important to maximise the air traffic service benefits from the introduction of ADS-B into the environment.

A.2.3 OBJECTIVE

In terms of function, the objective of ADS-B-NRA is to provide surveillance services (Document Ref 2, Chapter 8) in non-radar airspace using ADS-B. This will significantly increase the controller’s situational awareness of traffic in the air and enable the traffic to be handled in a more efficient way than today’s procedures. These benefits will also serve as incentives for aircraft operators to equip, in turn leading to even wider ADS-B benefits. Hence, the objective will be to provide the following benefits:

Safety Benefits:

- Improved controller situational awareness provides controllers with improved recognition (detection) of potentially unsafe situations.

- Enabler for introduction of automatic safety nets (such as STCA, MSAW, AIW etc) that provide controllers with improved recognition (detection) of potentially unsafe situations.
- Reduced workload associated to conflict resolution
- Improved monitoring of flights crossing sector or FIR boundaries (in particular to check proper co-ordination between centres).
- Automatic trajectory-compliance monitoring tools may be used to inform controllers of deviations from an expected route or flight level.
- More precise traffic information issued to flight crews thus reducing visual acquisition time and failure rates.
- Enabler for added traffic advisory service (including avoidance advice)
- Improved quality of information for Alerting Services providing improved search and rescue response capabilities.

Capacity and Efficiency Benefits

- Reduction in the need for pilot position reports resulting in reduced communications congestion thus increasing sector capacity
- Enabler to more efficient traffic flow through a combination of accurate position information and a reduction in separation minima (compared to procedural) such as:
- Improved tactical manoeuvring through vectoring,
- Improved operational flexibility such as choice of routes and flight levels
- Improved co-ordination and hand-over of flights crossing sector or FIR boundaries

Strategic benefits

- Enabler for flexible use of airspace and user preferred routes

Note that many of these benefits will apply to both controlled and uncontrolled airspace (as defined in Reference 3). Additionally the range of possible enhancements of services and levels of benefits will depend upon the proportion of aircraft with ADS-B equipage.

A.2.4 PROCEDURE DESCRIPTION

A.2.4.1 Current Non-Radar procedures

Current procedures are in accordance with those defined in Ref 2 (i.e. PANS-ATM Document 4444), but excluding those procedures that specifically require radar surveillance.

Essentially, ATS situational awareness for the management of air traffic is currently achieved by knowledge of flight plan information, updated by position reports from aircrew at designated reporting points or at agreed times (e.g. passing over waypoints, at sector hand-over).

Separation is achieved by applying a procedural service (as described in Ref 2, Chapter 5). Most significantly, these procedures require substantial lateral separation standards between aircraft on adjacent tracks and longitudinal separation standards (e.g. time and distance) between aircraft on the same track and between aircraft on merging and crossing routes where vertical separation is not assured..

A.2.4.2 Proposed procedures

The ADS-B-NRA application shall provide controllers with very similar facilities and control benefits to those available from SSR radar. Consequently, the intention is that some of the procedures using radar services (as described in Chapter 8 of Ref 2) will be extended for ADS-B use, assuming that the quality of service of ADS-B surveillance data is similar to (or better than) SSR radar and that direct controller pilot communications is available.

Current procedures in Ref 2 for SSR radar services will be affected or modified slightly by the introduction of ADS-B-based surveillance. Specific ADS-B procedures (Ref 2) have been proposed by the OPLINK Panel and are pending approval by the ANC .These changes to PANS-ATM are addressed below.

A.2.4.2.1 ATC Surveillance system capabilities (Ref 2 Chapter 8.1)

An ADS-B system providing surveillance will be expected to provide at least equivalent levels of reliability, availability and integrity to SSR ground sensors and aircraft transponders, however there are various differences between SSR and ADS-B.

ADS-B position information is entirely dependent and its quality may vary between aircraft or vary with time for the same aircraft. Note also that the ADS-B transmissions are expected to be much less error prone than the SSR Mode A/C transmissions which may be corrupted in 'garble' situations. Furthermore, the ADS-B report provides some information about its expected accuracy and integrity (as determined by the aircraft equipment). This information shall be used by the ground system to indicate to controllers whenever the ADS-B surveillance quality of particular aircraft or the ADS-B system as a whole falls below acceptable limits for particular purposes (e.g. for application of certain separation minima).

The ADS-B transmitter is not necessarily the same for all ADS-B aircraft – presently there are three different types of ADS-B data links (using different frequencies and formats). Hence, it is assumed that for effective use of ADS-B surveillance that either all aircraft are equipped with the same type of ADS-B transmitter or that ground sensors for each type exist and have similar coverage in the area of concern.

In some states, it is recognised that SSR Mode A code will be required in ADS-B reports for compatibility with existing radar and flight data processing systems (i.e. these systems require Mode A code for correlation with flight plans to obtain aircraft identification). However, ADS-B will also transmit the aircraft identification and the aircraft address [see Ref 2, Appendix 2 for aircraft identification, registration and aircraft address]. Future systems should be capable of using the aircraft identification from ADS-B directly for display. Furthermore, the aircraft identification and/or aircraft address from ADS-B may be used for correlation with the flight plan.

ADS-B contains additional aircraft information (beyond that provided by SSR Mode A/C) and this may be used by the system to enhance the facilities available to controllers and also to enhance other automatic monitoring tools and safety nets.

A.2.4.2.2 Situation Display (Ref 2 Chapter 8.2)

ADS-B surveillance information should be presented to the controller in a similar way to radar (assuming that the quality of service of ADS-B data is sufficient).

A.2.4.2.3 Provision of ATS Surveillance Services (Ref 2 Chapter 8.4)

The same services as are supported by SSR can be supported by ADS-B surveillance, providing that ADS-B surveillance quality and equipage are equivalent. Any ADS-B equipment failure or service degradation (including for individual aircraft) must be recognised in the same time frames as for radar equipment failures so that reversion to non-radar procedures can be achieved safely.

Automatic functions, such as flight plan correlation, safety net and flight path monitoring can be enabled (and enhanced) by the availability of ADS-B surveillance.

A.2.4.2.4 Use of SSR Transponders and ADS-B Transmitters (Ref 2 Chapter 8.5)

It is expected that the aircrew will interface to the ADS-B equipment in a similar way to a SSR (or Mode S) transponder. It is expected that the operating procedures for ADS-B equipment will be defined (in a similar way to Part III Section 3 PANS-OPS Document 8168).

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The flight crew shall be able to check [26]the aircraft identification information set on board and subsequently transmitted by the ADS-B equipment. Aircraft identification is envisaged to be the primary means of identification with ADS-B. The term 'Aircraft Identification' is understood to include either call-sign or registration mark (as filed in field 7 of the ICAO flight plan).

Whenever the aircraft identification transmitted by an ADS-B-equipped aircraft is different from that expected from the aircraft, the pilot shall be requested to confirm aircraft identification, then re-enter and confirm that the assigned aircraft identification has been selected.

In addition to using the aircraft ID the IDENT (i.e. SPI) feature is also required by the proposed procedures in Ref 2. This will be operated similarly to the corresponding functions in Mode A and S.

In regards to altitude information, ADS-B merely introduces a new transfer medium and not a new source of data, as such it is expected that verification of the barometric flight level provided by ADS-B will be the same as for current verification procedures for use of SSR Mode C.

A.2.4.2.5 General Procedures (Ref 2 Chapter 8.6)

Controller procedures for performance checks on the ADS-B surveillance data will be required, in a similar way to those specified for radar surveillance data. The system must provide the controller with indications when the working status of ADS-B ground sensors degrades such that service provision levels are affected.

Controllers shall be provided with an indication of the accuracy of ADS-B position reports (for example different track symbols to differentiate position accuracy that is good enough for separation services from those that are not).). It may be necessary in some environments to display warnings when the accuracy of ADS-B position is likely/planned to be degraded by the deterioration of navigational sources (for example by ground monitoring the GNSS satellite state).

It is envisaged that transfer of identification for ADS-B will be done in accordance with the procedures proposed in Ref 2

In operations where controllers vector aircraft, current heading of the instructed aircraft may be aircraft-derived .

A.2.4.2.6 Use of ATS Surveillance Systems in the Air Traffic Control Services (Ref 2 Chapter 8.7)

Separation minima applied between ADS-B-equipped aircraft will depend upon ADS-B surveillance data quality (in terms of accuracy, integrity and availability) in the particular environment. These factors need to be considered by the local ATS authority in determining the appropriate separation minima for the environment. It is anticipated that ADS-B surveillance will enable the use of separation minima much smaller than present procedural separation. Furthermore, where the quality of ADS-B surveillance is similar to, or better than radar, then similar separation minima may be appropriate. Moreover, in some environments, separation minima applied to ADS-B surveillance may be smaller than the radar minima currently applied in similar conditions (e.g. in comparison with SSR from long range).

However, the possibility of the ADS-B surveillance quality of individual aircraft (as indicated by the accuracy and integrity information in the ADS-B report) falling below certain levels also needs to be considered in the separation procedures. During circumstances of variable position quality during an aircraft flight, a local authority may decide that various surveillance separation standards will be applied depending on the quality. However, as input to the SPR work, this OSED assumes that only one 'surveillance' separation standard will be applied in the airspace concerned (this may be the minimum ICAO standard which is yet to be confirmed or another larger standard as dictated by the local implementation environment and safety case).

A.2.4.2.7 Emergencies, Hazards and Equipment Failures (Ref 2 Chapter 8.8)

In the event of an aircraft reporting or appearing from the ADS-B surveillance information to be in an emergency situation, then the same emergency procedures as for radar control will apply.

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[26] to be discussed the operational requirement of changing the aircraft identification

Emergency modes in the ADS-B report are expected to signify, as a minimum, the same emergency conditions as are presently signified by Mode A emergency codes (i.e. 7700 general emergency, 7600 communications failure and 7500 unlawful interference). ADS-B may also provide for urgency modes (minimum fuel and/or medical) where available on the aircaft.

These emergency and /or urgency modes in ADS-B shall be used and displayed by the system in the same way as present SSR

It should be noted that some of the current avionics systems are only capable of transmitting an 'emergency' indicator. However whenever the capability for the pilot to select discrete emergency codes is present, the ADS-B system shall be able to transmit the appropriate discrete emergency and/or urgency modes.

Similar procedures as described for the failure of an aircraft transponder are required for the failure of the aircraft ADS-B transmitter in airspace where equipage is mandatory.

Procedures in the event of a complete failure of the ADS-B system will be similar to procedures for radar equipment failure. [Assuming that there is no radar coverage, as is the case for NRA by definition].

In situations where more than one ADS-B link type operation is supported, the complete failure of one of these links (but not the others) may also need to be considered.

A.2.4.2.8 Use of ATS Surveillance Systems in the Approach Control Service (Ref 2 Chapter 8.9)

Present radar approach control using primary radar has the capability of detecting all aircraft in the vicinity and it is not envisaged that ADS-B will replace current primary radar as such it is not within the scope of this application.

A.2.4.3 Partial Equipage

The question of airborne ADS-B equipage rates associated with the implementation of NRA is an important one for the safety, efficiency and business case activities. This issue can be solved at the local/regional level through various methods from mandating airborne equipage, segregating airspace between equipped and non-equipped traffic or permitting controllers to tactically manage a mixed equipage environment. It is recognised however that the objective in many regions will be to have all aircraft equipped to maximise benefits.

It is important to note that the partial equipage issue has been identified during the Operational Hazard Assessment process. Mitigation strategies corresponding to this hazard are required at the operational level and not required at the technical level. Thus the Safety and Performance Requirements work has not integrated this into the Allocation of Safety Objectives and Requirements process. There is also the desire not to force regions into applying one particular variation of the resolution methods suggested above (e.g. mandates).

When implementing NRA it is therefore vital to ensure that the impact on controllers' situational awareness from this partial equipage issue is accounted for as it has been in radar environments that do not contain complete SSR transponder equipage.

- Changes to routes, airspace boundaries and local procedures may be necessary to achieve efficient control of traffic in a particular environment.
- In some airspace, priority may be given to equipped aircraft to provide economic benefits to those aircraft that equip and thereby encourage greater equipage for the benefit of all.

A.2.4.4 Operational examples

The examples illustrate how, at a local level, operations using ADS-B surveillance may be implemented, in particular to deal with partial equipage. Firstly, an operational example of the procedures used with ADS-B surveillance in the Kiruna environment is given in Appendix A. In this environment, it was appropriate to segregate certain parts of the airspace as being only available to ADS-B equipped aircraft. In contrast, the Australian example of a mixed environment where segregation of equipped and non-equipped aircraft is not necessary is given in Appendix B.

A.2.4.5 Roles and responsibilities

There are no fundamental changes in the roles and responsibilities of the aircrew or controllers. The controller remains responsible for the management of the airspace, maintaining separation and providing information to aircrews, whilst the aircrews are responsible for acting upon ATC instructions and providing information to ATC.

However, there may be impact on controller and aircrew workloads because of the possible new control procedures and the provision of enhanced services. [There is also the potential to increase traffic because of the capacity benefits of ADS-B surveillance, but this is not considered as being part of the current definition for this application]. On the other hand, there is expected to be some reduction in workload due to the simplification of separation standards to be applied and the reduced need for voice position reports, since the aircraft parameters will be broadcast and received automatically by ADS. This workload reduction may be reliant on ADS-B equipage rates (see Partial Equipage).

A.2.4.6 Impact on Phraseology

It is anticipated that phraseology for aircraft in ADS-B surveillance should be very similar to that used today in radar surveillance services. The phraseology may need to be changed slightly for the new information source. However, the detailed changes of phraseology are outside the scope of this document and will be subject to validation and ICAO standardisation.

It is anticipated that voice for procedural reporting of position will be reduced.

A.2.4.7 Impact on Coordination and Transfer

Existing coordination procedures in PANS-ATM Chapter 10 are not expected to be impacted on through the implementation of ADS-B in to non-radar areas. It is expected that prior to the aircraft leaving the ‘defined airspace volume’ (refer definitions section) within which the ADS-B service is being applied, the controller will establish the necessary separation standard applicable to the airspace the aircraft is entering, as per existing requirements for aircraft exiting radar coverage (i.e. PANS_ATM 10.4.1.3 h).

A.2.5 AIRSPACE CHARACTERISTICS AND OPERATIONAL ENVIRONMENT

A.2.5.1 General

The generic airspace characteristics and operational environment are described in Annex B of the general Operational Services and Environment Definition [Reference 3]. The sub-sections below highlight the aspects of the airspace characteristics and operational environment that are of particular significance to the ADS-B-NRA application.

A.2.5.2 Surveillance Environment

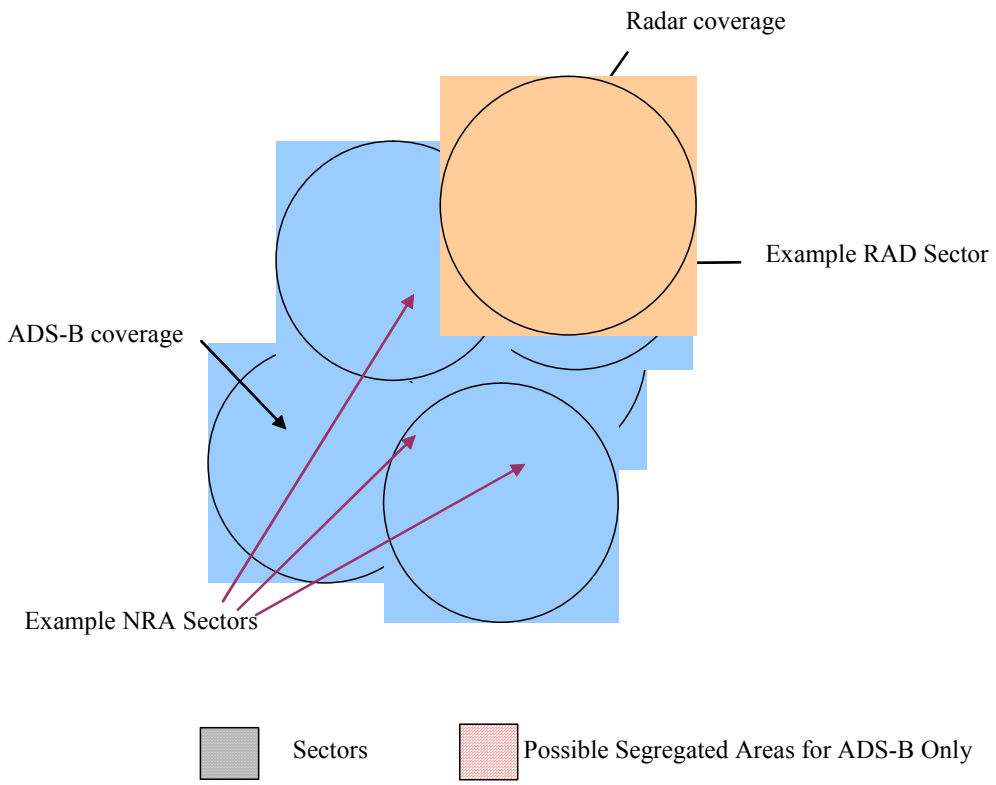

Figure 4 ADS-B-NRA Surveillance Environment Illustration

Figure 1 below illustrates the surveillance environment for the application of ADS-B in a non-radar environment (including an example of an ADS-B RAD sector to assist distinguishing from ADS-B-NRA).

The environment will contain ADS-B ground sensors to provide surveillance of ADS-B equipped aircraft. If more than one type of ADS-B data link is to be supported, then ground sensors for each type will be required. However ADS-B coverage of the entire sector may not be complete.

In some areas, there may be sufficient overlapping coverage of ADS-B sensors to provide multi-lateration measurements of certain types of ADS-B transmitters and also for non-ADS-B equipped aircraft with SSR transponders. The use of multi-lateration may provide additional integrity checks on ADS-B positions and also may enhance some services involving non-ADS-B equipped aircraft in the transition period.

The NRA application at this generic level assumes complete ADS-B-only coverage. However, in terms of local implementation, some parts of a sector may have limited radar coverage and in some places this may overlap with ADS-B cover (however this dual surveillance scenario is covered by the ADS-B RAD application).

In many regions the longer-term objective is to have all aircraft ADS-B equipped; however, in the shorter term, there may be a mixture of ADS-B-equipped and non-equipped aircraft and the safety impacts of this transitional issue will need to be carefully managed at the local level.

In some local environments, it may be most appropriate to segregate regions of airspace for ADS-B -equipped aircraft in a similar way to the present mandatory carriage of SSR transponders in many regions of managed radar airspace (such as in the example of Appendix A).

A.2.5.3 Ground-Air Communications Environment

The environment assumes complete ground-air coverage from VHF/HF communications. However this may be augmented with some form of data link (e.g. CPDLC) which might only partially cover the environment.

A.2.5.4 Control in different regions of the environment

The most efficient tactical control of aircraft can be achieved when all aircraft in a particular airspace volume are equipped.

In airspace with mixed equipage, the baseline will be procedural separation (as in the present NRA environment). However, in circumstances where two or more ADS-B-equipped aircraft are in the mixed environment then, surveillance separations may be applied between them to achieve more efficient use of the airspace. [There may be non-equipped aircraft in the vicinity – but procedurally separated]. This may be likened to the current NRA environment separation standard mix where some aircraft are separated by a DME distance provided they have the right equipment, whereas an aircraft without DME equipment would need to be spaced with DME-equipped aircraft using time standards. Also see section on Partial Equipage)

A.2.6 ADS-B-NRA CONTROL PHASES

A.2.6.1 Introduction

The control phases presented below concern the use of ADS-B surveillance to support Air Traffic Control (Separation based on ADS-B) and Alerting Services activities (applicable in airspace classes A to E). Flight Information Services (including traffic advisories) are not represented by phase diagrams because they are considered to be much less critical for safety and performance requirements.

The detailed phase diagrams are contained in Appendix C, but the table below summarises the six phases used in the diagrams and relates the activities involved in each phase to existing PANS-ATM (Ref 2) radar services.

Phases of operations	Handling of ADS-B equipped traffic
Phase 1 – ADS-B Data Acquisition	The aircraft transmits ADS-B messages. The ground processing receives and validates the ADS-B information. (similar to radar system capabilities in PANS-ATM 8.1)
Phase 2 – Initiation of ADS-B based Services	The ADS-B track automatically appears on the controller's surveillance display. (similar to presentation of radar information in PANS-ATM 8.2) Direct pilot-controller communications established (PANS-ATM 8.3.2) The flight crew receives contact from the ATC to establish ADS-B identification (similar to establishment of radar identification in PANS-ATM 8.6.2) Flight plan association of the ADS-B track is established.

Phase 3 – Provision of ADS-B based separation services	Monitoring of ADS-B traffic on the surveillance display and applying (surveillance) control procedures similar to PANS-ATM Chapter 8 procedures, in particular for: ATC service functions (like in 8.4 & 8.7.1) Co-ordination of equipped and non-equipped traffic (like in 8.7.2) Separation application (like in 8.7.3 and 8.7.4) Vectoring (like in 8.6.5 & 8.9) Surveillance monitoring (as per Radar Monitoring) [The provision of services requiring appropriate quality of surveillance information (like in 8.1.7)]
Phase 4 – System alerting	System alerting procedures are similar to those defined in PANS-ATM procedures for radar emergencies, hazards and equipment failures (Chapter 8.8), in particular for: Aircraft Emergencies (like in 8.8.1), Failure of equipment (like in 8.8.3), with 'ADS-B-out' failure requiring similar action as for SSR transponder failure - ADS-B equipment failure (like radar equipment failure in 8.8.4)
Phase 5 –Termination of ADS-B-based Service(s) (due to either expected or unexpected terminations)	For unexpected termination, ADS-B Separation can no be longer be applied, and the controller applies procedural separation. For expected termination transfer is co-ordinated with the adjacent sector (or aerodrome). Control procedures similar to PANS-ATM chapter 8: Co-ordination of traffic (like 8.7.2) - Transfer of control (like in 8.7.5)

Table 1 OSED - ADS-B-NRA Control Phases

A.2.7 ABNORMAL MODES

The following abnormal modes may occur with ADS-B surveillance data:

- Failure of the aircraft "ADS-B-out" system for a particular aircraft. In this case, procedures will be similar to those used for the failure of a SSR transponder in radar airspace.
- Complete failure of the ADS-B ground receiving and processing system. In this case, procedures will be similar to those used for the complete loss of radar data in radar airspace.
- Failure (or planned outage) of an ADS-B ground receiver, giving reduced coverage. Reversion to procedural control in the regions of no cover is required. Status monitoring of the ground receiver systems is required to detect when unexpected deterioration occurs. In this case, procedures will be similar to those used for the failure or planned outage of a radar sensor in radar airspace.
- Degradation of all ADS-B data due to deterioration of positioning sources (particularly those using GNSS). The position accuracy in many ADS-B reports may fall below that required for surveillance separation. Increased or procedural separation will be required. [Note that ADS-B reported barometric flight level information is not affected by GNSS degradation]. Methods of monitoring the integrity of the ADS-system (Incl. GNSS/Other positioning sources) by the ground are desirable to detect and predict when this condition is likely to occur. In this case, procedures could be similar to those used for degradation in performance of radar sensors in radar airspace.

- Degradation of ADS-B accuracy from a particular aircraft (due to deterioration of that aircraft's navigational sources). If the indicated position accuracy or integrity falls below a certain limit, then increased separation or procedural control should be applied between this aircraft and the surrounding traffic.
- Corruption of ADS-B data from a particular aircraft (due to a fault in the aircraft equipment). The corruption could affect any of the ADS-B data fields. It may be necessary to have procedures to confirm the aircraft position when ADS-B contact is made and whenever the aircraft position appears to be inconsistent with its expected route. If corrupt ADS-B information is detected, then control of the aircraft will revert to procedural methods. It may also be helpful to have other ground monitoring checks on the credibility of ADS-B data to detect such anomalies. [The situation is similar to the corruption of Mode C flight level information provided by the aircraft in a SSR radar environment].
- Degradation of the ADS-B surveillance picture due to intentional generation and broadcasting of false ADS-B targets (spoofing). A separate/independent means of validating ADS-B reports and appropriate procedures may be necessary to protect against such a hazard.

A.2.8 REQUIREMENTS

A.2.8.1 General

The sub-sections below highlight particular aspects of relevance to the ADS-B-NRA application. These requirements may be subject to further change as a result of the SPR and INTEROP processes.

A.2.8.2 CNS Infrastructure

An ADS-B ground infrastructure is required

The ADS-B ground system provides surveillance processing for ADS-B data: e.g. creation and maintenance based on ADS-B reports and display of these tracks on the CWP and track termination.

Ground-air communications for provision of ATC services (e.g. VHF coverage for tactical control) are required as defined by the class of airspace (see Annex 4 of Ref 1).

A.2.8.3 ATS

As prerequisites, it is assumed that the CWP is equipped with an Air Situation Display.

OR 1 : The following list of surveillance parameters shall be provided to the controller
-Identity
-Position
-Indication of the quality of ADS information (in particular, to indicate whether it is good enough for certain separation purposes).
-Emergency indicator(s) (as a minimum "general emergency" but may also include "communications failure" and "unlawful interference").
-Special Position Identifier (SPI)
-Barometric Altitude
-Ground Velocity

Note, these are parameters required by the controller. The ATS system processing may require other information in the ADS-B messages (e.g. time stamp) to provide these parameters, but these details are outside the scope of this document.

The ground velocity required by the controller may be determined by the ground system from successive position updates or taken directly from the ADS-B data (if aircraft-derived ground velocity is sent).

Although there is also potential for geometric altitude to be sent which may be used by the ground system (such as for cross checking barometric altitude data) this parameter is outside the scope of NRA but may be considered in other applications such as ADS-B ADD (Aircraft Derived data)

A.2.8.4 Aircraft

Aircraft will be required to equip with an ADS-B transmitter, including interfaces to the on-board data sources.

A.2.8.5 Airport vehicle

Not applicable

A.2.8.6 Quality of Service Requirements

The quality of service is expected to be similar to or better than present SSR radar.

A.2.8.7 Operational Requirements

The following represents a list of operational requirements related to implementation of ADS-B-NRA.;

System capabilities

OR 2 : Requirements as developed in "Air Traffic Management", ICAO, PANS-ATM, Document 4444, Fourteenth edition (proposal to update Amendment 4 to include ADS-B procedures in Chapter 8 'Surveillance Services'; yet to be approval by the ANC) shall be met by ADS-B-NRA.

Although already covered by OR1 various specific requirements have been selected to facilitate traceability with requirements expressed in the main body:

OR 3 : It is expected that the aircrew shall interface to the ADS-B transponder in the same way to a SSR (or Mode S) transponder.

OR 4 : Aircraft equipped with ADS-B having an aircraft identification feature shall transmit the aircraft identification as specified in Item 7 of the ICAO flight plan or, when no flight plan has been filed, the aircraft registration.

OR 5 : The ADS-B system shall be at least as reliable and available as for today's SSR system (ground and airborne components included)

OR 6 : Where various datalinks are used by the system to transmit and receive ADS-B data these shall be transparent to the controllers.

OR 7 : When altitude information being transmitted through ADS-B is verified as being inaccurate there shall be a function (either airborne or ground) to enable manual filtering of this data item (either prior to or at the CWP).

Information Presentation

OR 8 : The ADS-B system shall indicate to ATCO's whenever the surveillance quality of particular aircraft or the surveillance system as a whole falls below limits that are acceptable for the various functions of ATC (e.g. Enroute or TMA).

OR 9 : The ADS-B system shall provide an alert to ATCO's whenever the surveillance quality of the position source of surveillance system as a whole falls below limits that are acceptable for the various functions of ATC (e.g. Enroute or TMA)

OR 10 : Surveillance information shall be presented to the controller in a clear and concise manner in a similar way to radar (e.g. Surveillance tracks refresh rate).

OR 11 : ATCO's shall be provided with an indication when aircraft position information is not received or is being filtered by the ground system due to detected errors (e.g. radar track coasting symbol)[27]

Service Provision

OR 12 : Appropriate ATS authorities shall provide controllers with contingency procedures in the event of degradation of the quality of the position information sources, for example expected Receiver Autonomous Integrity Monitoring (RAIM) outage for GNSS.

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[27] this OR is not being picked up in reference in chapter 3 – to be checked.

OR 13 : When SPI functionality is available ADS-B **shall** provide it upon ATC request.

Emergencies

OR 14 : Whenever the capability for the pilot to select discrete SSR emergency codes is available the ADS-B system shall be able to transmit the appropriate discrete emergency and/or urgency modes. These discrete and/or urgency modes are:
-emergency
-communication-failure
-unlawful-interference
-minimum-fuel
-medical

OR 15 : Indication that an aircraft is transmitting an emergency and /or urgency mode shall be displayed to the controller in a clear and expeditious manner.

A.2.9 REFERENCES

"Air Traffic Services", ICAO, Annex 11 to the convention on International Civil Aviation, Thirteenth edition, July 2001

1. "Air Traffic Management", ICAO, Procedures for Air Navigation Services, Document 4444, Fourteenth edition - proposal to update Amendment 4 to include ADS-B procedures in Chapter 8 'Surveillance Services'; yet to be approval by the ANC
2. "Package I Operational Services and Environmental Definition (OSED)", V 1.2 [RFG internal document – refer Eurocontrol One Sky Teams].

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Appendix A.1 An example of a mixed operations environment at Kiruna

Refer to NUP II local OSED ADS-B Kiruna Application version 2.1, dated 25/09/2002.

Appendix A.2 An example of a mixed operations environment in Australia

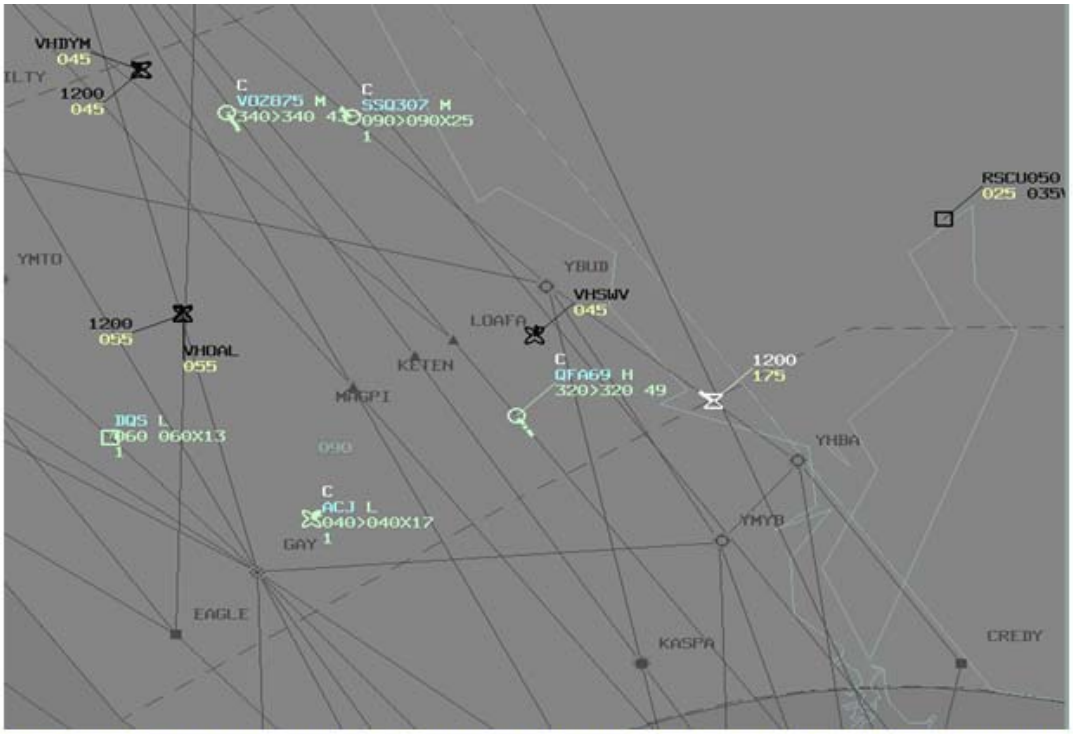
The summary below illustrates the concept in which ADS-B and non-ADS-B are not segregated to allow surveillance services to be executed in an en-route environment.

Environment

The Airspace is non-radar airspace with good VHF voice communication and good ADS-B ground station coverage over the whole continent.

The ATC automation system presents radar, ADS-B, ADS-C and flight plan tracks to controllers as electronic plan view presentation without any paper strips. The whole FIR (all sectors) have all capabilities in an integrated ATM system. Individual ATC sectors have both regions of radar coverage and areas without radar coverage. They also have some aircraft equipped with ADS-B and some without. The controller applies procedural separation standards but may apply radar separation standards to aircraft inside radar coverage and may apply ADS-B separation standards to pairs of aircraft equipped with ADS-B.

Track display indicates to controllers whether the track is based on radar, ADS-B, ADS-C or flight plan data.



Screen capture of Australian air situation display showing radar, ADS-B and flight plan tracks

- **Position derived from RADAR**
- **Position derived from ADS-B (below radar coverage)**
- **Flight plan track (no surveillance)**

A GNSS availability prediction system provides controllers with estimates of potential loss of ADS-B service. In such a case, procedural control, as applied to non equipped aircraft is used. If loss of ADS-B occurs, the track display transitions to a flight plan track.

Operational

In this environment, division into ADS-B and non ADS-B airspace is not required. No specific airspace entry points or airspace management is required.

Controllers have adequate tools, training, procedures and backup systems to manage mixed equipage.

Controllers are also supported by integrated safety nets (STCA, MSAW, Danger area infringement warning, Route adherence warning, Cleared level adherence warning) and ADS-B updates to the flight plan processing. These tools provide some protection against erroneous ADS-B data.

Operational priority is provided to equipped aircraft.

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Appendix A.3 Phase Diagrams

- The following diagrams present the control phases for the use of ADS-B surveillance to support the provision of Air Traffic Control/Separation task and Alerting Services (applicable to airspace classes A to E).

Definitions of Terms used in Phase Diagrams

In the subsequent phase diagrams, the following convention is used to indicate who or what is responsible for the task:

Gnd-Pro = A task performed specifically by the ground processing equipment.
Gnd-ATCO = A task performed specifically by the ground Air Traffic Controller.
Gnd = A task performed by ground processing equipment or by Air Traffic Controller or by a combination of both.
A/C-Av = A task performed specifically by the aircraft avionics
A/C-FC = A task performed specifically by the aircraft Flight Crew
A/C = A task performed by the aircraft avionics or by the Flight Crew or by a combination of both.

The meanings of other terms concerning ADS-B surveillance information are further detailed in Appendix D.

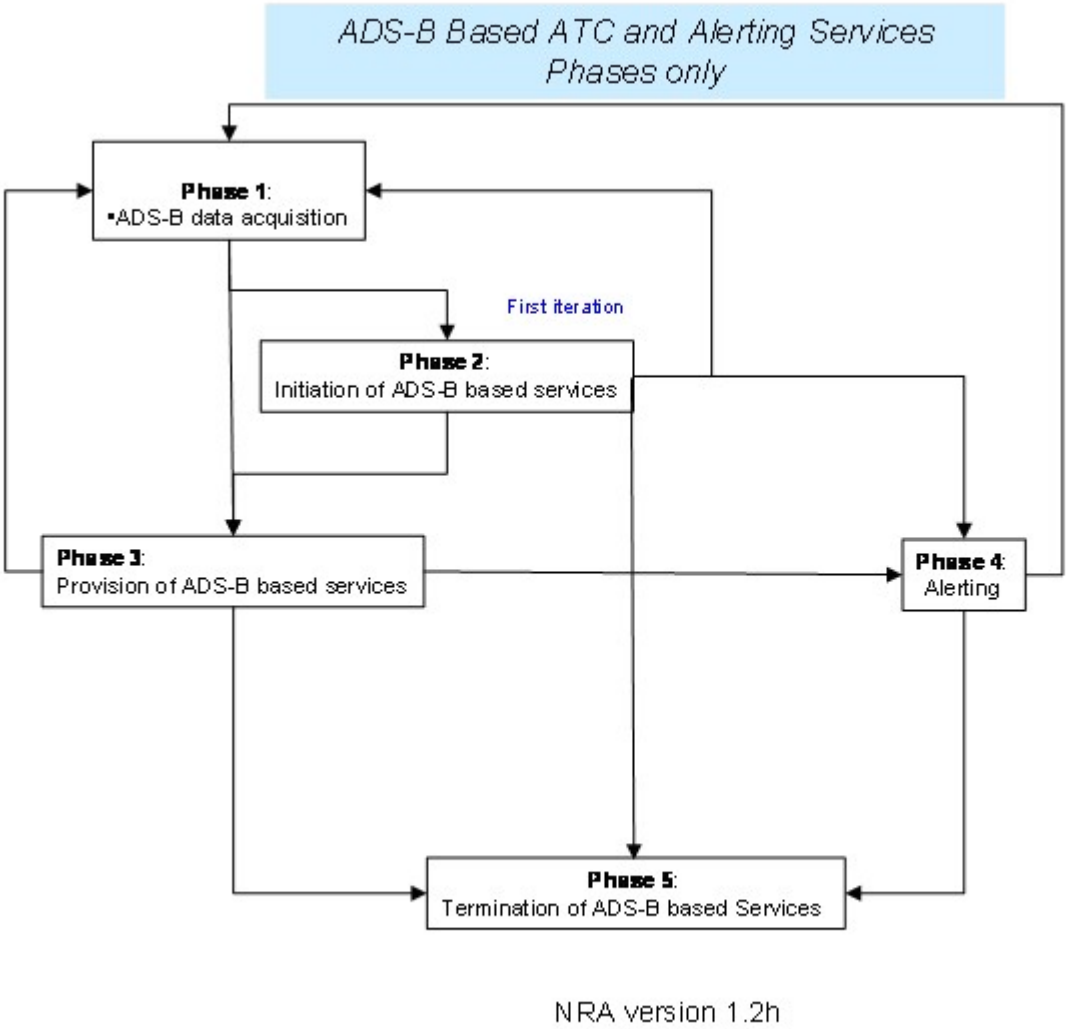

Figure 5 : OSED – High-level Phase diagram

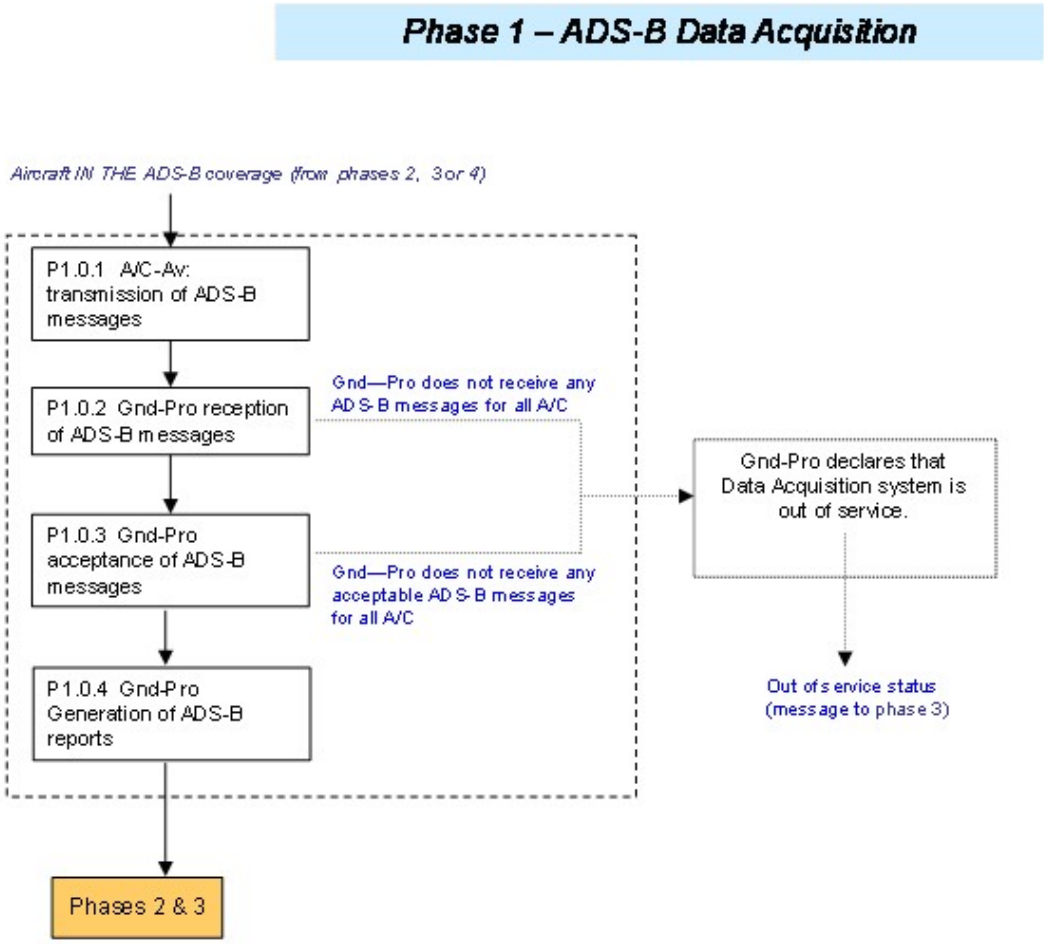

Figure 6 : OSED – Phase 1 ADS-B Data Acquisition

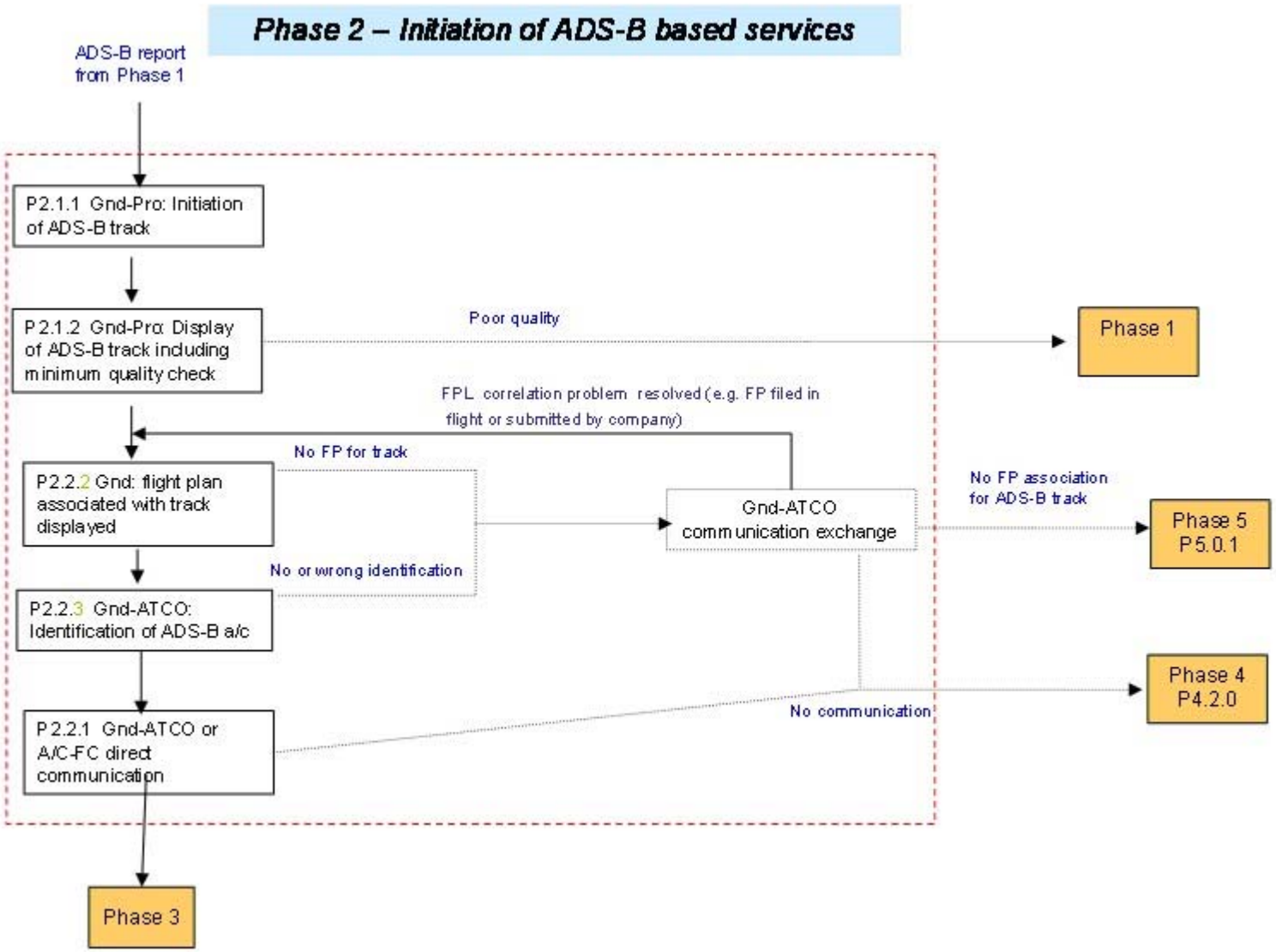

Figure 7 : OSED – Phase 2 Initiation of ADS-B Based Services

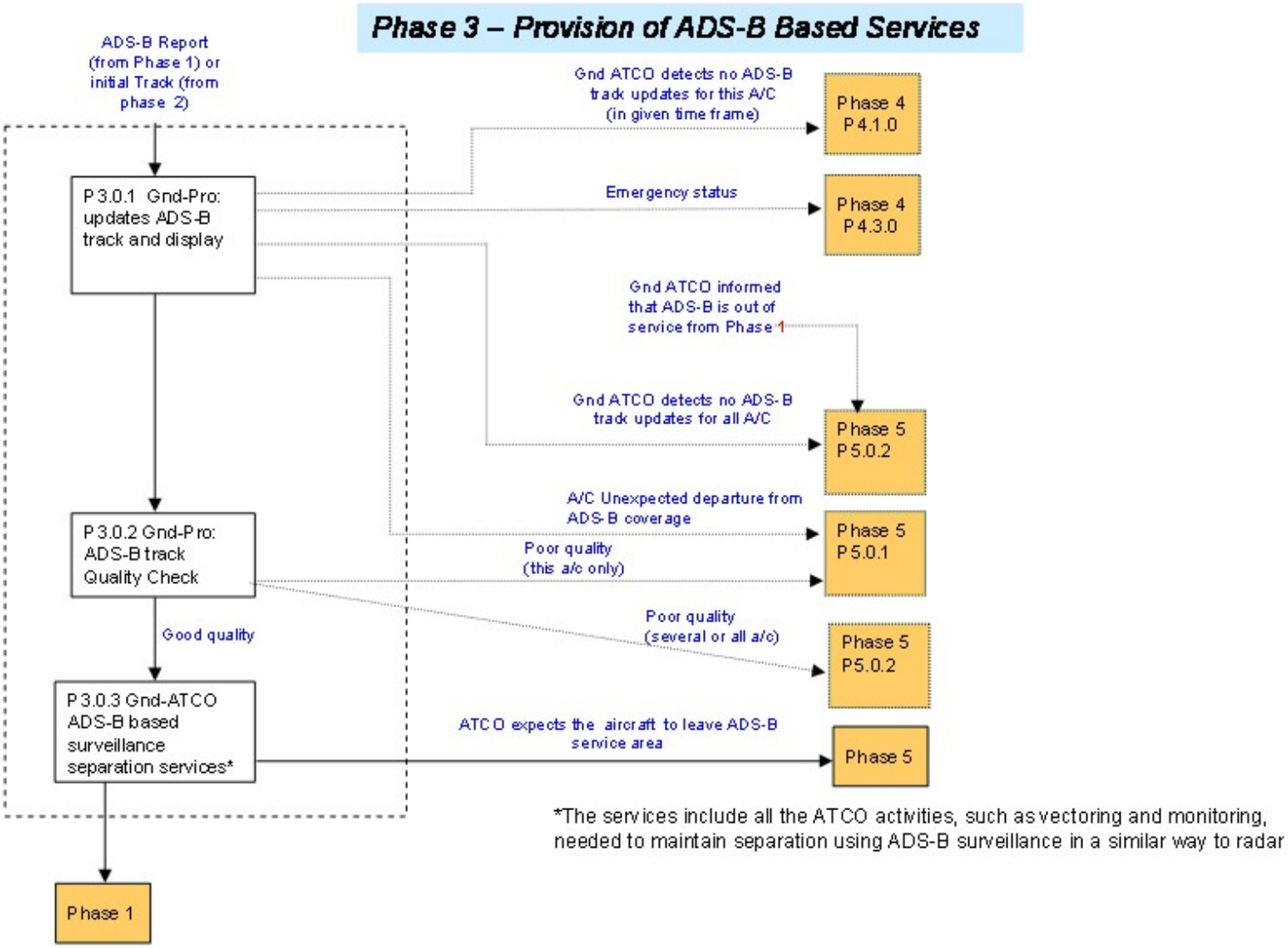

Figure 8 OSED – Phase 3 Provision of ADS-B Based Services

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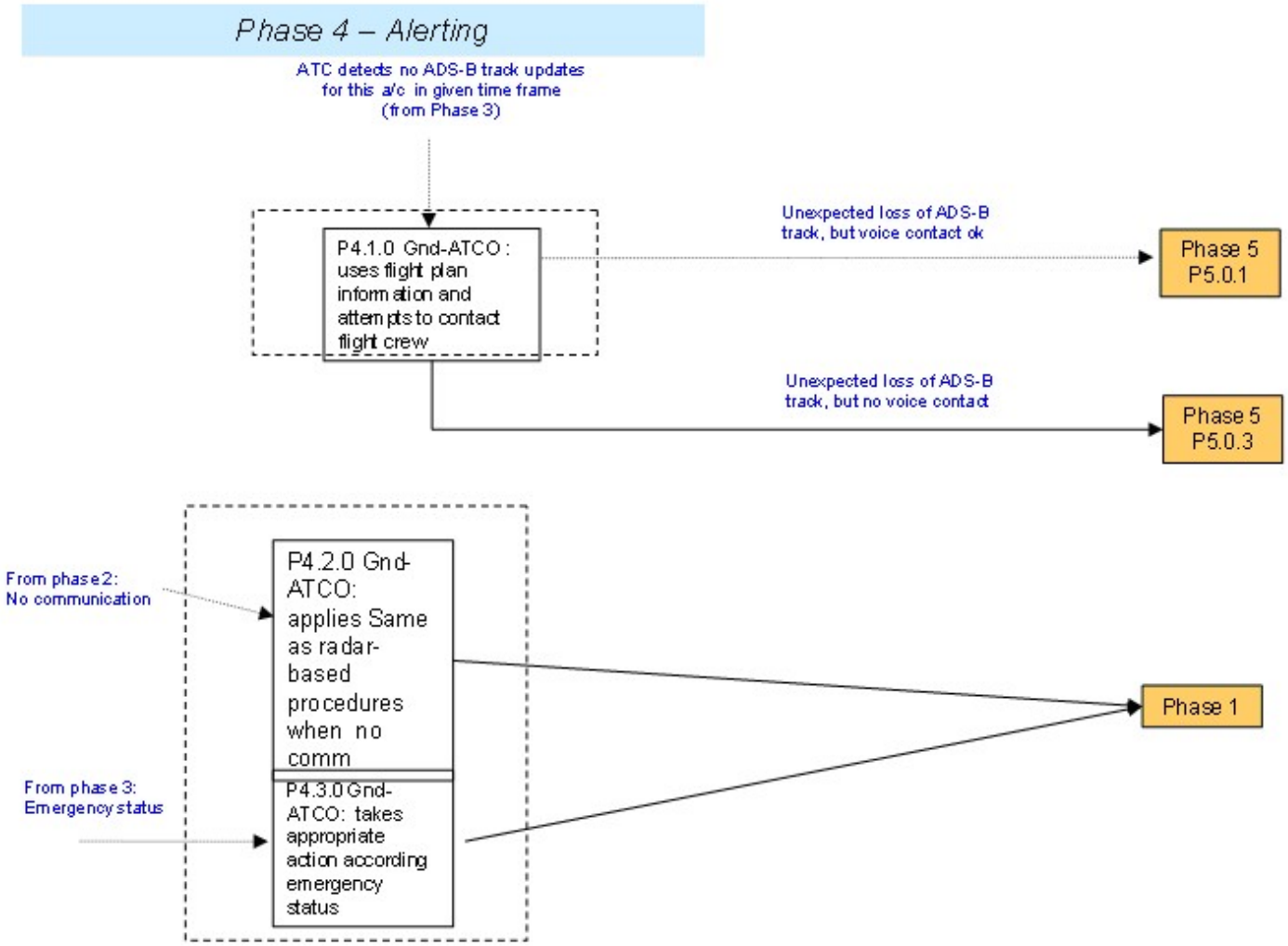

Figure 9 OSED – Phase 4 Alerting

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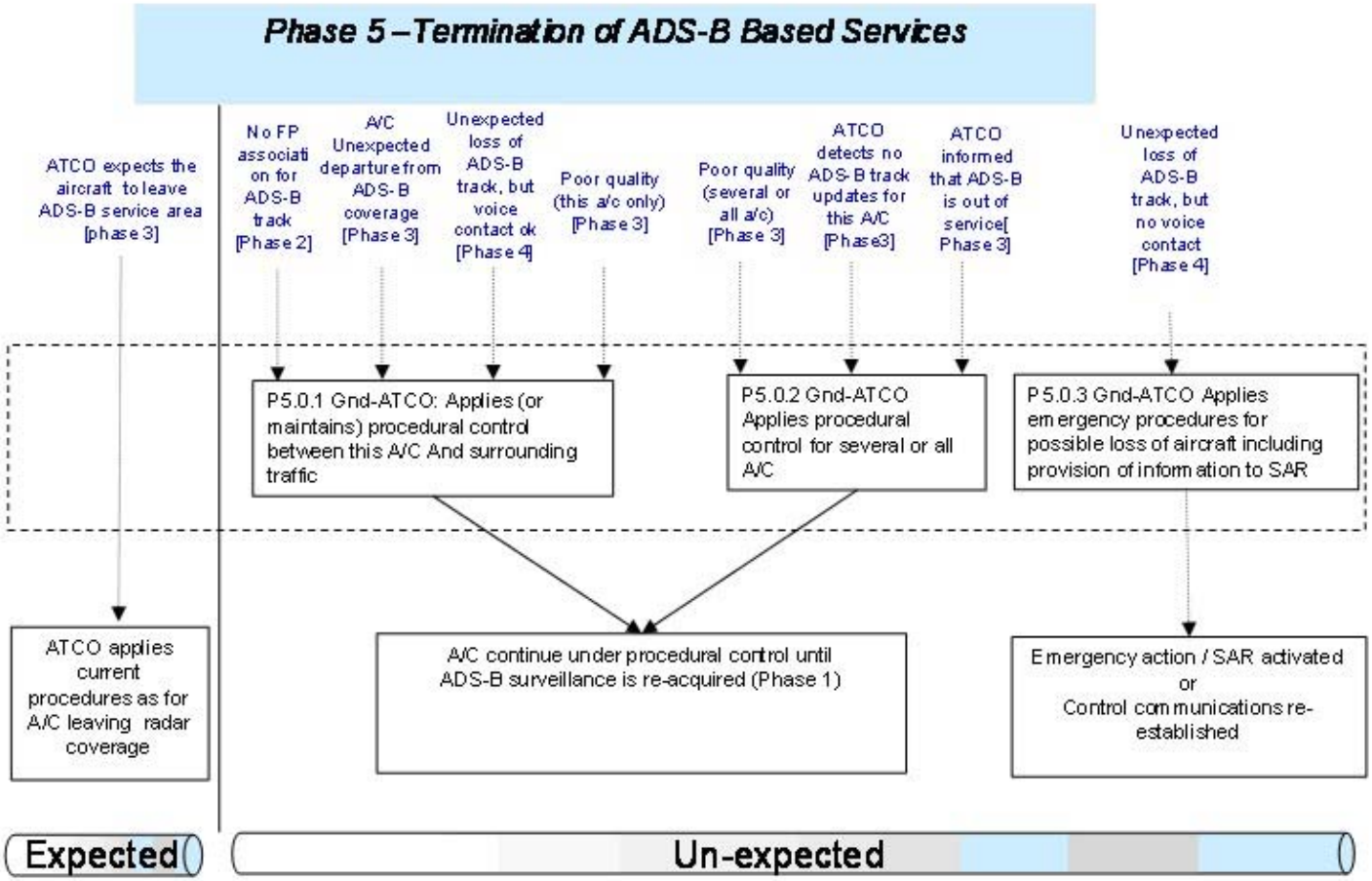

Figure 10 OSED – Phase 5 Termination of ADS-B Based Services

Appendix A.4 Definition of ADS-B surveillance terms

The meanings of various terms and functions concerning ADS-B surveillance as used in the Phase Diagrams (Appendix C) are defined below:

ADS-B message:

An ADS-B message is a package of information broadcast by the aircraft/vehicle. Each ADS-B message contains a defined set of aircraft/vehicle parameters but these parameters may be only a subset of the available parameters. The format of the message is link specific, as is the number of different messages required for providing all the required set of parameters. Generally, the message will contain additional error protection information to reduce the risk of undetected errors in the decoding of the message by the receiving system.

[The detailed characteristics of the ADS-B messages are defined in each of the particular ADS-B link MOPS].

Acceptance (of ADS-B information)

The objective of the acceptance function[28] is to check that the ADS-B information is correct (or is very likely to be correct). In practice, the acceptance function may involve various levels of checking, as indicated below (not exhaustive).

The basic level of acceptance checking will be to apply the error detection capability inherent in the transmission format of the ADS-B message (this will be link specific). The error detection (and sometimes correction) capability will reduce the likelihood of the information in the ADS-B message being decoded incorrectly by the receiving system, or will reject incorrect messages.

In addition, some independent method of checking the acceptability of individual aircraft/vehicle parameters may be applied. This may include, for example, tests on the angle of arrival or relative times of arrival at sensors. In a mixed ADS-B/radar environment, the radar reports may be used to provide independent checking of the ADS-B information. [Such methods may also detect ADS-B spoofing].

Note:

The functioning of the ADS-B system may be checked by various methods, such as the use of known (fixed) ADS-B target emitters. However, these methods are not strictly considered to be part of the process of acceptance of ADS-B information, but are considered to be part of the system checks necessary to determine whether the ADS-B system is working properly and fit for operational purposes.

ADS-B equipped

- This term assumes the aircraft has suitably certified equipment and is broadcasting the required data parameters for the application on an appropriate link.

ADS-B report

An ADS-B report contains aircraft parameters assembled from ADS-B messages received and successfully decoded by the receiving sensor system. The report is sent to the user application. The data format of the report should be independent of the particular type of ADS-B link.

A report may be sent immediately when an update of ADS-B parameters is received from an ADS-B message, or sent when an update of all parameters are received (from more than one message), or sent at certain update time intervals. How and when the reports are sent will depend upon other system considerations, such as the bandwidth of the available communications and the processing capabilities of the receiving application.

Further information (such as a time stamp) may be added to the report to support the needs of the receiving application.

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[28] : this function may be implemented in various physical components

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Defined Airspace Volume

This refers to a volume of airspace defined by vertical and lateral limits within which the ADS-B-NRA application is applied by one executive controller. This may be a segmented portion of a sector or may encompass an entire sector volume.

Quality (of ADS-B information)

Quality particularly concerns the accuracy and integrity of the ADS-B position information. Inherently, the accuracy of ADS-B information will depend upon the navigation source on board the aircraft/vehicle and the integrity will depend upon the capability of checking whether the navigational accuracy is maintained within certain limits. The ADS-B messages are expected to contain quality indicators, as determined by processing of navigational sources on board the aircraft/vehicle.

Furthermore, the receiving system may apply additional checks on the quality of ADS-B information, (for example checks on the age of the information) and additional quality indicators may be added to the ADS-B report by this process.

ADS-B track (and in general a surveillance track)

A track represents the best estimate of the current state of the aircraft/vehicle (i.e. position, velocity, possibly accelerations etc) as determined from ADS-B (surveillance) reports. The track may be calculated from a sequence of recent reports or more simply represented by the latest ADS-B report.

The track estimate may be provided to the application at times that are not synchronised to the receipt of surveillance reports, for example, to provide a periodic update to a display.

Furthermore, the track processing may also be used to enhance the acceptance checking of ADS-B information by comparing the latest ADS-B information with that predicted from the previous track.

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Annex B OPA

B.1 INTRODUCTION

B.1.1 PURPOSE

The purpose of this document is to provide the outcome of the Operational Performance Assessment (OPA) for the Non Radar Area (ADS-B-NRA) application.

B.1.2 THE CNS/ATM SYSTEM

A functional description of the CNS/ATM system required for NRA operations is depicted in Figure 3 ADS-B-NRA architecture, “points of measure

B.1.3 GLOSSARY OF TERMS

Term	Definition
ADS-B Message	An ADS-B message is a package of information broadcast by the aircraft/vehicle. Each ADS-B message contains a defined set of aircraft/vehicle parameters and these parameters may be only a subset of the available parameters. The format of the message is link specific, as is the number of different messages required for providing all the available set of parameters. Generally, the message will contain additional error protection information to reduce the risk of undetected errors in the decoding of the message by the receiving system.
ADS-B Out	Represents the functional capability of the transmitting aircraft. ADS-B Out functions include the on-board navigation sensors, altitude sensors, Surveillance Transmit Processing (STP) function and ADS-B transmission function.
ADS-B Surveillance Report	An ADS-B Surveillance[29] report contains aircraft/vehicle parameters determined from ADS-B messages received and successfully decoded by the receiving system. The data format of the ADS-B Surveillance report should be independent of the particular type of ADS-B link. From an ADS-B-NRA perspective, there are 3 different types of ADS-B Surveillance reports containing different types of minimum information **Position** = containing at least the time of applicability, position, barometric height, quality indicators and ICAO 24 bit airframe (or aircraft ?) address. **Identity** = containing at least the aircraft identity/Mode A code) and ICAO 24 bit aircraft address. **Emergency/SPI** = containing at least the emergency status indicators or SPI and ICAO 24 bit aircraft address. [When the flight crew sets either an emergency or a SPI condition]. .

29 ADS-B Surveillance reports are reports delivered at the output of the ADS-B Receive Sub System and are to be distinguished from the notion of MASPS report. Depending on a given implementation they can be atomic elements (i.e. types 1 or 2 or 3) or consolidated ones (i.e. vectors resulting from combination of types 1, 2 and 3)

Minimum ATC Separation	The prescribed distance, measured vertically in feet, and laterally and longitudinally in distance (NM) and time, applied between aircraft, or aircraft and obstacles, that ensures an acceptable collision risk exists.

Table 2 OPA Glossary of terms

Note: Surveillance performance parameters are described in section C4

B.2 ADS-B-NRA OPA APPROACH

The following sub-sections summarise the major elements of the approach.

B.2.1 SCOPE OF THE ADS-B-NRA OPA

The ADS-B-NRA application generally expects that certain ATS capabilities will be enabled by ADS-B surveillance (and expects that aircraft are suitably ADS-B equipped) in a similar way as when radar is available. In particular, for the separation services, it is assumed that ADS-B can be used to support separation minima similar to that of radar if the ADS-B technical surveillance performance is "equivalent or better than radar" (see B.2.2). Hence, it is assumed that all other non-technical surveillance aspects of the service (i.e. people and procedures) will be largely unchanged.

Consequently, the scope of this OPA is

- focused on surveillance technical aspects
- focused on the separation task that is assumed to be the most demanding ATS for ADS-B requirements

ASSUMP 2 : It is assumed that separation task is the most demanding ATS for deriving ADS-B requirements

In addition, this document provides sections for provision of apportion of surveillance requirements to airborne and ground segments (section B.6)

Note, the OPA does not cover the any effects of illegal interference, either accidental or malicious, on the surveillance system (either for radar or ADS-B in comparison).

B.2.2 COMPARATIVE APPROACH AND REFERENCE RADAR

The comparative approach requires a reference radar for which the relevant quality of service attributes are known (or can be defined). It is assumed that the reference radar is capable of supporting safe ATC separation services with the required separation minima up to a certain operating range. The required ADS-B surveillance attributes are then derived in comparison with the reference radar attributes. The comparison is therefore conducted between ADS-B and a single radar.

ASSUMP 3 : Reference radar for comparison is capable of supporting safe ATC separation services, with the required separation minima (5NM) as sole means of surveillance. .

ASSUMP 4 : The comparisons of surveillance quality of ADS-B and radar is conducted at the input of the "ATC Processing System" and ADS-B requirements are therefore expressed at ADS-B Surveillance report level. It is assumed, based on existing experience, that current ATC processing systems achieve adequate levels of performance (availability, continuity, integrity…) for implementation of the ADS-B-NRA application. Functions required to process ADS-B are largely equivalent to those required to process radar. Therefore, no specific new quantitative requirements on existing ATC processing systems are imposed.

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The quality of service requirements are expressed in terms of a number of performance parameters defined in Section C4 and the required values of these parameters are provided in Section C5. Furthermore, for some parameters there are issues concerning differences in what is provided by radar and what is (expected to be) provided by ADS-B. These issues are addressed in Sections C4 and C5 so that the comparison between radar and ADS-B is clear.

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B.3 REQUIRED DATA ITEMS AT THE INPUT OF THE "ATC PROCESSING SYSTEM"

B.3.1 LIST OF REQUIRED SURVEILLANCE DATA ITEMS

As indicated in section B.2, the ADS-B requirements are expressed in this document **at the input of the ATC system** (where the comparison with radar reports is performed). At this level, the following set of data items is required[30]:

Required Surveillance Data Items	Reference Radar (SSR)	ADS-B (Surveillance report level)
Aircraft Identification & Mode A code	Mode 3/A;	Aircraft Identification and/or Mode 3/A code;
SPI[31]	SPI code bit added to Mode 3/A reply.	SPI indicator from ADS-B message
Horizontal Position	Range; azimuth	Latitude; longitude
Barometric Altitude	Mode C from SSR	Barometric altitude from ADS-B
Time stamp[32]	Time of measurement from signal reception at the input of the radar	Time of applicability of ADS-B information in the report.
Quality indicator[33] affecting individual a/c	No specific data item, but radar range imposes limits for certain separation minima (affects surveillance quality of individual a/c according to their range)	Quality Indication on an individual a/c basis as a means to determine whether position quality is suitable for surveillance separation
Emergency indicators[34]	From mode A codes	Emergency indicators from ADS-B messages

Table 3 OPA Required data Items at the input of the ATC processing system

A quality indicator is required to indicate to the controller whether or not the surveillance information is good enough for a certain purposes, in particular for the use of certain separation minima. In radar, sufficient quality is assumed when the radar is working properly and the controller knows the range from the radar of individual aircraft. In ADS-B, in addition to the working status of the systems that will affect all aircraft, a quality for each aircraft is required. **Hence, the ADS-B system[35] is expected to provide information on the quality of the**

[30] The OSED (ref 1 & 2) contains the list of data items as required at ADS-B-NRA Application Description level (Controller's perspective)

[31] The provision of this information may be optional for some low capability aircraft fits that may be appropriate to certain local environments – see INTEROP

[32] Some means for the ground system to determine the time of applicability of the information is required by most ATC Processing Systems. [This does not imply that absolute time has to be sent in ADS-B messages, but may be determined, for example, by the time of receipt at the ground receiver and assuming the on-board aircraft equipment delays are insignificant or are known].

[33] Required as it is assumed that the position quality may vary significantly in time (otherwise would not be required) and from a/c to a/c.

[34] The provision of this information may be optional for some low capability aircraft fits that may be appropriate to certain local environments – see INTEROP

[35] ADS-B system is limited to the ADS-B Transmit function and the ADS-B Receive sub-system – see figure 1.

position of individual aircraft. The ADS-B-NRA application will use this information with certain thresholds to decide whether or not the accuracy and integrity are of sufficiently good levels for a certain purposes, in particular for the application of a certain separation minima. The required performance information specified in this OPA, as determined from a reference radar, can then be used to define the required thresholds with respect to the ADS-B accuracy and integrity information. [Note that other applications may use different thresholds on the ADS-B quality information].

The ADS-B-NRA application may require that ground velocity be provided to the controller. As this may be determined by the system from successive position updates, it is not considered a required item at the output of the ground data acquisition function (but could be used if available/required by another application[36]).

[36] Ground velocity may be provided directly by ADS-B or determined by the ground system from tracking of surveillance positions. If ground velocity is provided by ADS-B, it should be at least as good as velocity determined from radar positions. Otherwise, there are no further requirements expressed for velocity in this OPA.

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B.4 DEFINITION OF THE PERFORMANCE PARAMETERS

This section addresses the following groups of surveillance parameters:

- Update interval and update probability
- Accuracy
- Integrity
- Reliability
- Other surveillance parameter definitions
- Parameters relating to the transition from nominal mode of operation to non-nominal mode of operation

B.4.1 UPDATE INTERVAL AND UPDATE PROBABILITY

Term	Definition
Update Interval	The time interval between surveillance report receipts For radar this is fixed by the radar antenna scan. Furthermore, all the required surveillance report information (position, Mode C barometric height, Mode A identity, emergency indicators and SPI) is gathered each scan [and there is no more than one report each scan] For ADS-B the required surveillance information may be spread between more than one type of ADS-B Surveillance reports and each of these may be produced at different times and rates. The reports are linked to the same aircraft by the ICAO 24 bit airframe address. Hence, for the purposes of comparison in this OPA, the update interval between the following types of ADS-B Surveillance report is distinguished: **"Position report"** = containing at least the time of applicability, the position, the barometric height, the quality indicators and the ICAO 24 bit airframe aircraft address. **"Identity report"** = containing at least the aircraft identification/ Mode A code and the ICAO 24 bit aircraft address. **"Emergency/SPI[37] report** "= containing at least the emergency status indicators or SPI and the ICAO 24 bit aircraft address. [When the flight crew sets either an emergency or a SPI condition]. Note that after an Identity report (2) has been received, its information can be used to identify position reports (1) using a link with the common ICAO 24 bit airframe address.

[37] The provision of this information may be optional for some low capability aircraft fits that may be appropriate to certain local environments – see INTEROP

Term	Definition
Update probability	Probability that a report with the required information is received within the required **update interval** <u>For radar:</u> Probability that a radar target report is generated (i.e. detected by the radar) Probability of Mode A code validated Probability of Mode C code validated Probability of Emergency/SPI code validated Probability of code validation is the probability that, for each radar target report, the correct validated code data, corresponding to the interrogation modes, is produced. <u>For ADS-B</u>: The probability is expressed separately for each type of ADS-B Surveillance report information (position, identity, emergency) – see definition of update interval above.

Table 4 OPA - Update interval and update probability parameters definition

B.4.2 ACCURACY

Term	Definition
Accuracy	This is essentially the position measurement error distribution.
Horizontal Position Accuracy	This is essentially the horizontal position measurement error distribution For radar, the horizontal position accuracy is normally expressed in terms of range and azimuth. The azimuth error distribution is of prime concern. The overall errors are considered to have the following component errors: Core errors (usually expressed as a standard deviation σ) Tail errors Systematic biases The significance of each of these component errors to the comparison with ADS-B is explained further Annex A. For ADS-B, horizontal position accuracy is usually defined as the radius of a circle centered on the target's reported position such that the probability of the target's actual position being inside the circle is 95%. The required accuracy is derived from comparison with radar accuracy at some nominal range of operation, in particular the range within which a certain radar separation minimum is supported. The 95% limit is assumed to be equivalent to the radar 1.96σ position error value at this range. However, the core accuracy alone is insufficient to describe the full accuracy requirement. ADS-B position reports (with acceptable quality indicators) must also ensure that the larger position errors are within the tails of the radar error distribution. See Annex A.
Vertical Position Accuracy	This is essentially the vertical position measurement error distribution. For both radar and ADS-B, encoder(s) on the aircraft provides the altitude and the encoded data is transmitted to the radar or ADS-B ground station. Therefore, vertical accuracy at ATC processing depends on altimeter accuracy (Avionics standard - reference ? - define the altimeter accuracy requirements) and transmission errors resolution

Table 5 OPA - Accuracy Parameter Definitions

B.4.3 INTEGRITY

B.4.3.1 Integrity issues concerning radar and ADS-B surveillance.

Integrity concerns the level of trust in a particular piece of information and specifically concerns the likelihood of errors beyond a certain magnitude being detected.

The integrity of the surveillance information from radar and ADS-B is to be compared at the input of the ATC processing function. At this point the resultant integrity of the surveillance information is determined from the series of:

a. The integrity of the on-board avionics sources (including external navigation sources).

b. The integrity of the data link to the sensor system.

c. The integrity of the processing in the sensor (such as radar signal processing).

d. The integrity of the data link from the sensor to the ATC processing system.

Obviously, the contributions to integrity from (a), (b) and (c) above will differ between radar and ADS-B, whilst the contribution from (d) is assumed to be the same for both.

ADS-B is expected to use have integrity monitoring from of the navigational sources, so that the reported aircraft horizontal position will be qualified by a level of integrity [i.e. the ADS-B quality indicators – individual aircraft].

In contrast, the overall integrity of radar systems is not generally quantified. It is usually expected that combinations of various internal self-tests and external monitoring methods will ensure, with very high integrity, that the radar equipment is working properly (or otherwise a fault is detected quickly). While the radar is declared to be in a fault free operation, there is no other error detection (or integrity values) in the radar plot measurements provided to the input of the ATC system. Hence, in fault free operation, radar plot position errors of any magnitude are all passed as undetected errors and the likelihood of an error being beyond a certain magnitude is entirely determined from the radar error distribution function.

Paragraph B.7 gives more information on radar errors. Furthermore, a method of comparing the surveillance risk of radar and ADS-B position errors is described in paragraph B.8

Term	Definition
Integrity risk	The integrity risk is usually expressed in terms of the probability that an error larger than a certain threshold in the information is undetected (i.e. not alerted) for longer than a time to alert threshold.
Horizontal position Integrity risk	The probability that the surveillance horizontal position error is outside a given distance (containment radius) for a given duration (time to alert) without alert. <u>For radar</u>: Integrity is not quantified in this way. However, the nominal radar accuracy error distribution (see Annex A) can be compared to undetected position error distribution from ADS-B (see Annex B). <u>For ADS-B</u>, the proposed definition can be used directly. However, integrity risk for avionics is usually expressed as a probability *per flight hour*.

Term	Definition
Vertical Position Integrity	The probability that the surveillance vertical position error at the ATC processing level is outside a given vertical distance, without alert. Therefore, integrity vertical position depends on: Altimeter integrity (Avionics standard, i.e. the specified barometric altimeter accuracy requirements). The integrity of the data link to the sensor system The integrity of the processing in the sensor (such as radar signal processing) For both radar and ADS-B, (a) is assumed to be the same. <u>For radar</u> The resultant of (b) and (c) can be described by the probability of a validated Mode C error in a SSR plot report. For ADS-B The resultant of B and C for comparison is the probability of the vertical position being transmitted or decoded incorrectly.
Operational Identification Integrity	The probability of the operational identification information being incorrect and not alerted. Therefore, integrity identification depends on Integrity of a/c setting Integrity of the data link to the sensor system. Integrity of the processing in the sensor (such as radar signal processing) For both radar and ADS-B, (a) is assumed to be the same. <u>For radar</u> The resultant of (b) and (c) can be described by the probability of a validated Mode A error in a SSR plot report. For ADS-B The resultant of (b) and (c) for comparison is the probability of the aircraft identification/mode A code and the 24 bit ICAO aircraft address being transmitted or decoded incorrectly.
SPI Integrity	This concerns an additional method of identification, usually activated by the pilot under instructions from ATC for the purposes of further confirmation of identification or to recognise an unidentified aircraft on the surveillance picture. The SPI is also required to acknowledge R/T instructions in the case of aircraft R/T transmitter failure (and not receiver failure). <u>For radar</u>: same integrity as for SSR mode A codes <u>For ADS-B</u>: same integrity as for the aircraft identification/mode A code and the 24 bit ICAO aircraft address
Emergency indicators Integrity	This concerns the ability to detect correct aircraft emergency information <u>For radar</u>: same integrity as for SSR mode A codes <u>For ADS-B</u>: same integrity as for the aircraft identification/mode A code and the 24 bit ICAO aircraft address

Term	Definition
Integrity on the Object of Interest (i.e. false target rate)	Probability of occurrence of false target reports. A false report does not represent a real aircraft. For radar: False SSR target reports are caused by various reasons (FRUIT, reflections, side-lobes etc). The maximum rate of such reports from the reference radar, expressed as a proportion of targets reports, is used for comparison. For ADS-B: In principle, false ADS-B reports could be caused by undetected corruption of ADS-B messages (albeit very unlikely). Note: as indicated in section B.2.1, false reports due to malicious interference are outside the scope of the expected ADS-B performance.

Table 6 OPA - Integrity Parameter Definitions

B.4.4 RELIABILITY

Term	Definition
Availability	The probability of a system to perform its required function at the initiation of the intended operation. It is quantified as the proportion of the time the system is actually available to the time the system is planned to be available. Periods of planned maintenance are discounted from the availability figures. Overall availability is composed of the availability of functions affecting all a/c (e.g. external positioning function, ground data acquisition function) : the availability of system affecting only one a/c (e.g. transponder function): expressed per flight hour. <u>For radar</u> The availability of ground radar and data transmission equipment will affect the service for all aircraft. The availability of an individual aircraft SSR transponder function will affect the service for that aircraft. <u>For ADS-B</u> In addition to the availability of ground receiving and data transmission systems, the availability of navigation sources (including satellite configurations) of sufficient quality in the region will affect many aircraft.
Continuity	The probability of a system to perform its required function without unscheduled interruption, assuming that the system is available when the procedure is initiated. Overall continuity is composed of the continuity of functions affecting all a/c (e.g. satellite function, ground data acquisition function): expressed in a number of disruption per year. the continuity of system affecting only one a/c (e.g. transponding function): expressed per flight hour. <u>For radar</u> The continuity of ground radar and data transmission equipment will affect the service for all aircraft. The continuity of an individual aircraft SSR transponder function will affect the service for that aircraft. <u>For ADS-B</u> In addition to the continuity of ground receiving and data transmission systems, the continuity of navigation sources (including satellite configurations) of sufficient quality in the region will affect many aircraft.

Table 7 OPA - Reliability Parameter Definitions

B.4.5 OTHER SURVEILLANCE PARAMETER DEFINITIONS

Term	Definition
Capacity	Capacity relates to the maximum numbers of aircraft in the system for which all the service surveillance performance parameters have to be provided. Capacity will depend upon the particular environment characteristics (i.e. traffic densities, area of coverage required). Total load: Maximum number of aircraft in coverage. Density: Maximum number of targets within a confined area or azimuth sector. <u>For radar</u> The capacity of an individual radar is usually designed for high density environments (i.e. much higher traffic loads than required for NRA). The numbers of aircraft in an azimuth sector are important for radar processing in high density environments <u>For ADS-B</u> The capacity figures do not necessarily imply the processing capability of a single sensor, since the required capacity may be achieved by a number of ground sensors distributed geographically. The numbers of sensors and their receiving range will depend upon the particular environment.
Coverage	The geographical volume in which all the service surveillance attributes can be provided. <u>For both radar and ADS-B</u> Coverage will depend upon the detection range and locations of ground sensors. In practice, the required coverage will be determined by local operational environment and will require confirmation by flight trials.
False information due to interference	False information due to interference (either intentional or accidental): <u>For radar</u> Interference may produce many false plots. <u>For ADS-B</u> It is possible for aircraft-like ADS-B messages to be introduced intentionally (i.e. spoofing). However, as indicated in section B.2.1, the performance of ADS-B (or radar) against interference is considered to be outside the scope of this OPA.

Term	Definition
Latency See also B.9	The age of the information when it is received at the input of the ATC processing system. Note that any subsequent delays in the processing and display of the surveillance information to the controller that may occur within the ATC system are outside the scope of this OPA. Latency requirement may be quantified in terms of the maximum age of the information contained in a report being no longer than a certain time since measurement or extrapolation (see below for ADS-B) Latency is particularly of significance to the use of position and barometric altitude information. It is also of significance for the emergency and SPI indicators. <u>For radar</u> The latency is the time between the measurement of aircraft position (including barometric altitude) when it is in the radar beam and the eventual reception of the report at the input of the ATC processing system. The latency is produced by delays in the radar processing at the radar site and in the ground communications system. The on-board latency of the barometric altitude input into the airborne transponder is assumed to be insignificant. Emergency and SPI indicators are included with the Mode A reply to the radar. It is assumed that the on-board latency between the setting of this information and its input to the transponder is insignificant. <u>For ADS-B</u> It is recognised that the airborne position may be determined from the navigation sensors (e.g. GPS) at some time prior to the ADS-B output. The value output in the ADS-B message may be adjusted (extrapolated) using the velocity vector. The age of the position information is the difference in time between the time of reception into (ground) ATC processing system and the time to which the ADS-B position has been extrapolated (by the airborne system). For barometric altitude, SPI and emergency indicators, the on-board latency is expected to be similar to the radar case. Unlike radar, aircraft identification/mode A code and the 24 bit ICAO aircraft address in ADS-B may be sampled and broadcast separately from the SPI and emergency indicators. The on-board sampling of aircraft identification/mode A code and the 24 bit ICAO aircraft address, SPI or Emergency must ensure that a change of Identity is recognised within the corresponding required update interval.
Time Stamp Accuracy See also B.9	This is the accuracy to which the time of measurement is determined (by time information in the message or by timing in the detection system)[38] <u>For radar</u> This will depend upon time stamping accuracy of the received radar returns and the method of time synchronisation with the user system. <u>For ADS-B</u> This will depend upon the on-board sampling rate and the time stamping of ADS-B messages at the reception by the ground system. Note, a time stamping inaccuracy will be seen as degradation in the along track position accuracy (depending upon the speed of the aircraft)

[38] Time stamping may not be required for some systems that simply display the ADS-B information as it is received. However, time stamping accuracy is important for more sophisticated and multi-sensor tracking systems where a means of determining the time of applicability is required.

Table 8 OPA - Other parameter Definitions

B.5 PERFORMANCE REQUIREMENTS AT THE INPUT OF THE "ATC PROCESSING SYSTEM"

This section addresses the required performances for the following groups of surveillance parameters:

- Update interval and update probability
- Accuracy
- Integrity
- Reliability
- Other surveillance parameter definitions
- Parameters relating to the transition from nominal mode of operation to non-nominal mode of operation

Performances expressed in the following tables are required to be reached for maximum Capacity figures as expressed in Table 13 OPA - Other performance Requirements.

It is assumed that the reference radar would be capable of supporting safe ATC separation services with the required separation minima up to a certain operating range. Performance figures are subdivided into **TMA** and **En-route** cases, where it is generally assumed that the most demanding case of **3NM** and **5NM** separation minima respectively could be enabled by the reference radar [39]. However ICAO does not consider in its current development Separation minima lower than 5 NM.

B.5.1 REFERENCES FOR PERFORMANCE VALUES

The radar performance values shown in the Tables below have been determined from a combination of the values specified in the Eurocontrol Surveillance Standard [Ref 7] and values for current USA radars provided to the SPR group by FAA. Many of the performance values were found to be very similar, but in cases where values were found to be significantly different, then a reasonable compromise value has been taken. [For example, the update rate of 10s for en-route is a compromise between the Eurocontrol standard maximum of 8s and the USA maximum of 12s].

Consequently, the reference radar performance values are believed to be "representative" of present SSR radar for comparison purposes. It is also recognised that some performance parameters will be subject to circumstances in local environments (e.g. capacity), but nevertheless some indicative values are given.

[39] Assuming all other performance are equally met by NAV, COM, Human factor, etc to support safe separation in the reference environment

B.5.2 UPDATE INTERVAL AND UPDATE PROBABILITY REQUIREMENTS

Update interval and update probability Requirements	Value (En-route)	Value (TMA)
Update interval		
Radar systems: Update interval (all items) = radar scan period	≤10 s	≤5 s
ADS-B systems: Update interval for: 1. Position report & quality indicators change (equivalent to a radar scan) 2. Identity (aircraft identification/mode A code & 24 bit aircraft address) report (acquisition time)* 3. Emergency/SPI report[40] * Acceptable acquisition time assumed to be the equivalent of two radar scans	≤10 s ≤20 s ≤10 s	≤5 s ≤10 s ≤5 s
Update probability		
Reference radar: Target report (with at least lateral position): Mode A code validation (per target report) Mode C code validation (per target report) Emergency/SPI code validation (same as for Mode A code validation)	> 0.97 > 0.98 > 0.96 > 0.98	> 0.97 > 0.98 > 0.96 > 0.98
ADS-B systems: Probability of update for 1. Position report (same as for radar target)[41] 2. Identity report (aircraft identification/mode A code & 24 bit aircraft address) 3. Emergency report Note: different update intervals for each type of ADS-B report are specified above.	> 0.95 > 0.95 > 0.95	> 0.95 > 0.95 > 0.95

Table 9 OPA - Update interval and update probability Requirements

[40] For aircraft capable of Emergency/SPI reporting

[41] Since ADS-B position is accompanied by barometric height, the 0.95 figure for ADS-B is equivalent to combination of radar position and Mode C height update probabilities (0.97*0.96).

B.5.3 ACCURACY REQUIREMENTS

Accuracy Requirements	Value (En-route)	Value (TMA)
Accuracy Horizontal Position		
Reference radar system: *Core accuracy:* Described by the standard deviation (σa) value of the azimuth error distribution multiplied by the range of application of the separation minimum to give the plan position error distribution (σp): The core accuracy is taken for monopulse SSR. [See Annex A] Azimuth error standard deviation (σa) Range of applicability (for separation minimum) Plan position error (σp)at range of applicability *Tail accuracy* The tail error distribution is taken from the most demanding model in Annex A. The error distance for certain error rates are specified	σa < 0.08 degrees 180 NM (5NM) σp < 465 m =10^{-3}errors> 2.37NM =10^{-5}errors> 3.19NM =10^{-7}errors> 3.84NM	σa < 0.08 degrees 60 NM (3NM) σp < 155 m =10^{-3}errors> 0.52NM =10^{-5}errors> 0.71NM =10^{-7}errors> 0.85NM
ADS-B system: Described by 95% bound in absolute plan position errors. Theses values are determined from the reference radar 1.96$\times\sigma$p errors at the range of applicability. 95% bound (= 1.96σp of radar) Additional requirements are for distribution of larger undetected errors to be within radar tail errors [see Annex A]	< 911 m <10^{-3}errors> 2.37NM <10^{-5}errors> 3.19NM <10^{-7}errors> 3.84NM	< 304 m <10^{-3}errors> 0.52NM <10^{-5}errors> 0.71NM <10^{-7}errors> 0.85NM
Accuracy Vertical Position		
Reference radar system: Altimeter accuracy Resolution in Mode C	Avionic standard[42] ≤100 ft	Avionic standard ≤100 ft
ADS-B system	Same as above	Same as above

[42] Altitude encoders are defined in FAA TSO C88a which points to SAE standard AS 8003 (Society Automotive Engineering Standard).

Table 10 OPA - Accuracy performance Requirements

B.5.4 INTEGRITY REQUIREMENTS

Integrity Requirements	Value (En-route)	Value (TMA)
Integrity Horizontal Position		
Reference radar system: Not directly specified as such, but surveillance position errors being outside certain limits are indicated from tails of nominal radar accuracy performance, see sections 4.3.1 and Annex A.		
ADS-B System: Integrity of navigational position is provided in quality indicators. See sections 4.3.1 and Annex B of how this can be compared with radar risk of surveillance position error.		
Time to alert for detection of integrity loss (Comparison is two radar scans)	<20 s	<10s
Integrity Vertical Position		
Reference radar: Altimeter source integrity Probability of incorrect Mode C validation	 Avionic standard <0.001	 Avionic standard <0.001
ADS-B system: Altimeter source integrity Probability of incorrect height information (i.e. different to altimeter source) based on radar Mode C validation comparison.	 Avionic standard <0.001	 Avionic standard <0.001
Integrity Identification		
Reference radar: Mode A source integrity Probability of incorrect Mode A validation Probability of incorrect Emergency/SPI code[43]	 Avionic standard <0.001 as for Mode A	 Avionic standard <0.001 as for Mode A
ADS-B system: Identity source integrity (includes Operational identity - including Mode A setting) Probability of incorrect aircraft identification/mode A code (i.e. different to identity source) based on radar Mode A validation comparison Probability of incorrect SPI	 At least as good as SSR Mode A <0.001	 At least as good as SSR Mode A <0.001

[43] For aircraft capable of Emergency/SPI reporting

Probability of incorrect emergency codes	< 0.001 < 0.001	< 0.001 < 0.001
Integrity Object of Interest (False Target Rate)		
Reference radar: False target to real report ratio [Figure from Eurocontrol SSR radar standard – ref7]	< 0.001	< 0.001
ADS-B system: False target to real report ratio	< 0.001	< 0.001

Table 11 OPA - Integrity performance Requirements

B.5.5 RELIABILITY REQUIREMENTS

B.5.5.1 Special Considerations

Reliability (i.e. Availability and Continuity) of ground systems will depend upon various equipment and environment factors such as the amount of equipment redundancy, local site conditions, accessibility etc. Whilst reliability of ground systems can be improved by increased expenditure on equipment and maintenance infrastructure, there are of course cost effectiveness considerations to be made by the local ATS administration. In particular, the consequences of loss of service with respect to the traffic levels in the region will be important considerations. Hence, the reliability of ground systems is really a local issue. Some figures are included for typical radars for information only.

The reliability of the on-board "ADS-B out" and the avionics equipment supplying the ADS-B information (excluding navigation sources) is expected to be similar to present SSR transponders and the sources of Mode A/C on the same type of aircraft.

Furthermore, in ADS-B, the reliability of the external navigation sources is also to be considered, in particular the GNSS satellite sources. The reliability not only concerns complete failure (however unlikely) but also the occasions where the quality of the information may fall below that required for a certain separation (e.g. when numbers of satellites and their geometry is unfavourable). These conditions may affect all or a substantial proportion of aircraft in the locality and the likelihood of occurrence has to be considered with respect to the local ATC environment. However, it is possible to predict when satellite conditions will be unfavourable and this might be used as mitigation against the loss of availability (i.e. the outages become planned).

Reliability Requirements	Value (En-route)	Value (TMA)
Availability all a/c		
Reference radar system Single radar availability (figures for information only)	≥0.997	≥0.999
ADS-B system Ground data acquisition function External airborne navigational sources.	Local issues (see 5.4.1) ≥0.997 (unscheduled)	Local issues (see 5.4.1) ≥0.999 (unscheduled)
Availability single a/c		
Reference radar system: SSR mode A/C transponding function Typical values Civil commercial aircraft General aviation[44]	≥10000 h MTBF ≥3000 h MTBF	≥10000 h MTBF ≥3000 h MTBF
ADS-B system: ADS-B out transponding function Avionics availability affecting only this a/c	Same as for radar transponder	Same as for radar transponder

[44] It is assumed that single transponder is required for GA.

Continuity all a/c		
Reference radar system Unscheduled disruptions (failures of radar) Continuity probability per hour	≤ 3 per year >0.999	≤ 3 per year >0.999
ADS-B system (including ground data acquisition function + airborne external data source function) Unscheduled disruptions (failures of ground data acquisition function + failures and degradations of airborne external navigational data sources) Planned outage Continuity probability per hour	Local issues (see 5.4.1)	Local issues (see 5.4.1)
Continuity single a/c		
Reference radar system Continuity of SSR mode A/C transponding system (typical values per flight hour) Civil Commercial General aviation	0.9999 0.9997	0.9999 0.9997
ADS-B system Continuity of ADS-B out function Continuity of avionics positional sources (affecting only this a/c)	Equivalent or better than SSR (transponding function)	Equivalent or better than SSR (transponding function)

Table 12 OPA - Reliability performance Requirements

B.5.6 OTHER PARAMETER REQUIREMENTS

Surveillance Performance Parameter (at the surveillance report level)	Value (En-route)	Value (TMA)
Latency		
Reference radar system Maximum age for position (including barometric altitude), Mode A code, emergency and SPI.	2 s	2 s
ADS-B system Maximum age for position (including barometric altitude), Operational Identification, 24 bit aircraft address, emergency and SPI. See also B.9	2 s	2 s
Time Stamp		
Reference radar system Max Time inaccuracy of position measurement (range and azimuth measurement)	0.2 s	0.2 s
ADS-B system Max Time inaccuracy in determining the time of applicability of ADS-B position information (including airborne transmission sampling and ground receiving system timing). See also B.9	0.2s	0.2 s
Capacity		
Capacity refers to the ADS-B-NRA Environment Description. Ref 2 includes typical maximum figures for ADS-B-NRA environment. These (generic) figures will be used as conditions under which the performance requirements should be met. In addition local capacity figures will have to be taken into account when implementing the system.		
Reference radar system Total load	See ref 2	See ref 2
ADS-B system	Same as above	Same as above

Table 13 OPA - Other performance Requirements

B.6 ADS-B REQUIREMENT BREAKDOWN BETWEEN TRANSMIT AIRCRAFT DOMAIN AND GROUND DOMAIN

This section deals with the apportionment of requirements between airborne and ground domains, as derived from the values expressed in the previous chapter 5.

Similarly to chapter 5, this section addresses the required performances for the various domains for the following groups of surveillance parameters:

- Update interval and update probability
- Accuracy
- Integrity
- Reliability
- Other surveillance parameter definitions
-
- Apportionments of requirements are presented in various tables for which:
- The two first column are extracts from previous chapter 5 performance figures (En-Route and TMA),
- the third column (GROUND) defines the ground requirements
- the fourth column (AIRBORNE) defines the airborne requirements

Figure 3 ADS-B-NRA architecture, “points of measure provides a functional system description that includes interfaces (“PoM” - point of measure) in order to delimit areas of responsibilities. These “PoM” have been indicated in the requirement tables.

B.6.1 ADS-B UPDATE INTERVAL AND UPDATE PROBABILITY REQUIREMENTS

For update interval and update probability, the performance is essentially link dependent (i.e. involving the rate transmission of ADS-B messages from the airborne end of the link and the reception of the messages by the ground end of the link). The airborne system will provide the required information to the link and the ground system will convey the information provided by the link to the ATC system.

For a particular link, the update interval and update probability will depend upon the probability of successfully receiving an ADS-B message and this in turn will depend upon various environment factors (e.g. locations of receiving stations, design of receiving stations, numbers of aircraft transmitting ADS-B, other co-channel interference sources, etc).

Note that the ground end of the link includes the formation of ADS-B surveillance reports from ADS-B messages and the transfer of these reports to the ground system in the appropriate format required by the ground system (a link independent format).

Update interval and update probability Requirements	**Value (En-route)**	**Value (TMA)**	**GROUND (between "C1" and "E2")**	**AIRBORNE (at "C1")**
Update interval				
"Position report"[45] (containing at least the time of applicability, the position, the barometric height, the quality indicators and the ICAO 24 bit airframe aircraft address)	≤10 s	≤5 s	**PR 1 :** The update interval for report containing at least the time of applicability, the position, the barometric height, the quality indicators and the ICAO 24 bit aircraft address (measured at point E2) shall be no longer than 10s (En-route) and 5s (TMA) Note: The update interval is to be provided by the ground in conjunction with the link.	Note: It is assumed that the airborne system provides data as required by link
"Identity report"[46] (containing at least the aircraft identification/mode A code and the 24 bit aircraft) acquisition time[47]	≤20 s	≤10 s	**PR 2 :** The update interval for report containing at least the aircraft identification/ mode A code and the & 24 bit	Note: It is assumed that the airborne system provides data as required by link

[45] See section B.4.1

[46] see section B.4.1

[47] See section B.4.1. For aircraft first coming into cover of ADS-B and subsequently for any identity change whilst in cover.

			aircraft address (measured at point E2) shall be no longer than 20s (En-route) and 10s (TMA) Note: The update interval is to be provided by the ground in conjunction with the link.	
"**Emergency/SPI report**"[48] (containing at least the emergency status indicators or SPI and the 24 bit aircraft address). [When the flight crew sets either an emergency or a SPI condition].	≤10 s	≤5 s	**PR 3 :** The update interval for report containing at least the Emergency or SPI information and the 24 bit aircraft address (measured at point E2) shall be no longer than 10s (En-route) and 5s (TMA) Note: The update interval is to be provided by the ground in conjunction with the link.	Note: It is assumed that the airborne system provides data as required by link
Update probability				
Position report (same as for radar target with Mode C)	> 0.95	> 0.95	**PR 4 :** The update probability for report containing at least the time of applicability, the position, the barometric height, the quality indicators and the ICAO 24 bit aircraft address (measured at point E2) shall be greater than 0.95 (En-route or TMA) Note: The update probability is to be	Note: It is assumed that the transmissions by the airborne system of position reports occur at the required link rate.

[48] For aircraft capable of Emergency/SPI reporting

			provided by the ground in conjunction with the link.	
• aircraft identification/ mode A code, SPI & 24 bit aircraft address) report	> 0.95	> 0.95	**PR 5 :** The update probability for report containing at least the aircraft identification/mode A code & 24 bit aircraft address (measured at point E2) shall be greater than 0.95 Note: The update probability is to be provided by the ground in conjunction with the link.	Note: It is assumed that the transmissions by the airborne system of identity reports occur at the required link rate.
Emergency report	> 0.95	> 0.95	**PR 6 :** The update probability for report containing at least the Emergency or SPI information and the 24 bit aircraft address (measured at point E2) shall be greater than 0.95 Note: The update probability is to be provided by the ground in conjunction with the link.	Note: It is assumed that the transmissions by the airborne system of emergency reports occur at the required link rate.

Table 14 OPA - Ground and Airborne ADS-B Requirements for update interval and Update probability

B.6.2 ADS-B ACCURACY REQUIREMENTS

Accuracy Requirements	Value (En-route)	Value (TMA)	GROUND ("between "C1" and "E2")	AIRBORNE (at "C1")
Accuracy Horizontal Position				
95% accuracy	< 911 m	< 304 m	**PR 7 :** The ground (including link) shall not degrade the airborne horizontal position accuracy	**PR 8 :** For TMA, the 95% accuracy of the horizontal position shall be less than 304 m **PR 9 :** For En-route, the 95% accuracy of the horizontal position shall be less than 911 m
Tail accuracy	$<10^{-3}>$ 2.37NM $<10^{-5}>$ 3.19NM $<10^{-7}>$ 3.84NM	$<10^{-3}>$ 0.52NM $<10^{-5}>$ 0.71NM $<10^{-7}>$ 0.85NM		**PR 10 :** For TMA the tail error distribution shall be better than ($<10^{-3}>$ 0.52NM, $<10^{-5}>$ 0.71NM, $<10^{-7}>$ 0.85NM) **PR 11 :** For En-route the tail error distribution shall be better than ($<10^{-3}>$ 2.37NM, $<10^{-5}>$ 3.19NM, $<10^{-7}>$ 3.84NM)
Accuracy Vertical Position				
Altimeter accuracy			N/A	**PR 12 :** Altimeter accuracy shall be no worse than for SSR case Avionic standard
Resolution in Mode C	100 ft	100ft	**PR 13 :** The ground (including link) shall not degrade altitude resolution to worse than 100ft	**PR 14 :** The resolution of the Barometric altitude shall be ≤100 ft

Table 15 OPA - Ground and Airborne ADS-B Requirements for Accuracy

B.6.3 ADS-B INTEGRITY REQUIREMENTS

Integrity Requirements	Value (En-route)	Value (TMA)	GROUND (between "C1" and "E2")	AIRBORNE (at "C1")
Integrity Horizontal Position				
Integrity of navigational position is provided in quality indicators.			**PR 15 :** The ground shall not significantly degrade the integrity of the quality indicators, i.e. a) the undetected error rates in the ground-ground transmission of ADS-B surveillance reports should be no worse than in current transmission of radar surveillance reports and b) the undetected errors in the transmission of ADS-B messages by the air-ground link shall not be more than xxx rate per message and cause corruption in ADS-B position information..[49] [50]	Note: Integrity is considered in OSA.
Time to alert for detection of integrity loss	<20 s	<10s	N/A	**PR 16 :** The time to alert regarding a change of the quality indicator shall be <10s in TMA **PR 17 :** The time to alert regarding a change of the quality indicator shall be <20s in En-route
Integrity Vertical Position				

[49] Undetected error rates in the ground-ground transmission of ADS-B surveillance reports should be no worse than in current transmission of radar surveillance reports.

[50] Undetected errors in the transmission of ADS-B messages by the air-ground link may occur at a certain rate per message and cause corruption in ADS-B position information.

Altimeter source integrity	Avionic standard	Avionic standard	N/A	**PR 18 :** in the airborne system, Altimeter source integrity shall be no worse than for SSR case Avionic standard
Probability of incorrect height information (i.e. different to altimeter source)	<0.001	<0.001	**PR 19 :** The ground vertical position integrity[51] error shall be less than 0.001 per ADS-B report containing this data item	**PR 20 :** in the airborne system, probability of incorrect height information (i.e. different to altimeter source) shall be no worse than for the current SSR case
Integrity Identification (Aircraft identification/Mode A code, 24 bit ICAO address, SPI & Emergency)				
Identity source integrity (includes setting of Operation identity, address including Mode A setting)	At least as good as SSR Mode A	At least as good as SSR Mode A	N/A	**PR 21 :** In the airborne system, Identity source integrity shall be no worse than for SSR case
Probability of incorrect aircraft identification information (i.e. different to identity source)	<0.001	<0.001	**PR 22 :** The probability that the ground domain (between C1 and E2) degrades the aircraft identification shall be less than 0.001 (per ADS-B report)	**PR 23 :** The probability that the airborne domain degrades the aircraft identification information (i.e. different to identity source) shall be no worse than in current SSR case
Probability of incorrect mode A code information (i.e. different to identity source)	<0.001	<0.001	**PR 24 :** The probability that the ground domain (between C1 and E2) degrades the mode A code shall be less than 0.001 (per ADS-B report)	**PR 25 :** The probability that the airborne domain degrades the mode A code information (i.e. different to identity source) shall be no worse than in current SSR case
Probability of incorrect the 24 bit ICAO address (i.e. different to identity	<0.001	<0.001	**PR 26 :** The probability that the ground (between C1 and E2)	**PR 27 :** The probability that the airborne domain degrades the 24 bit aircraft address

[51] Undetected error rates in the ground-ground transmission of ADS-B surveillance reports should be no worse than in current transmission of radar surveillance reports.

source)			degrades the 24 bit address (i.e. different from identity source) shall be less than < 0.001 (per ADS-B report)	information (i.e. different to identity source) shall be no worse than in current SSR case
Probability of incorrect SPI	<0.001	<0.001	**PR 28 :** The probability that the ground domain (between C1 and E2) degrades the SPI information shall be less than 0.001 (per ADS-B report)	**PR 29 :** The probability that the airborne domain degrades the SPI information (i.e. different to identity source) shall be no worse than in current SSR case of mode A
Probability of incorrect emergency codes	<0.001	<0.001	**PR 30 :** The probability that the ground domain (between C1 and E2) degrades the Emergency information shall be less than 0.001 (per ADS-B report)	**PR 31 :** The probability that the airborne domain degrades the Emergency information (i.e. different to identity source) shall be no worse than in current SSR case
Integrity Object of Interest (False Target Rate)				
False target to real report ratio	< 0.001	< 0.001	**PR 32 :** The ground shall not create any significant numbers of false reports Link errors causing false ADS surveillance reports < 0.001 per report [52]	N/A

Table 16 OPA - Ground and Airborne ADS-B Requirements for Integrity

[52] An undetected link error may produce a false ADS-B surveillance report, for example if the error occurs in the 24 bit address.

B.6.4 ADS-B RELIABILITY REQUIREMENTS

Reliability Requirements	Value (En-route)	Value (TMA)	GROUND (between "C1" and "E2")	AIRBORNE (at "C1"
Availability all a/c				
	Local issues (see B.5.5.1)		Local issues (see B.5.5.1)	Note: an availability (all aircraft) value cannot be provided in the OPA, as there is no direct comparison with radar, other than in the availability of the radar ground equipment. The value would be better derived from the OSA perspective.
Availability single a/c				
Avionics + ADS-B out transponding function availability affecting only this a/c:	Equivalent to SSR transponder function typical figures:			
- Civil Commercial	≥10000 h MTBF		N/A	**PR 33 :** for civil commercial aircraft, the airborne availability shall be ≥10000 h MTBF (as good as SSR transponder)
- General aviation	≥3000 h MTBF		N/A	**PR 34 :** for general aviation, the airborne availability shall be ≥3000 h MTBF (as good as SSR transponder)
Continuity all a/c				
Disruptions, degradations or failures of ground data acquisition function + airborne external navigation data sources.	Local issues (see B.5.5.1)		Local equipment deployment issues (see B.5.5.1)	Note: a continuity (all aircraft) value cannot be provided in the OPA, as there is no direct comparison with radar, other than in the availability of the radar ground equipment. The value would be better derived from the OSA perspective. See section B.5.5.1
Continuity single a/c				

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Continuity of ADS-B out function	Equivalent or better than SSR transponding function.	N/A	**PR 35 :** the continuity of the airborne system ABS-B out function shall be as good as for current SSR transponding function. Requirement to be discussed
Continuity of avionics positional sources (affecting only this a/c)	Equivalent or better than SSR transponding function.	N/A	**PR 36 :** the continuity of the airborne system positioning function shall be as good as for current SSR transponding function. Requirement to be discussed

Table 17 OPA - Ground and Airborne ADS-B Requirements for Reliability

B.6.5 ADS-B OTHER REQUIREMENTS

Surveillance Performance Parameter (at the surveillance report level)	Value (En-route)	Value (TMA)	GROUND (between "C1" and "E2")	AIRBORNE (at "C1"
Time of applicability				
Per report			**PR 37 :** each ADS-B report shall contain a time of applicability **PR 38 :** The time of applicability within each ADS-B report shall be valid for all data items of the report See section C.4.1 ("position report")	
Latency				
Maximum age for horizontal position	2s	2s	**PR 39 :** The maximum age for horizontal position (measured between points C1 and E2) shall be less than 2s[53]	**PR 40 :** Any airborne horizontal position latency shall be compensated for at the time of transmission, in order that the residual time stamping error is less than 0.2 seconds see definitions in Table 8. Note: Any residual latency will appear as an error in the determination of the time of applicability (time stamp accuracy)
Maximum age for horizontal quality indicators			**PR 41 :** The maximum age for quality indicators(measured between points C1 and E2) shall be less than 2s[54]	**PR 42 :** Any airborne quality indicator latency shall be compensated for at the time of transmission, in order that the residual time stamping error is less than 0.2 seconds

[53] equivalent to radar plus ground network latency
[54] equivalent to radar plus ground network latency

Maximum age for barometric altitude,	2s	2s	**PR 43 :** The maximum age for barometric altitude (measured between points C1 and E2) shall be less than 2s[55]	**PR 44 :** The maximum age for barometric altitude (measured between B1 and C1) shall be no greater than in the current SSR case
Maximum age for aircraft identification	2s	2s	**PR 45 :** The maximum age for the aircraft identification (measured between points C1 and E2) shall be 2s	**PR 46 :** The latency (measured between points B1 and C1) of aircraft identification shall be no greater than in the current implementation for SSR
Maximum age for mode A code	2s	2s	**PR 47 :** The maximum age for the mode A code (measured between points C1 and E2) shall be 2s	**PR 48 :** The latency (measured between points B1 and C1) of mode A code shall be no greater than in the current implementation for SSR
Maximum age for 24 bit aircraft address change	2s	2s	Not applicable	Not applicable
Maximum age for SPI (once set)	2s	2s	**PR 49 :** The maximum age for the SPI (measured between points C1 and E2) shall be 2s	**PR 50 :** The latency (measured between points B1 and C1) of SPI shall no be greater than in the current implementation for SSR
Maximum age for Emergency (once set)	2s	2s	**PR 51 :** The maximum age for the Emergency indicator (measured between C1 and E2) shall be less than 2s	**PR 52 :** The latency (measured between points B1 and C1) of Emergency shall be no greater than in the current implementation for SSR Emergency
Time Stamp				
Time accuracy of position information (including airborne transmission and ground receiving system timing).	≤0.2s	≤0.2 s	**PR 53 :** The ground, in conjunction with the link, shall provide the time of applicability of the information to within 0.2s.	(see above latency related requirement)
Capacity/Total load				

[55] equivalent to radar plus ground network latency

Capacity refers to the ADS-B-NRA Environment Description (Annex G1). These (generic) figures will be used as conditions under which the performance requirements should be met. In addition local capacity figures will have to be taken into account when implementing the system.	150 a/c	50 a/c	**PR 54 :** The ground shall have capacity to handle the reports from the maximum load of aircraft in the environment as described in annex G1. Link must support transmission and reception of ADS-B from the numbers of aircraft required in the environment.	N/A

Table 18 OPA - Other Ground and Airborne ADS-B Requirements

B.7 ADDITIONAL MATERIAL – RADAR ERRORS FOR COMPARISON

B.7.1 CLASSES OF RADAR ERRORS

For the purposes of SPR, radar errors are subdivided into the following three classes

- Radar Equipment Failures
- False targets
- Radar measurement errors

Radar equipment failures (hardware or software) may have many effects on the resulting radar plot outputs. Although such failures may be regarded as a loss of radar equipment integrity, in practice, such occurrences are not specified in integrity terms. Usually, various internal monitoring (e.g. self tests with injected test signals) and external monitoring (e.g. use of site monitor transponders) are required to ensure that the radar equipment is being used in a fault free condition. In the OPA, the only aspect of radar equipment failures is concerns the overall reliability. For the purposes of comparison of radar measurement errors in this OPA we assume that **errors from radar equipment failures are not present** (i.e. the radar equipment is working in a fault free state when it is providing radar reports). The effects of faulty aircraft transponder equipment are also discounted from the radar measurement errors.

False targets are due to various imperfections in the environment where the radar is located (e.g. reflecting surfaces, sidelobe responses, FRUIT replies from other interrogators). Such false targets may be regarded as a radar integrity failure in the detection of an object of interest. Years of experience of radar processing has enabled such false detections to be minimised to an acceptable level. In the OPA, the likelihood of false plots from radar is used to specify the integrity of the object of interest. For the purposes of comparison of radar measurement errors in this OPA we assume that **all false plots are removed from the radar measurement error characteristics**.

Radar measurement errors are present on the target positions reported by the radar in its normal mode of operation (i.e. no radar equipment faults). There is no indication from the radar about the magnitude of the error (i.e. all these errors are undetected by the radar). The important characteristics of radar measurement errors are described in more detail below.

B.7.2 RADAR MEASURENT ERRORS

Although radar errors are quantified in range and azimuth dimensions, in practice the azimuth errors are of most significance, firstly because azimuth is more problematic for a radar to measure than range and secondly, because azimuth errors are magnified by range in projected plan position. [Azimuth errors are sometime referred to as ‘cross range’ errors when projected in plan]. The error distribution is considered to have the following components:

1. Systematic biases
2. Core errors
3. Tail errors

Systematic biases will cause a common offset in position for all targets seen by the same radar. However, for the comparative assessment, we assume the best-case radar separation situation of two targets seen by the same radar. Hence, all radar systematic biases are discounted.

The core errors are typically due to the inherent accuracy limits in the particular radar sensor (such as receiver signal to noise, quantisation, interrogation rate, beam shape). Typically, the core errors for a particular type of radar are well known and relatively easy to measure. The radar measurement performance is usually expressed as a standard deviation (σ) from the mean. The distribution of core errors is generally Gaussian in shape within the 2σ bounds and errors are assumed to be independent from scan to scan.

Tail errors are the larger off-boresight azimuth errors. They are typically caused by various local radar site factors (such as local multi-path, diffraction, multiple target resolution, effects of other

interrogators). Furthermore, the exceptionally large tail errors are often highly correlated for the same target from scan to scan.

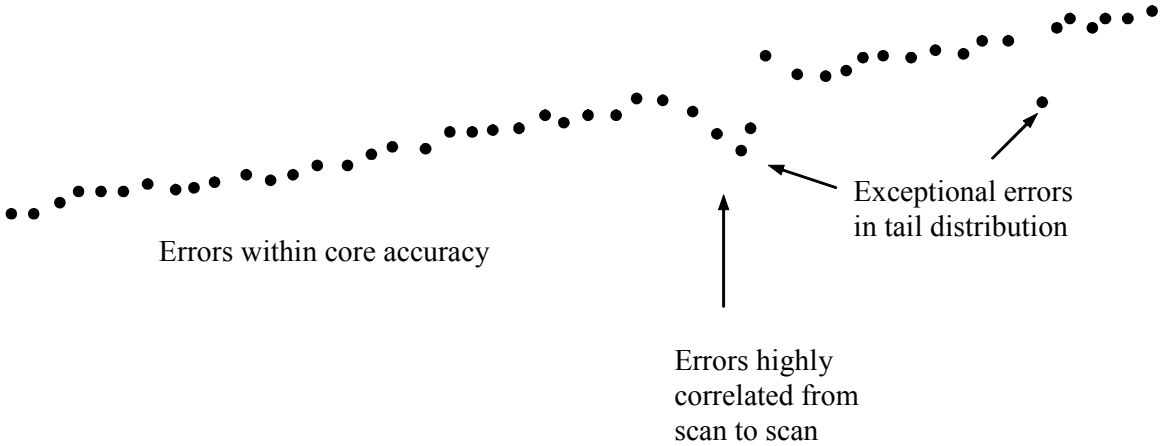

Figure 11 : OPA - Radar Measurent Errors

B.7.3 RADAR ERROR MODELS

In practice, the radar tail error distribution is much more problematic to measure than core errors because many millions of plots need to be analysed to get sufficient samples of the larger errors in the tails. Furthermore, the tail error distribution is very site dependent, particularly because of the local site multi-path effects.

However, for OPA purposes, we need to have representative models for comparison purposes and indeed more than one model has been proposed.

The simplest model of radar position errors is to assume a single Gaussian distribution. In this case, the tails of the errors decrease very rapidly (in the normal Gaussian way) and so this is the most conservative model in respect to the tail errors (i.e. most demanding for performance comparison).

However, in the normal operation of the radar, it is found in practice that the tails of radar azimuth position errors are much worse than expected from a single Gaussian. Consequently, other radar models assuming certain double error distributions have been included as defined below.

The overall probability density function of radar azimuth errors is described by a double distribution function:

Overall error probability density function $Pd(a) = (1-\alpha)\, Pc(a) + \alpha Pt(a)$

Where:

'a' is the azimuth error

Pc(a) is the probability density function distribution of the 'core' errors

Pt(a) is the probability density function distribution of the 'tail' errors

α is a weighting factor (determined empirically, see below)

Pc(a) and *Pt(a)* are assumed to be Gaussian distributions with different standard deviations (σc and σt). In practice, the values of σc, σt and the weighting factor α are determined to fit radar errors experienced for a particular radar site.

Various radar error models have been used for the purposes of comparison with ADS-B in Reference 6. The models are of concern and the characteristics of their error probability density are detailed below:

A. From the Eurocontrol Surveillance Standard specification [Reference 7]. The core monopulse azimuth accuracy is specified as ≤ 0.08° standard deviation and the tails are specified by azimuth errors > 1° assumed to be < 0.025% of plots. [This core accuracy value is also representative of the USA monopulse radar but there is no specification of the tails]
B. The USA sliding window model used for the calculations in reference 6 assumes a core azimuth accuracy of 0.23° is continued in perfectly Gaussian fashion for all azimuth errors. [Note that current USA sliding window systems have actually better core accuracy than this and a value of 0.176 is specified from the maintenance order. However the tails are not specified. Hence, the increased core accuracy was used to widen the distribution].
C. The USA sliding window model above is widened in its tails by a double Gaussian distribution [Reference 6]

Model	Core σc degrees	Tails σt degrees	Weighting factor α
A	0.08	0.5	0.005
B	0.23	-	0
C	0.23	0.3818	0.164

Table 19 OPA - Radar Model Parameters

B.7.4 SPECIFICATION OF RADAR PLAN POSITION ERRORS

The radar plan position errors that occur at the maximum range of application of a certain separation minima are used to define minimum required position measurement performance of the new surveillance system.

From the assumed radar error distribution (from whatever appropriate radar model), the expected OPA performance may be defined by a number of points on the error distribution as illustrated in the diagram below.

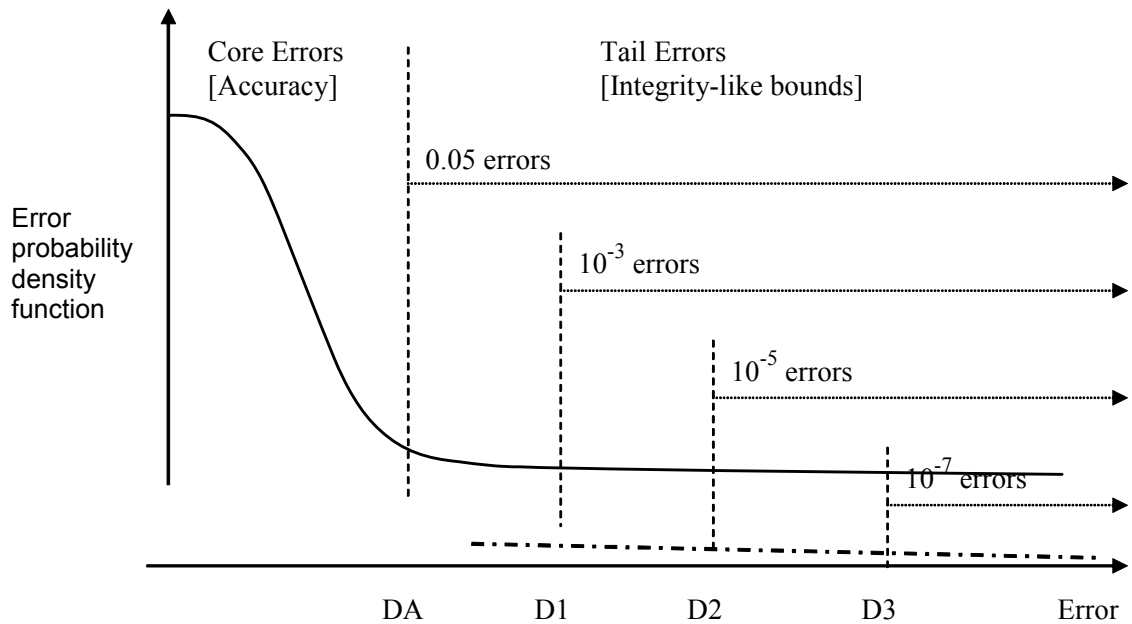

Figure 12: OPA – Position Error Distributions

Firstly, DA is the 95% accuracy boundary and it is approximately the 1.96σp of the radar error distribution, where σp = σa * maximum range of application, and σa is the radar azimuth error standard deviation.

D1 to D3 are the distances thresholds in the radar error distribution that give error rates that are analogous to error containment bounds familiar to the ADS-B community.

From an OPA performance point of view we expect the position errors from a new surveillance systems (i.e. ADS-B) to achieve:

1. The Core Accuracy is at least as good as radar (i.e. 95% of the new surveillance system position errors fall within a smaller distance threshold than achieved by radar).
2. The numbers and magnitudes of position errors in the tails are no more than experienced in the normal operation of radar.

B.7.5 RADAR ERROR DISTRIBUTIONS

From the radar probability density function of the assumed radar models, the probability that a plot error will be outside certain limits can be calculated.

Firstly, the range of application for en-route (5NM separation) and TMA (3NM separation) is chosen for the models as follows:

TMA: 60NM for model A, 40NM for models B and C

En-route: 180NM for all models.

The table Table 20 OPA - *Single plot error threshold distances for L= 10-7 to 10-3* ***per plot***below gives the distance limits Δ (D1 to D3) to give error rates corresponding to for L=10^{-3} , 10^{-5} and 10^{-7} for each radar model.

Radar	Distance Δ to give probability of **L** of plot exceeding Δ NM	
	En-route (5NM separation)	TMA (3NM separation)

model	$L=10^{-3}$	$L=10^{-5}$	$L=10^{-7}$	$L=10^{-3}$	$L=10^{-5}$	$L=10^{-7}$
A	2.01	4.85	6.70	0.67	1.61	2.23
B	2.37	3.19	3.84	0.52	0.71	0.85
C	3.29	4.80	5.98	0.73	1.06	1.33
Mean	2.56	4.28	5.50	0.64	1.13	1.47

Table 20 OPA - Single plot error threshold distances for L= 10^{-7} to 10^{-3} per plot

Note that these values are expressed as a probability per surveillance (plot) measurement and therefore have to be compared with ADS-B on a per measurement basis.

A more demanding requirement for En-route is to have the same operating margin as required by TMA. [This is suggested in Reference 6]. In this case, the range of application is scaled according to the separation minima, i.e. by 5/3. Hence the equivalent range of applicability is 100NM for model A and 67NM for models B and C. The error thresholds in this case are shown in Table 21 OPA- Error thresholds for En-route scaled in proportion to TMA operational range

Radar model	Distance Δ to give probability of **L** of plot exceeding Δ NM					
	En-route (5NM separation) scaled in proportion with TMA					
	$L=10^{-3}$	$L=10^{-5}$	$L=10^{-7}$			
A	1.12	2.68	3.72			
B	0.87	1.18	1.42			
C	1.22	1.77	2.22			
Mean	1.07	1.88	2.45			

Table 21 OPA- Error thresholds for En-route scaled in proportion to TMA operational range

B.7.6 RECONCILIATION BETWEEN RADAR MODELS

For the OPA, it is preferable to have a single performance value and not a choice of three model values (although different ATC authorities may select different models based on their own operational experiences and needs). The question then whether to use the most demanding value or to have some compromise value. However, the most demanding value has the advantage of being likely to satisfy all user needs.

For the core accuracy (95% error limit), model A is the most demanding (it uses an azimuth standard deviation of 0.08 degrees).

For tail errors radar model B is the most demanding, albeit very optimistic (it assumes a single Gaussian, whilst models A and C include an additional distribution for the tails).

B.8 ADDITIONAL MATERIAL – COMPARISON OF SURVEILLANCE RISK

[Note this may be considered to be an appropriate Annex to the OSA]

B.8.1 SURVEILLANCE RISK

For separation purposes, the collision risk from the misrepresentation of surveillance position information may be expressed as:

Risk from undetected surveillance position error = Fn (Accuracy) + Fn (fault detection limits)

Since the integrity of radar cannot be quantified, we assume the best case for comparison that it is always working in a fault-free condition, i.e. *Fn (fault detection limits)* = 0 for radar.

For ADS-B, *Fn (fault detection limits)* is not zero and it will depend upon the integrity checking capability of the navigational position for individual aircraft. In practice, it is expected that the probability of an undetected position error outside a certain magnitude (i.e. containment radius) is quantified by an integrity level indicated by the ADS-B quality indicators (for individual aircraft). Consequently, the surveillance risk from ADS-B can be determined from these quality indicators [in particular, the integrity value determines *Fn (fault detection limits)*]. Errors exceeding the containment radius might occur in two ways:

1. Rare events in the no fault condition (i.e. tail distribution errors)
2. Events associated with undetected fault condition.

A method of comparing surveillance risk of radar and ADS-B is described in Reference 6. The method applies the calculation of the close approach probability (CAP) that is already an ICAO accepted method of comparing surveillance risk to support the application of a certain separation minima, as described in Reference 5.

The remainder of this Annex summarises the significant aspects of this method, whilst fuller details can be found in the references.

B.8.2 CAP METHOD

The CAP is the probability that, when the surveillance positions of two aircraft appear to be separated by a distance S, their true separation is actually within a distance A (the size of an aircraft and typically 200ft is used). The CAP is calculated from the assumed surveillance error distribution function (i.e. from the probability density function of the errors).

In the case of radar, the position error distribution is taken for azimuth errors (cross-range errors) projected at the limit of the range of applicability of the separation minima (S). Ideally, the error distribution is determined from the analysis of real radar measurements. Note that this error distribution is for the normal operation of the radar in its particular environment with no radar equipment fault conditions (but including the tail errors caused by environmental effects). It is assumed that all the radar errors in the distribution are undetected by the radar. [These are the same radar error distribution characteristic as assumed in Appendix A].

If the position error distribution of a new surveillance system is known (from measurements and/or analytical predictions) then the surveillance risk can be calculated and compared to the reference radar system. Also, the surveillance risk between an aircraft position measured by existing radar and another measured by the new source of surveillance can be calculated.

In the case of ADS-B, a quality indicator will qualify the expected accuracy of the ADS-B reported position and some integrity checking of the position is expected in conjunction. However, there will be some probability of not detecting position errors outside certain bounds and these errors will contribute to the overall undetected ADS-B position error distribution.

The CAP comparison approach for ADS-B is applied in detail in Reference 6, where the same radar error models as described in Annex A are used as references for comparison. The key aspects of the approach are summarised below. Full details, including the mathematics, can be found in Reference 6.

B.8.3 CAP FOR RADAR REFERENCE BASELINE

In the case of radar, the position error distribution is taken for azimuth errors (cross-range errors) projected at the limit of the range of applicability of the separation minima (S). Ideally, the error distribution is determined from the analysis of real radar measurements. Note that this error distribution is for the normal operation of the radar in its particular environment with no radar equipment fault conditions (but including the tail errors caused by environmental effects). It is assumed that all the radar errors in the distribution are undetected by the radar.

The worst-case aircraft separation situation for radar is where two aircraft are both at the maximum range of applicability and are separated in azimuth (i.e. cross-range direction). The CAP calculation uses this worst-case radar position error distribution and assumes that the errors on each aircraft plot are independent.

Using the radar models (A,B,C) as defined in Annex A (and also used in Reference 6), the graphs below show the CAP values for different aircraft separations and radar ranges of application.

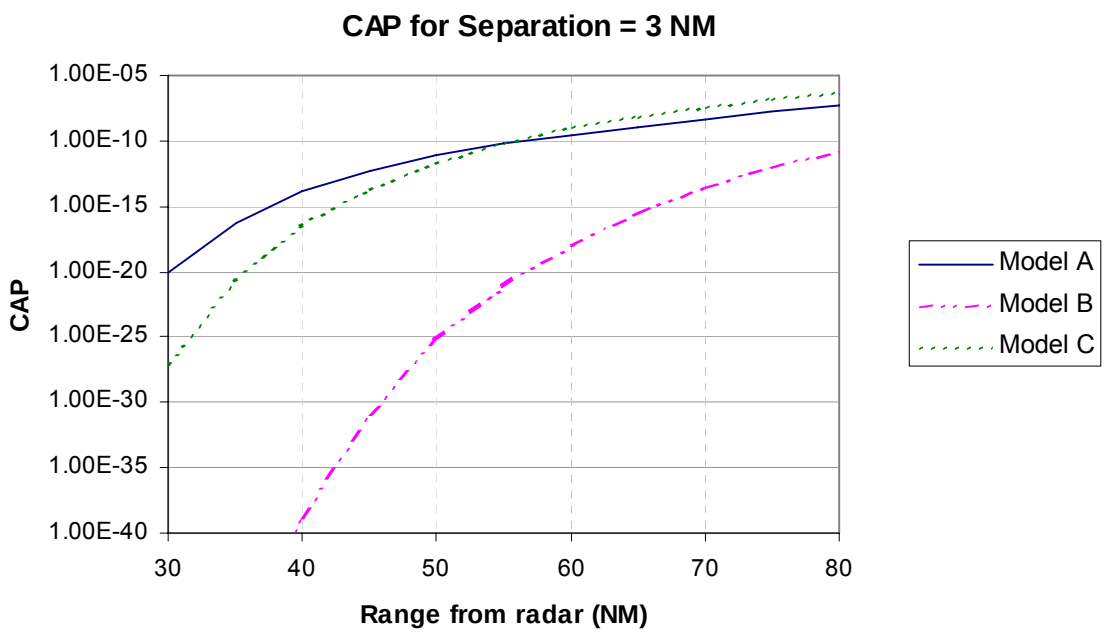

Figure B-1. CAP dependence on range with aircraft separated by 3 NM (TMA situation).

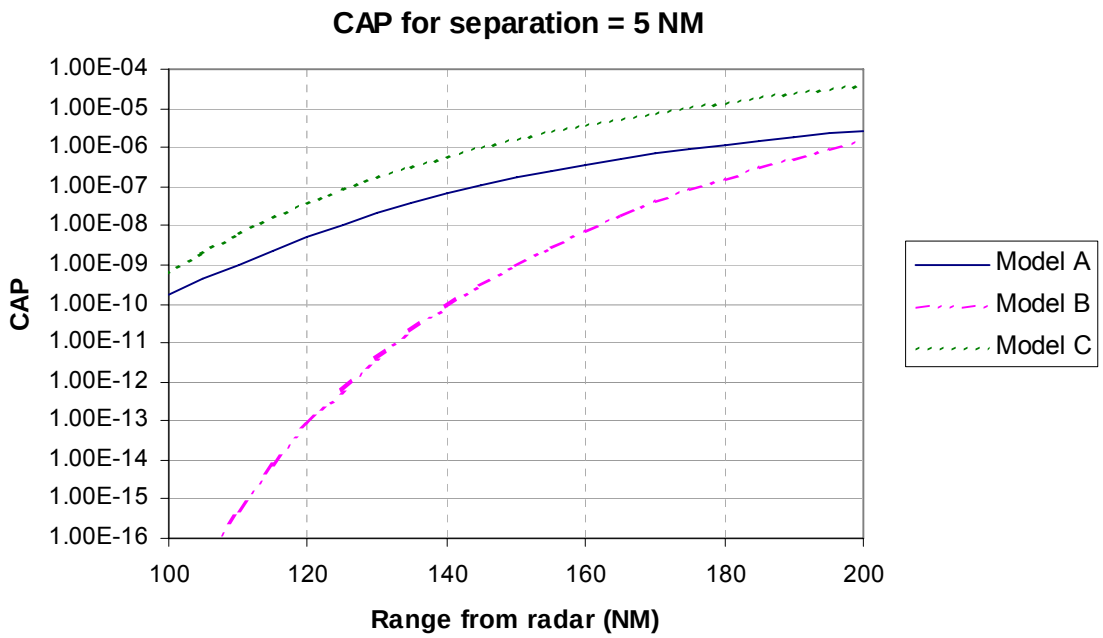

Figure B-2. CAP dependence on range with aircraft separated by 5 NM (En-route situation).

It can be seen from the graphs that the CAP value depends very much upon the radar model; in particular it is very sensitive to the tail error distribution. Notably, radar model B is a single Gaussian (most demanding model in respect of tails), whereas models A and C have additional tail distributions that are more representative of real radar errors.

In the TMA situation (Fig B-1), where 40 NM range of application is used in USA for sliding window radar (Models B and C), the CAP is very low (<1E-38) for model B and therefore not well conditioned for comparative calculation. Hence, a more appropriate way of considering the situation, as is done in Reference 6, is to calculate the CAP value for different separations at the radar maximum range of applicability, such as shown in Figure B-3.

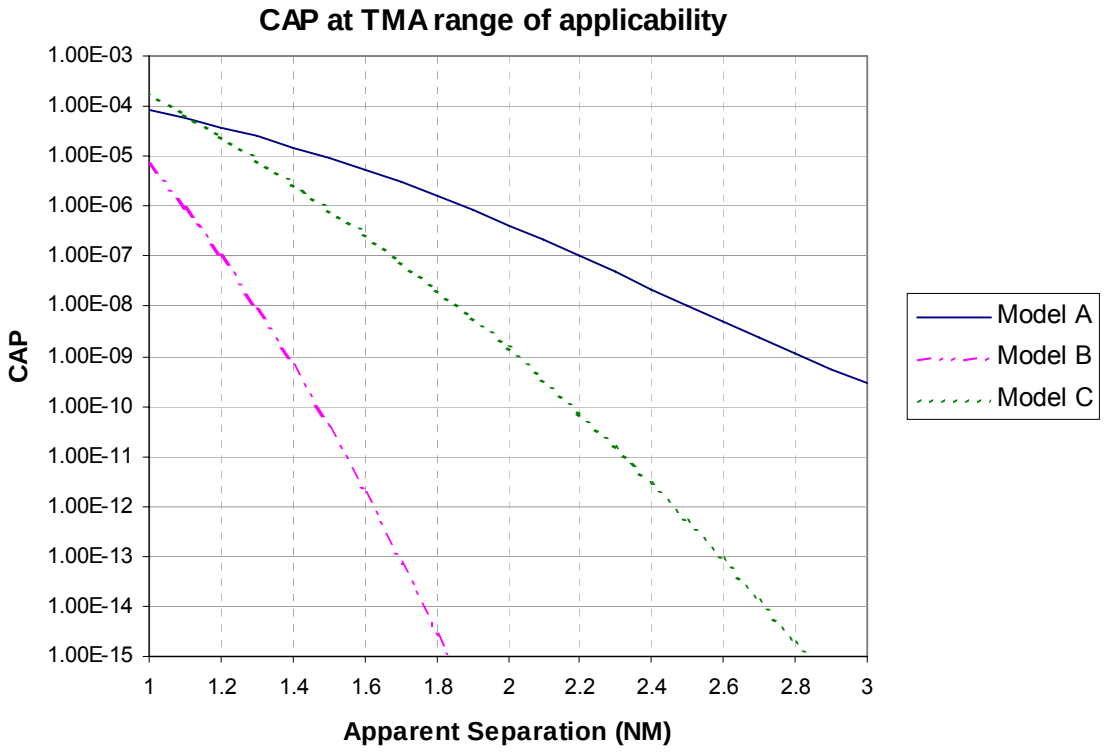

Figure B-3. CAP variation with apparent aircraft separation for different radar models at their range of applicability (= 60NM for model A and 40 NM for models B and C).

A target maximum CAP value is decided for the system. Generally the target CAP value will depend upon various other mitigating factors in the ATC system environment that combine to give the overall target level of safety (TLS) prescribed by ICAO [A TLS of 5E-9 is required for new systems, see Reference 5]. In particular, for surveillance risk associated with the use of lateral separation minima these factors will include:

- Proportion of overall risk allocated to surveillance.
- Probability of aircraft requiring lateral separation (whilst being at similar heights).
- Probability of controller not recognising the surveillance position error (worse case = 1)

Consequently, the apparent aircraft separation fulfilling the target CAP can be determined from a graph like Figure B-3.

In Reference 6, the target CAP of 3E-12 was used for the TMA situation. This CAP value is met with a separation of 1.6 NM for the most demanding radar model (model B in Figure B-3). In this case, there is an “operational margin” of 1.4 NM from the TMA separation of 3 NM.

Hence, for comparison, the requirement for the new surveillance system (i.e. ADS-B) is for it to achieve the same target CAP with at least the same or better operational margin than radar.

However, in the case of en-route radar, the same target CAP of 3E-12 required in Reference 6 is not met by any of the radar models at the maximum range of application (200NM for USA), as can be seen from Figure B-1. A higher CAP value is acceptable for en-route radar because the risk is counteracted by the other mitigating factors in the en-route environment (e.g. air routes give a low probability of aircraft being separated by 5NM). Nevertheless, a more demanding en-route requirement for ADS-B than radar is suggested in Reference 6 – the same CAP value as for TMA is demanded when the aircraft are separated with an operational margin scaled from

the TMA case (i.e. scaled by 5/3). Some other margins are also considered to take account uncertainties in multi-radar biases and different update times (if the aircraft is separated using two different radars).

B.8.4 COMPARATIVE ASSESSMENT APPROACH FOR ADS-B

Unlike radar, ADS-B position accuracy depends upon the particular aircraft navigation sources and is independent of the aircraft distance from the receiving ground station. Another significant difference from radar is that ADS-B position integrity is primarily determined by onboard monitoring of the navigation source rather than assured by ATC equipment monitoring practices. The aircraft system declares the expected accuracy and integrity level of the ADS-B position in the “quality indicators”.

The comparative process is described in detail for GPS in Reference 6, but the approach is equally suitable for any integrity monitored navigation source. The approach is summarised in Figure B-4 below. Note that in this figure the separation “So” is the baseline radar separation at which the required CAP value is reached (e.g. So = 1.6NM for the most demanding model in the TMA case).

Firstly for ADS-B, the “no fault condition” CAP value is computed for the minimum baseline separation reduced by the cross-track manoeuvre margin that could occur because of the asynchronous reception of ADS-B reports. Secondly, the “fault condition” CAP value is computed for the baseline separation reduced by the integrity risk error containment bound and the risk is this value multiplied by the probability the fault occurs and is undetected. The total CAP is the sum of these values. The hourly integrity failure rate for ADS-B is converted to a probability of integrity loss during a close approach interval by assuming the two aircraft are in close separation for an interval of half an hour.

This resulting ADS-B minimum separation CAP value must be no greater than the radar CAP computed for the particular environment (TMA or en-route).

Since the ADS-B quality indicators have a number of values to indicate different accuracy and integrity bounds, the analysis has to be repeated for different quality indicator values in order to find which combinations satisfy the required CAP at the required separation. In Reference 6, quality indicators were assumed to be as defined in RTCA Doc-260A (i.e. NIC, NAC, SIL) and certain values of these were shown to meet the required surveillance risk in comparison with the radar baseline. The same approach could be used for the quality indicator defined in the earlier RTCA Doc 260 (i.e. NUC), assuming this parameter also depends upon integrity checking of the navigational source.

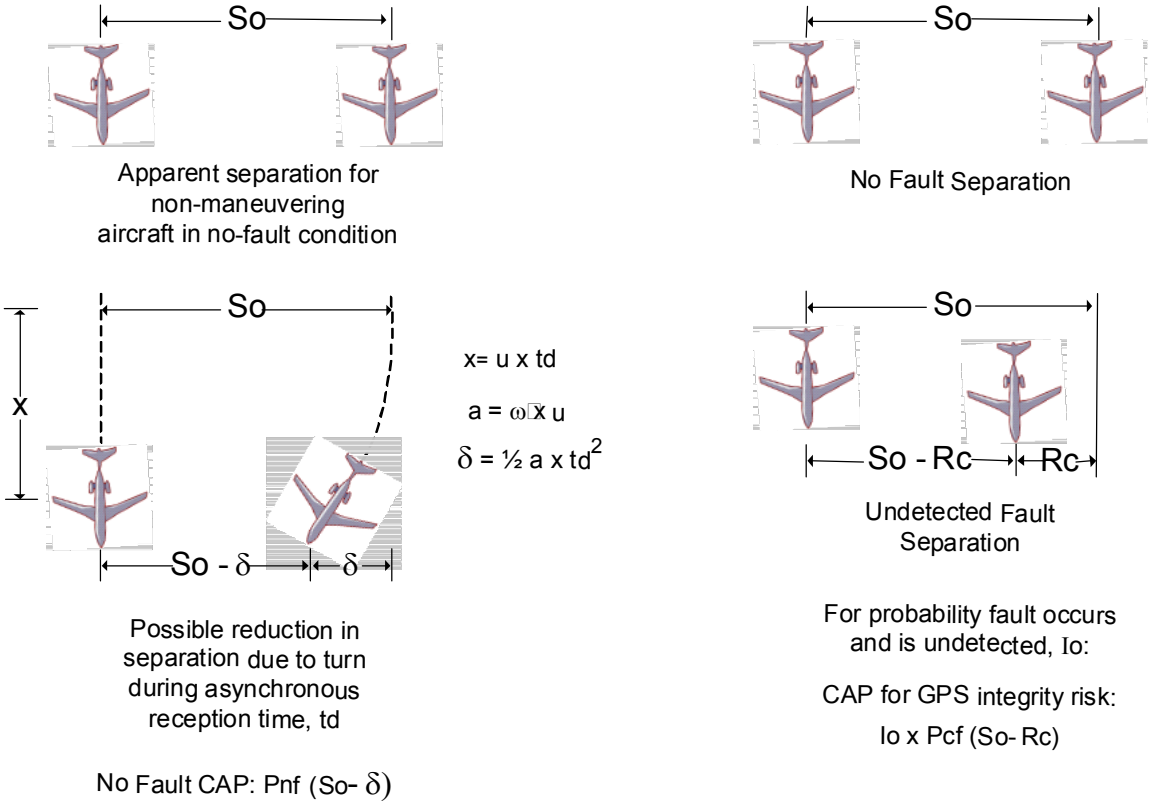

Figure B-4. CAP Evaluation Approach for ADS-B Surveillance Risk Assessment.

B.9 ADDITIONAL MATERIAL – TIME STAMPING AND LATENCY OF SURVEILLANCE DATA

B.9.1 INTRODUCTION

Fundamentally, the ground system needs to know the time of applicability (TOA) of the information – this is the time the information is valid, i.e. the time dimension of the information.

Knowledge of the time characteristics of surveillance information is very important for position that is changing rapidly with time. In this OPA, the required time characteristics are specified by two parameters: time stamping accuracy and latency (see Table 8 in Section 4).

The time stamping accuracy is the accuracy in time to which the TOA of the information can be determined.

Latency is the age of the information at the point where it is becomes available. In our case, the end point of concern is at the input of the ATC system. Hence:

- Overall latency = the time that information is available at input of ATC system – TOA.

For radar surveillance, the time characteristics of position information are entirely dependent upon the ground system, whereas for ADS-B, they also depend upon the airborne system. Consequently, in the OPA there is a further subdivision of time characteristics between ground and air.

In practice, for radar systems, there are a wide variety of methods that are used to determine time characteristics and these are summarised below. For ADS-B there are important issues concerning time stamping and latency requirements and these are clarified below for the purposes of this OPA.

B.9.2 RADAR TIME CHARACTERISTICS

For radar, the time of applicability of a position is the time of measurement by the radar – this is generally assumed to be the time when the aircraft was at the centre of the radar antenna beam.

For some older radar and display systems, the time of applicability is simply assumed to be the time of receipt of the radar data and there is no qualification of time stamping or latency requirements. However, for more modern systems, particularly those using multi-radar data processing, time stamping and latency are very important requirements.

The time stamp (i.e. time of applicability) of the radar information may be determined in various ways, for example:

- An absolute time stamp is put on each radar plot by the radar site equipment.
- Absolute time stamps are put on radar rotation markers (azimuth sector messages) at the radar site. The receiving system determines the plot time from the plot azimuth position with respect to the sector messages.
- Radar sector messages (minimally North/South marker) are sent with known (or minimal) delay from the radar site. Consequently, the receiving system can determine the radar antenna azimuth of the radar with time and therefore time stamp the radar plots according to their azimuth position.
- The radar sends "time in store" information on each plot. This is the time difference between the time of measurement and the time of output of the plot from the radar (i.e. the age of the information). Consequently, the receiving system can determine the time stamp from the time it receives the plot (assuming negligible or known transmission delay from the radar).

The latency of radar plot information is generally due to two factors:

- Inherent delay in the radar equipment processing. Most notably, many modern radars include scan to scan processing (i.e. tracking) to enhance plot detection and this may introduce a significant delay in confirming a plot.

- Queuing delay in the communication of plots from radar to ATC system. The delay will depend upon the bunching of plots in azimuth and the bandwidth of the communications link.

Generally, in most radar data processing systems used in ATC, the latency (i.e. age) of the received plot information is considered and a plot will be discarded if its latency is beyond a certain threshold age.

B.9.3 ADS-B TIME CHARACTERISTICS

Just as for radar, the ground system needs to determine the time of applicability (TOA) of the ADS-B information. There are different possible methods that this may be determined:

- TOA is assumed to be the time of transmission of the ADS-B message. The ground system measures the time of receipt (and could correct for propagation delay, albeit very small).
- Absolute time information is encoded into the ADS-B message to indicate TOA (assuming a common clock source for ground and air systems).
- Relative time (i.e. age) information is encoded into the ADS-B message to indicate the time difference of TOA from the time of transmission.
- The method that is actually applied will depend upon the particular ADS-B link implementation. However, there are some important issues to recognise concerning time stamping and latency.
- In particular, for method (a) the ground system has no knowledge of any on-board latency in the information, whereas for methods (b) and (c) the latency of the information can be realised from information in the message.
- Consequently, for method (a), any latency that is not compensated (see below) will become an additional bias error in the time stamping accuracy. A time stamping error will have the effect of increasing the apparent position error (predominantly in the along-track direction).
- For ADS-B, the time of position measurement from the navigation source is not necessarily the same as the time the information transmitted. [In Figure 3 of section 6, the point B1 is where the measurement is made and point C1 is where the information is transmitted; in between is the surveillance transmit processing (STP) and ADS-B transmit functions].
- To account for position change during the time difference between the time of measurement and time of transmission, the position can be extrapolated, using the latest velocity vector – this is referred to as “position latency compensation”. There may be some loss of position accuracy due to uncertainty in the velocity, but this is likely to be very small for short extrapolation times.
- Hence, the ADS-B system may either:
  - Extrapolate the position to take account of internal delays (position compensated latency); or
  - Adjust (or limit) the position quality indicators to cover the reduction in accuracy due to uncertainty in time.

From the OPA performance point of view we simply require the accuracy (and integrity) of the ADS-B position information to match the required time stamping accuracy.

Annex C OSA

C.1 INTRODUCTION

C.1.1 ANNEX OBJECTIVES

The objective of this annex is to provide the results of the Operational Safety Assessment (OSA) performed for the "Enhanced ATS in Non Radar Areas using ADS-B Surveillance" (ADS-B-NRA).

C.1.2 OSA PURPOSE AND SCOPE

The purpose and scope of the OSA is to allocate minimum safety objectives and requirements to the various domains (both air and ground) of the ADS-B-NRA application. Complying with those requirements and the environmental conditions identified should ensure safe ADS-B-NRA implementations.

In order to develop this OSA, two major processes were performed by the Requirements Focus Group (RFG): the **Operational Hazard Assessment** (OHA) and the **Allocation of Safety Objectives and Requirements** (ASOR), as proposed in the ED78A/DO264 guidelines [13]

These EUROCAE/RTCA guidelines, originally defined for the approval of the provision and the use of Air Traffic Services supported by data communications, are tailored to the needs of the safety work which focuses on the implementation of ADS-B. ADS-B is considered to be a key enabler for Ground Surveillance Applications (GSA) and Airborne Surveillance Applications (ASA).

C.1.3 REFERENCES

EUROCAE ED78A / RTCA DO264: Guidelines for Approval of the Provision and Use of air Traffic Services Supported by Data Communications, March 2002.

EUROCONTROL Safety Regulatory Requirement – ESARR 4: Risk Assessment and Mitigation in ATM, Edition 1.0.

SRC DOC 20: Assessment of EUROCAE ED78A as a Means of Compliance with ESARR 4

EUROCONTROL EATMP: Air Navigation System Safety Assessment Methodology (SAM). Edition 2.0

C.1.4 DEFINITION OF SAFETY TERMS

This section briefly introduces the main terms used in the proposed safety approach. The use of these terms is further described in the following sections.

Term	Abbr.	Definition
Abnormal Event	AE	Any event that can cause or contribute to a hazard. Abnormal Events are identified from the different actions constituting the application description.
Basic Cause	BC	They are the lowest level of failures considered in the ASOR analysis from which requirements are derived. In general they are defined from the functional description of the system.
Event Tree	ET	An event tree is a graphical representation of the logic model that identifies and quantifies the possible outcomes following an initiating event, i.e. the hazard. Event tree analysis provides an inductive approach to reliability assessment as they are constructed using forward logic.

Term	Abbr.	Definition
Environmental Conditions	EC	Environmental Conditions are characteristics of the operational environment in which the application will be used that pertain to the safety of the operation (e.g., separation minima, airspace configuration, traffic rates, geometry, etc.).
External Mitigation Means	EMM	Factors considered external to the application itself that help reduce the impact of an operational hazard once the hazard has occurred.
Fault Tree	FT	Fault trees graphically represent the interaction of failures and other events within a system. Basic events at the bottom of the fault tree are linked via logic symbols (known as gates) to one or more TOP events. These TOP events represent identified hazards for which a safety objective is assigned.
Hazard Classification	HC	Collective presentation of Severity Classes.
Internal Mitigation Means	IMM	Factors within the application that help to meet the Safety Objective assigned to the hazard.
Operational Effect	OE	The potential ultimate result of a hazard. The severity of the effect is reduced by external mitigations when they are available.
Operational Hazard	OH	Any condition, event, or circumstance which could lead to an operational effect (accident or an incident). Hazards are identified at the boundary of the application under assessment.
Risk Classification Scheme	RCS	Collective presentation of Safety Targets showing that the more severe the effect of the hazard the less desirable it is that the hazard occurs.
Safety Objective	SO	Statement that defines the maximum frequency or probability at which an Operational Hazard can be tolerated to occur.
Safety Requirement	SR	Safety Requirements are risk mitigation means. A safety requirement is a requirement that when implemented, will help the system meet the safety objective or reduce its effects. Safety requirements may take various forms, including organizational, operational, procedural, functional, performance, and interoperability requirements or environment characteristics.
Safety Target	ST	Statement that defines the overall (i.e. ATM) maximum frequency or probability at which an Operational Effect for a given Severity Class can be tolerated to occur.
Severity Class	SC	Qualitative classification of severity of the Operational Effects. Severity Class is used to determine the Hazard Class based on hazard's effects on operations.

Table 22: OSA - Definition of Safety terms

C.2 SAFETY ASSESSMENT APPROACH

This section includes an overview of the methodology adopted to perform the Operational Safety Assessment with the overall target of defining the application's Safety Requirements.

This overview follows the description of the process through the "bow-tie" model (refer to Figure 13). In line with this model, the following steps shall be performed in the given sequence:

- In the centre of the model stands the Operational Hazard (**OH**), both expressed for the detected and undetected case at the boundary of the application. Hazards are identified based on the application modelling and the identification of Abnormal Events.
- On the right-hand side resides the Operational Hazard Assessment (**OHA**)**,** from the boundary of the application up to the operational effects on the airspace. The OHA objective is to set the Safety Objective for the OH (for each the detected and undetected case). Accounted for external mitigation means become Safety Requirements.
- The left-hand side depicts the Allocation of Safety Objectives and Requirements (**ASOR**) process, located inside the application. The objective of this process is the identification of the basic causes leading to the operational hazard, along with the associated fault tree and the allocation of the lower level safety objective(s). Based on these, the corresponding safety requirements per domain are defined to meet the overall OH Safety Objective, also taking account the identified Internal Mitigation Means.

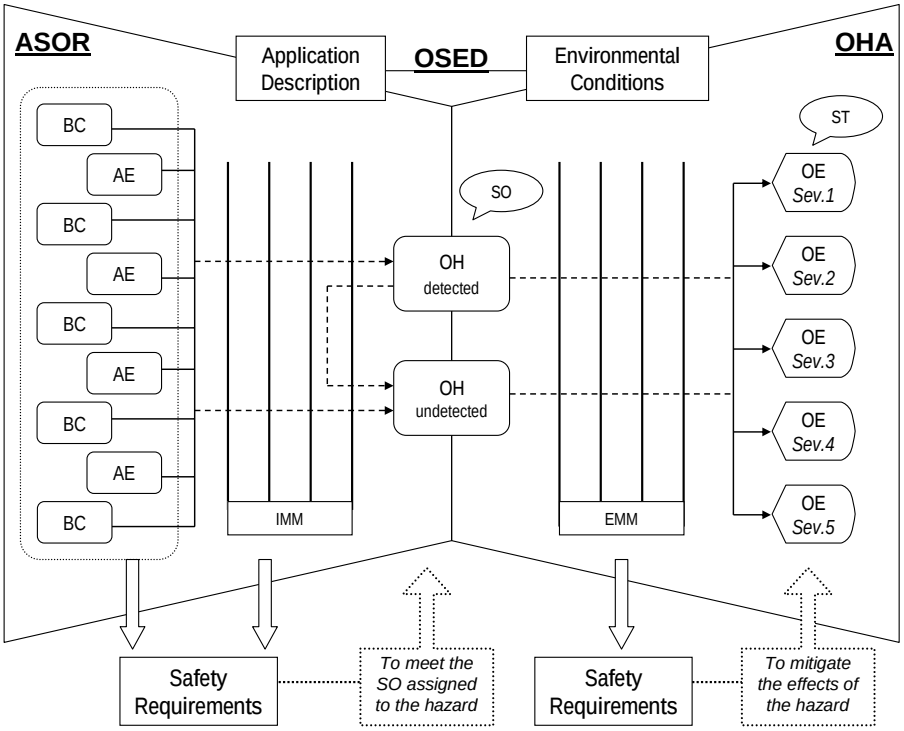

Figure 13: OSA process overview

The above sequence might be optionally reiterated, e.g. in case an initial assessment was executed with too conservative assumptions leading to too stringent safety requirements.

C.2.1 OHA PROCESS

C.2.1.1 OHA purpose

The purpose of this OHA is to qualitatively assess the Operational Hazards related to the ADS-B-NRA application and, based on this, to establish Safety Objectives and Safety Requirements related to each identified hazard. The aim is to specify the safety level to be achieved by the ADS-B-NRA application.

C.2.1.2 OHA Scope

During the OHA, the application modelling is examined, phase by phase, to identify Operational Hazards (OH) that could adversely affect the application.

An OH may result from an action that could not be performed at all or could be performed erroneously. The hazard effects are then described at sufficient level of detail in order to deduce possible effects on operations (i.e. accident, major, minor incidents) and air navigation services.

Environmental Conditions (EC), as described in the OSED, and External Mitigation Means (EMM), which could relieve the effects of an OH, are identified during the assessment of the OHs. These mitigation means are taken into account in order to determine all the possible effects of each hazard. Operational hazards are then classified according to the severity of their operational effects as per a common classification scheme.

At the end of the OHA process, based on this classification and the effectiveness of the external mitigation means, a Safety Objective is assigned for each OH.

C.2.1.3 Steps to perform the Operational Hazard Assessment

Four steps apply during the OHA process as described in Figure 14 and subsections below:

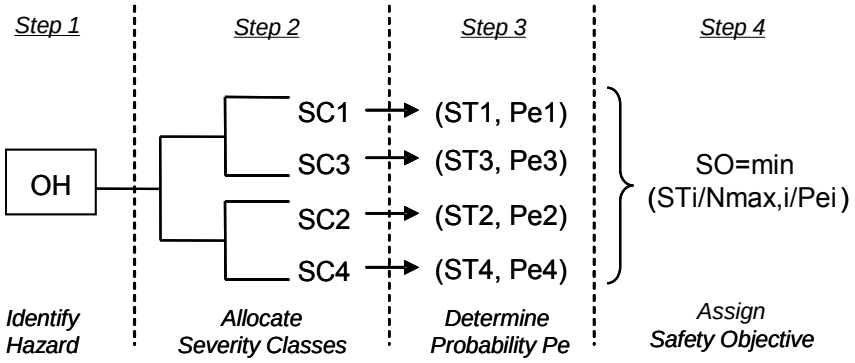

Figure 14: OSA - OHA Steps

The results obtained from applying this process are presented in sections C.4

C.2.1.3.1 Step 1: Hazards Identification

The Operational Hazards are identified based on the application modelling, which describes the application at the phase, sequence, and action level. This modelling is presented in the Annex A in diagram and tabular form.

Hazards are identified at the boundary of the application under assessment and in general, “detected” and “undetected” cases are distinguished.

Two sub-steps are followed in order to identify the operational hazards, i.e. from:

1.A. The phase modelling assessment,

1.B. An expert analysis involving operational experts.

Sub-step 1.A:

Firstly, a list of Abnormal Events (AE) is obtained by applying the following failure modes to each of the identified actions expressed in the OSED modelling:

- *Loss*: action not available or not executed
- *Incorrect*: action is performed incorrectly or is performed using incorrect information
- *Others*: actions executed in non-suitable conditions, or executed out of sequence.

From these abnormal events, a list of Operational Hazards (OH) is determined by grouping the Abnormal Events leading to a same hazard. The list of Operational Hazards needs to be validated and completed by operational personnel (see "Sub-step B").

For ADS-B-NRA, only the results from this sub-step are presented in this annex (C.4.1.1) (i.e. the list of resulting Operational Hazards and not the Abnormal Events assessment itself).

Sub-step 1.B:

In order to identify, from an operational point of view, Operational Hazards that can affect the application, an expert analysis is conducted with Air Traffic Controllers and Pilots. This takes place through brainstorming sessions based on the information contained in the OSED.

The list of hazards obtained from these sessions is used to complete and validate the one resulting from previous sub-step.

For ADS-B-NRA, the results from the OHA sessions performed for this application are presented in C.4.1.2

C.2.1.3.2 Step 2: Hazard assessment and Severity Class allocation

Before starting the safety assessment, the relevant Environment Conditions (from a safety point of view) are identified from the operational environment in which the application is expected to be used (described in the Annex A)

Once the Operational Hazards and the Environmental Conditions are identified, the assessment is performed identifying all the potential effects of each hazard. This assessment is performed based on safety expert judgment, but also using the information resulting from the operational analysis sessions mentioned before in Step 1 (Sub-step B).

During this assessment, External Mitigation Means (EMM) may be identified for certain Operational Hazards. These are mitigation means between the hazard and its final effects and therefore help in reducing the impact of a hazard once the hazard has occurred. Each time an External Mitigation Means is benefited of, a Safety Requirement shall be specified at the end of the OHA process capturing the expected performance of these mitigation means.

Taking into account the Environmental Conditions and these External Mitigation Means, the corresponding Severity Class is allocated to each effect. A severity class is associated with each identified hazard effect using the Hazard Classification matrix presented at the end of this section (Table 1).

Note: It is important to highlight the different role that the Environmental Conditions and External Mitigation Means have during the safety assessment:

- **EC** refers to the characteristics of the environment in which the application is expected to be used. They constitute the basic assumptions, as all the assessment is based on these statements and the results obtained (requirements) depends on them. Note that EC do not always reduce the effects of the hazards (e.g. traffic density).
- **EMM** refers to mitigation means (mainly procedures) that helps to "reduce" its effects. In general they are included in the OSED (from the beginning or once the OSED is updated based on OHA results). An EMM could be a procedure performed by the Controller (e.g. controller contacts the Flight Crew and procedural control is applied for this aircraft) as a result of the controller detecting a hazard (for example, the loss of an ADS-B track on the CWP).

To perform the assessment, Event Trees (ET) may be used to formalise the process and the results as shown in Figure 14 , step 2. In the Event Trees, each branch level describes a mitigation means. The trees are typically built on a binary accounting for the “success” or “failure” of the mitigation means in becoming effective.

At the end of the branches, the effects of the OH are described along with the corresponding Severity Class.

The Hazard Classification matrix used is based on the one proposed in ED78A/DO264 Ref.[1] , in which effects are classified per hazard class and per type of effect, addressing effects on operations, on occupants, on air crew and on air traffic services. In addition to the operational Effects (OE) proposed in ED78A/DO264, the RFG SPR SG has included a new row called “Examples of ASAS operational effects”.[56]

[56] Obtained from operational consequences proposed in ED78A/DO264 and ESARR4. matrices, but also those proposed following RFG SPR SG internal discussion.

The effects of the Operational Hazards to be considered are classified as presented in the following amended ED78A/DO264 Hazard Classification matrix.

Hazard Class	1 (most severe)	2	3	4	5 (least severe)
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*

Table 23 : OSA - ED78A/DO264 Hazard Classification Matrix

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C.2.1.3.3 Step 3: Determine Probability "Pe" and Apportion the ATM Risk budget

Equivalent Probability "Pe"

"Pe" expresses the probability that the hazard can generate its identified effects through quantification of the effectiveness (or not) of the identified Environmental Conditions and External Mitigation Means.

This probability is obtained, for the effect of every hazard, following one of the approaches below (or both):

Approach 3.A: quantifying each of the mitigation means identified for the specific hazard (based on simulation results, statistical feed-back, etc.). Event trees may be developed to support this process as proposed in previous Step 2 C2.1.3.2 . Pe is then calculated based on these probabilities for each effect (i.e. using Event Trees, for each of the branches of the event tree).

Approach 3.B: directly quantifying the Pe considering the mitigation means identified for the specific hazard in a global way (based on operational expertise, for example resulting from sessions proposed in Sub-step 1.B C2.1.3.1 . Event trees may also be developed to support this process as proposed in previous Step 2 C2.1.3.2 .

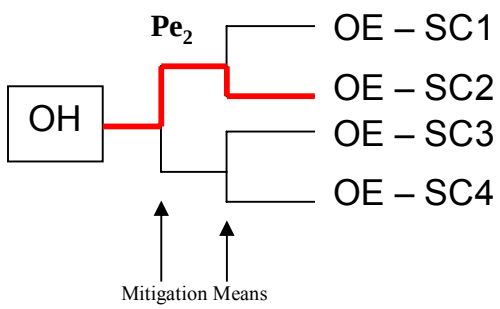

Figure 15: OSA - Probability per hazard-effect pair scheme

For ADS-B-NRA, the Pe considered for each hazard-effect pairs are presented in section C.4.3 .

Apportionment of the ATM Risk budget on the application:

The Risk Classification Scheme (RCS), based on the Hazard Classification matrix presented in the previous Step 2, aims at setting the maximum contribution of an ATM organisation to accidents and incidents.

The RCS consists of a table made of five Safety Targets[57] (one Safety Target per Severity Class) defined as follows:

- ST1: Safety Target for Severity Class 1 effects (Accidents)
- ST2: Safety Target for Severity Class 2 effects (Serious Incidents)
- ST3: Safety Target for Severity Class 3 effects (Major Incidents)
- ST4: Safety Target for Severity Class 4 effects (Significant Incidents)
- ST5: Safety Target for Severity Class 5 effects (No immediate effect on safety)

A Safety Target specifies the overall maximum frequency of occurrence of effects having a given Severity Class[58]. For example, ST1 specifies the overall maximum frequency of accidents

[57] In the framework of ESARR4.

whatever the kind of accident (e.g. mid-air collision, Controlled Flight Into Terrain (CFIT), aircraft collision on the ground, collision between an aircraft and a vehicle, etc.).

The agreed unique **Risk Classification Scheme**[59] (**RCS**) applicable to the overall ATM system, from which the Safety Objective (for each identified Operational Hazard for the specific application under assessment) is defined, is presented as follows:

Safety Targets	RCS per flight-hour	RCS per flight
ST1	**1E-08**	**1E-08**
ST2	**1E-06**	**1E-06**
ST3	**1E-04**	**1E-04**
ST4	**1E-02**	**1E-02**

Table 24: OSA - Risk Classification Scheme

Safety Targets used in the assessment could also reflect an "Ambition Factor" (effectively leading to more stringent safety targets).

However, for ADS-B-NRA, an Ambition Factor of 1 has been used, thus the Safety Targets used in the OSA for this application are the same as the ones presented in previous table.

As mentioned before, these Safety Targets are applicable to the overall ATM system. It is assumed that the ATM Service Provision can present approximately 100 hazards that can generate effects of Severity Classes between 1 and 4.

It is assumed that the risk of these **100** (one hundred) hazards is distributed as follows:

Contribution to:	N° ATM Hazards	$N_{max,i}$
Severity 1 effects	5	$N_{max,1} = 5$
Severity 2 effects	15	$N_{max,2} = 15$
Severity 3 effects	35	$N_{max,3} = 35$
Severity 4 effects	45	$N_{max,4} = 45$

Table 25 OSA – Number of ATM Hazards per Severity Class

As a Safety Target specifies the overall maximum frequency of occurrence of effects from the total number of all ATM hazards, $N_{max,i}$ shall to be determined because the available budget per severity class needs to be shared between all relevant hazards leading to that severity.

---

58 With other words: Safety Target = probability of occurrence "budget" per Severity Class

59 ESARR4 REF specifies the following ST1 = 1.55 E-8/fh or 2.31 E-8/flight assuming an average flight duration of 1.5 hour. For simplification purposes, an average duration of a flight of **1 hour** is used instead of 1.5 and values are rounded off an integer figure, i.e. ST1 = 1E-8/fh or 1E-8 / flight.
For Safety Target 2, two values are proposed:
a. ST2a: 1e-06 for airworthiness approach (JAR25-1309)
b. ST2b: 1e-05 for ATM (ED125, SAM v2, FHA chapter 3, Guidance Material Ev2.1)
For ADS-B-NRA the most conservative option has been retained (i.e. option a.: 1e-06).
For Safety Targets 3 and 4, two orders of magnitude difference between adjacent severity classes is used based on existing practices as in airworthiness (JAR25-1309)

C.2.1.3.4 Step 4: Assign Safety Objective

This last OHA step concerns the calculation of the quantitative Safety Objective per hazard, i.e. specifying the maximum acceptable frequency of occurrence of the hazard.

The following formula is applied to define the most stringent Safety Objective (SO) for each hazard in relation to the identified hazard-effect pairs:

$$SO = \min_i (ST_i / N_{max,i} / Pe_i), \text{ where:}$$

- **i:** index of each scenario of the event tree leading to a severity class i Operational Effect (as explained in section C2.1.3.2 Step 2).
- **$N_{max,i}$:** number of all ATM hazards having a given Severity Class i (as determined in section C2.1.3.3 Step 3).
- **Pe_i:** Pe per identified severity class, i.e. hazard-effect pair (as explained in section C2.1.3.3 Step 3).

At the end of the process, a Safety Objective is assigned per Operational Hazard as presented in section C.4.3 .

C.2.1.4 Units

The expression of Safety Targets per flight hour [fh] (or per flight using an average flight duration), matches the need for the aircraft integration/avionics system side (where “per fh” is used for certification purposes).

However, other system elements are more appropriately expressed through the use of other units (derived from the “per fh” safety objective quantification), e.g.:

- Air Traffic Services Unit: per ATSU hour
- Ground or satellite elements: per hour
- ADS-B message reception characteristics (e.g. per 10 seconds)

This needs to be taken into account during the quantification process. Also, special care needs to be taken that safety requirements are measurable and can be validated, as this is easily overlooked when translating (or not) between units.

Consequently, an approach needs to be developed to provide the linkage between these units. The following assumptions are proposed to allow such a conversion in the framework of ADS-B-NRA safety assessment.

These assumptions will become requirements on the operational environment, as infringing an assumption would mean that the operations are conducted out of the design envelope for which an acceptable level of safety is ensured.

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For ADS-B-NRA, the following airspace assumptions are considered:

- Average duration of a flight = one hour
- 30 aircraft managed per ATSU hour
- 100% of aircraft under ADS-B surveillance

From these assumptions, the following table provides a translation of the above Safety Target produced on a per-flight-hour basis into quantitative targets in the specific frame of the NRA application:

Safety Target	Quantitative Safety Target	
	flight hour	ATSU hour
ST1	**1E-08**	**3E-7**
ST2	**1E-06**	**3E-5**
ST3	**1E-04**	**3E-3**
ST4	**1E-02**	**3E-1**

Table 26: OSA - Units - Translation into Per ATSU hour

C.2.2 ASOR PROCESS

C.2.2.1 ASOR purpose

The purpose of the Allocation of Safety Objectives and Requirements (ASOR) process is to increase the detail of risk mitigation strategy to identify all possible causes in order to be able to apportion the corresponding lower level Safety Objectives and to identify the corresponding Safety Requirements per domain (i.e. ground, air/ground, aircraft) allowing to meet the Safety Objective of the Operational Hazard under consideration.

C.2.2.2 ASOR scope

For the hazards[60] classified Hazard Class from 1 to 3, fault trees are developed in order to apportion requirements among the functional components of the applicable CNS/ATM end-to-end system and their domains (and therefore their responsible organisations). The generic architecture, including those various components, necessary and sufficient to implement the ADS-B-NRA application is depicted in Chapter 2 or 3??? .

A fault tree is produced for each selected hazard that provides a detailed overview of the contribution of all domains for a given hazard. Fault trees are elaborated by decomposing the hazard in a combination of failures (i.e. Basic Causes) linked by different gates.

Once the fault tree is decomposed, the safety objective assigned to the hazard is apportioned among the failures identified. Internal Mitigation Means are proposed during this allocation in order to reduce the likelihood of occurrence of the Operational Hazard. IMMs are part of the application under assessment.

As a result of this quantitative allocation, basic causes (faults to mitigate) are obtained along with an allocated SO. Based on these results, a study of each basic cause is then performed in order

[60] Not all hazards are further assessed during the ASOR. SAM Ref.[4] recommends focusing on hazards of the highest hazard class. Consequently, it has been agreed to consider only operational hazards which have a hazard Class 1 to 3. In addition, hazards with a lower hazard class (4 or 5) having an impact on some other hazards (i.e. detected hazards making part of the same hazard when it is not detected) are also considered.

to derive the appropriate requirements. Safety Requirements are also obtained from the identified Internal Mitigation Means.

C.2.2.3 ASOR Steps per Operational Hazard

Three steps apply during the ASOR process as described in the figure and subsections below:

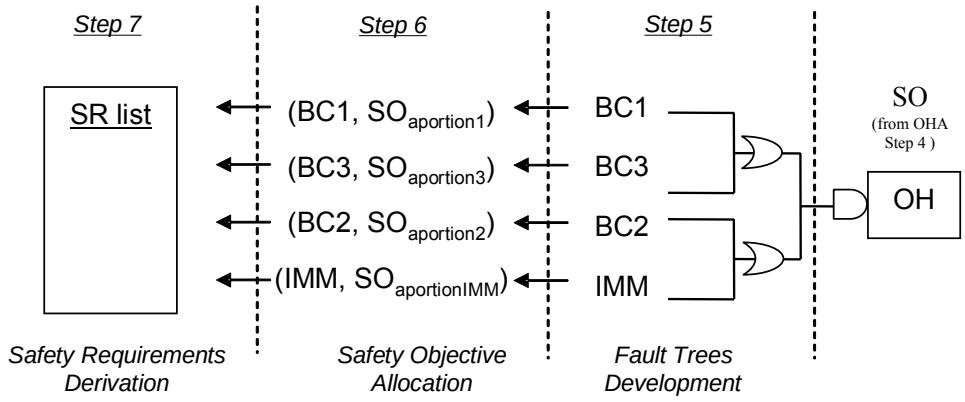

Figure 16: OSA - ASOR Steps

The results obtained from applying this process are presented in section C.5 .

C.2.2.3.1 Step 5: Fault Tree Development

A functional architecture for the application under consideration is required to be established before starting the fault tree development. Such architecture shall not include physical elements but only functions that are felt necessary to perform the application, from a ground and airborne perspective. The description of the functional architecture considered is included in Chapter 2 or 3??? .

To identify the possible causes leading to an Operational Hazard a fault tree is constructed. The fault tree provides a detailed overview of the contribution of all domains for a given hazard. Fault trees are elaborated by decomposing the hazard in a combination of failures (a top-down approach is adopted) linked by different gates: "AND" gates and "OR" gates.

In order to do this, it is necessary to take into account:

- the *Application Modelling*: the various actions[61] that are undertaken to perform the application (described in the OSED Annex A).
- the *Functional Architecture Description* (included in Chapter 2 or 3???). This description establishes the level to which the fault trees are to be decomposed.

The following picture provides a graphical view of the hazard fault tree:

[61] An action is defined as sub-operation and is the lowest breakdown level for the application chosen for the OSA process. An action is performed by one single actor (or domain); an action may be a human task or a system action. An action may be supported by a technical function.

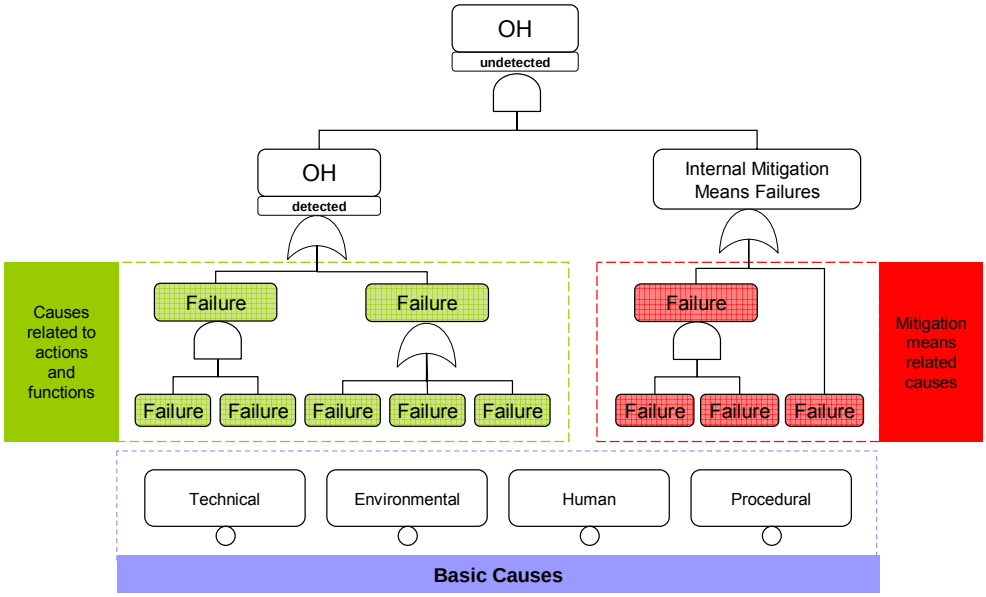

Figure 17: OSA - *Example of Fault Tree structure*

As shown in the previous figure, it is considered that undetected hazards are caused by the hazard itself AND the failure of the existing mitigation means. Nevertheless, it is important to note that in some cases it will be necessary to add a new branch to include the failures related to actions / architectural functions that directly lead to the undetected hazard (failures for which no mitigation means exist).

During the development of the fault trees, Internal Mitigation Means are also identified (based on the application description) and its possible failure integrated in the structure of the fault tree as shown in the previous figure.

Fault trees obtained from the ASOR process are included in Annex D .

C.2.2.3.2 Step 6: Safety Objective allocation

Through the specification and allocation of safety requirements, the ASOR identifies the mechanisms by which the architecture will meet its safety objectives and hence address or mitigate the risk-bearing system hazards. The purpose of the Safety Objectives allocation in the ASOR is to establish requirements which, if they are met, will eventually enable the architecture to achieve the Safety Objectives specified in the OHA.

According to that, the safety objective corresponding to the hazard assessed is apportioned to the different basic causes[62] (faults to mitigate including those related to Internal Mitigation Means) in order to derive these probability requirements.

In the fault tree, when the breakdown is represented as an OR relationship then this means that any of the lower paths could independently cause the undesired event to occur. Probabilities of the lower leaves would normally sum to achieve the upper level. An AND relationship means that all the conditions must be present at the same time in order to create the hazard. In such a case, there are generally several possibilities to allocate the probabilities of the lower leafs (probabilities multiply).

[62] Except for the environmental conditions (incl. external failures) which are considered as Assumptions. No Safety Objective is assigned to this kind of causes at the ASOR level. For example, a “GPS constellation” failure may be included in the fault tree analysis, but instead of defining a requirement on this element, an assumption clearly identifies the values used for this kind of failure.

This allocation should be carried out in 2 steps:

- A first allocation based on the safety judgement, in which existing documents may be used to allocate the likely probabilities or to check their validity.
- ASOR brainstorming sessions are organised in which operational and system experts of each domain participate to validate the results and conclusions. During this session not only the allocation of safety objectives is validated, but also the fault trees themselves, and the list of Internal Mitigation Means previously identified is also completed and validated.

During the allocation, specific means to support the decision making process of the Safety Objectives apportion on the different CNS-ATM elements may be used, as for example, a sensitive analysis to determine which causes (basic causes) probability may be modified while maintaining the required safety objective.

Sensitivity analysis allows identification of causes which probabilities variation significantly changes the resulting top event probability. Sensitivity analysis is systematically performed on all basic causes of the fault tree using certain fault tree dedicated software tools (e.g. ARALIA-SIMTREE). It consists in multiplying and dividing a basic event probability by some factors (e.g. divided by 100, then10, multiplied by 10, then 100), only one event at a time, in order to assess the potential impact of its probability variation on the resulting top event probability.

It is important to note that several different allocations of safety objectives may be possible in order to comply with the required maximum failure rate. However, the objective is to propose the most appropriate solution taking into account the existing architectures, requirements, procedures, etc. This can only be obtained by involving all the relevant stakeholders during the ASOR discussions mentioned before, and identifying the suitable shared risk mitigation strategy to be adopted (i.e. how the apportionment of the safety objectives is performed on the different elements of the application: ground and airborne).

As a result of this step, basic causes are obtained along with an assigned probability[63]. Note that in case a basic cause is involved in multiple fault trees, the final probability assigned to it is directly obtained from the most stringent one. A first list of Safety Requirements is also obtained capturing the expected performance of the identified and validated Internal Mitigation Means.

C.2.2.3.3 Step 7: Safety Requirements derivation

Based on the results obtained from the previous Step 6, a study of each basic cause (including those related to IMM) is then performed in order to derive the appropriate Safety Requirements. This assessment is done based on safety judgement and validated based on discussion involving operational and system experts of each domain.

Several types of safety requirements may be obtained depending on the nature of the basic cause considered:

- *Functional-system related basic causes*: quantitative safety requirements may be derived indicating, for example, the maximal allowable probability or frequency of occurrence for a specific failure. In the case of systems that are already in operation, feedback from field experience on these particular basic causes will help to define what is achievable, which can then be used as input in the allocation process. Some other qualitative safety requirements may be also identified concerning for example the specification of the system, or establishing specific procedures related to the used of some functions.
- *Human-procedures related basic causes*: NO quantitative safety requirements are derived from these kind of causes, but only qualitative ones. These requirements could be either a new procedure or the modification of an existing one, or the need to highlight during training the safety importance of a procedure (for example the read-back). Requirement that a specific human action to be supported by specific features of a tool may be addressed as well.

[63] See previous note.

Results are presents in C.5.3 in which each basic cause is listed with its derived Safety Requirements.

C.2.3 ROLE OF ACTORS IN OSA PROCESS

The following table summarised the roles of the various actors in the OSA process.

OSA	Steps	Safety experts	Operational experts	System experts
OHA	**Step 1.A**	Identification of Operational Hazards based on the application description (OSED).		
	Step 1.B	• Prepare OHA sessions if necessary • Capture results from OHA sessions and complete and validate the list of OHs.	**OHA sessions** to determine, from an operational point of view: • OH list • External Mitigation means • OH effects (severity class) • Pe per hazard-effect pair	
	Step 2	Assessment of the OHs' effects and assignment of a severity class per effect using results from OHA sessions.		
	Step 3.A	Determine Pe for each hazard-effect pair by quantifying the mitigation means identified (based on simulation results and feed-back from operational and system experts)	Feed back to quantify the identified mitigation means one by one.	Feed back to quantify the identified mitigation means one by one.
	Step 3.B	Determine Pe for each hazard-effect pair taking into account the identified mitigation means in a global way (based on results from OHA sessions and operational and system experts feed back)	• **OHA sessions** OR • Feed back to quantify Pe for each hazard-effect pair in a global way.	Feed back to quantify Pe for each hazard-effect pair in a global way.
	Step 4	Assign a Safety Objective per hazard based on results from step 3 and assumptions considered.		
ASOR	**Step 5**	Fault tree development using information included in OSED and feed back from operational and system experts if possible.	Feed back concerning the application description from an operational point of view.	Feed back concerning the application description from a functional point of view.

OSA	Steps	Safety experts	Operational experts	System experts
	Step 6	• Allocation of the safety objective assigned to the hazard though the fault tree to the basic causes. • Prepare ASOR sessions and capture results.	**ASOR sessions** to: • validate proposed fault trees • validate risk mitigation strategy (i.e. results from safety objective allocation) • validate and complete results from safety requirements derivation.	**ASOR sessions** to: • validate proposed fault trees • validate risk mitigation strategy (i.e. results from safety objective allocation) • validate and complete results from safety requirements derivation.
	Step 7	• Derive the appropriate Safety Requirements from the results obtained in previous step (i.e. from basic causes and the apportioned safety objective) • Prepare ASOR sessions and capture results.		

Table 27: OSA - Roles of OSA Actors

C.2.4 PROCESS AND RESULTS MAPPING

This section presents a document navigation table aiming at easily identify the results obtained during the OSA process for ADS-B-NRA for each of the steps previous described.

OSA	Steps	Results presented in Section
OHA	**Step 1.A:** OH identification from modelling	**C.4.1.1**
	Step 1.B: OH identification from experts	**C.4.1.2**
	Step 2: Hazards Assessment	**C.4.2**
	Step 3.A: Determine Pe barrier per barrier	**-**
	Step 3.B: Determine Pe in a global way	**C.4.3**
	Step 4: Assign Safety Objectives	**C.4.3**
ASOR	**Step 5:** Fault Trees development	**C.5.1 + Annex FT**
	Step 6: Safety Objectives allocation	**C.5.2**
	Step 7: Derivation of Safety Requirements	**C.5.3**

Table 28 : OSA – Navigation table

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C.3 MAJOR OSED OUTPUTS

The NRA application studied in this OSA is extensively described in the NRA OSED Annex A . The objective of this section is only to capture the most important information that has some impacts on the safety process.

C.3.1 NRA MODELLING

The NRA OSA is based on the modelling provided in the OSED Annex A .

C.3.2 IDENTIFICATION OF ENVIRONMENTAL CONDITIONS

Environmental Conditions (extracted from the Environment description included in the OSED Annex A) are used in the OHA in order to assess the operational consequences and define severity for each individual OH. This sub-section presents the relevant Environmental Conditions used during the safety assessment:

EC-1: Direct Controller Pilot Communications (VHF) **shall** be available.

EC-2: ATCo **shall** be able to apply alternate separation (could simply be a vertical standard)

EC-3: System segregation of route structure (e.g. SID/STAR separation, one way routes, hemispherical levels) **shall** exist. Although difficult to measure these can have a significant impact on the hazard if implemented into the environment concerned.

EC-4: Traffic density is medium/low

C.4 OPERATIONAL HAZARD ASSESSMENT (OHA)

As explained in section , an Operational Hazards is defined as any condition, event, or circumstance which could induce an operational effect (accident or an incident). Hazards are identified at the boundary of the ADS-B-NRA application

C.4.1 OPERATIONAL HAZARDS IDENTIFICATION

ADS-B-NRA hazards have been identified following the approach described in OHA Step 1 section C.2.1.3.1 i.e. combining results:

- From the phase modelling proposed in the OSED, and
- From an expert analysis involving Air Traffic Controllers

C.4.1.1 OH identification from modelling

Operational Hazards have been identified from the application modelling. The following table provides the list of these hazards per phases:

OH #	OH Description
Phase 3: Provision of ADS-B Based Services	
OH 3.0.3-1	Service is not provided to one a/c (although it should) *Note: a/c has not been identified*
OH 3.0.3-2	Service provided to one a/c (although it should not) (A) A/C with incorrect position information (B) A/C with incorrect quality indicator
OH 3.0.3-3	Service provided to all a/c (although it should not) (A) A/C with incorrect position information (B) A/C with incorrect quality indicator
OH 3.0.3-4	Degraded service is provided to one a/c (A) A/C without Id (B) A/C without altitude information
OH 3.0.3-5	Incorrect service is provided to one a/c (A) A/C with incorrect Id (B) A/C with incorrect altitude
OH 3.0.3-6	Untimely loss of service *Loss of track information for (A) one or (B) several aircraft previously identified in the sector*
Phase 4: Alerting	
OH 4.3.0-1	Gnd-ATCo does not take action according emergency status
OH 4.3.0-2	Gnd-ATCo takes incorrect action

Table 29: OSA - List of ADS-B-NRA Operational Hazards – From Modelling

C.4.1.2 OH identification from expert analysis

In order to identify Operational Hazards that can affect ADS-B-NRA, to assess their severity by comparison with similar operations in a radar environment and to identify relevant Environmental Conditions and potential Mitigations Means (both external and internal), an operational expert analysis was conducted with Air Traffic Controllers.

The following table only summarises the OH identified by the Air Traffic Controllers and the link with those coming from the modelling analysis.

OH#	OH description	OH from modelling
OH1	Loss of track information[64] for an aircraft under control in a sector	**3.0.3-6A**
OH2	Loss of track information for all aircraft in a sector	**3.0.3-6B**
OH3	Incorrect position information for all aircraft (or area-wide integrity failure)	**3.0.3-3**
OH4	Incorrect position information for one aircraft (or single-ship integrity failure)	**3.0.3-2**
OH5	Incorrect identification	**3.0.3-5A**
OH6	Incorrect altitude information for one aircraft (altitude information integrity failure)	**3.0.3-5B**
OH7	Loss of altitude information for a single a/c (altitude information continuity failure)	**3.0.3-4B**
OH8	Incorrect speed information transmitted by the a/c (where GSP is not calculated by ground RDPS)	**Not referred**

Table 30: OSA - List of ADS-B-NRA Operational Hazards – From Expert Analysis

Hazards OH3.0.3-1, OH4.3.0-1 and OH4.3.0-2 obtained from the modelling were found very improbable by the operational experts during the OHA sessions and therefore were no more investigated. Hazard OH8 from the OHA sessions, addressing speed, was also no more considered as speed was only proposed as optional information to be provided to the Air Traffic Controller. The full report from these OHA sessions is provided in Annex xx .

C.4.2 ASSESSMENT OF OPERATIONAL HAZARDS

The following table provides the final list of Operational Hazards identified during the OHA, the operational consequences along with the appropriate severity and the Environmental Conditions taken into account during the assessment.

OHA ref.	OH identification	EC	Worst Credible Operational Effect	Severity

[64] *Track information = ID + lat/long + altitude + speed*

OHA ref.	OH identification	EC	Worst Credible Operational Effect	Severity
OH 3.0.3-2	Incorrect position information for one aircraft (or single-ship integrity failure)	EC -1 EC-2 EMM-1	Detected: Workload increase	4
		EC-4	Undetected: Loss of separation as controller bases separation on displayed data	2
OH 3.0.3-3	Incorrect position information for all aircraft (or area-wide integrity failure)	EC-1 EC-2 EMM-1	Detected: Significant workload increase leading to possible loss of separation	3
		EC-3 EC-4	Undetected: Multiple Loss of separation	2
OH 3.0.3-4A	Loss of a/c identification		Detected: No impact	5
			Undetected: No impact	5
OH 3.0.3-4B	Loss of altitude information for a single a/c (altitude information continuity failure)	EC -1 EMM-1	Detected: Workload increase to establish current altitude, and increased monitoring to account for loss of system supported level monitoring	4
		EC-4	Undetected: Not applicable	
OH 3.0.3-5A	Incorrect identification for one aicraft	EC -1 EMM-1	Detected Workload increase	4
		EC-3 EC-4	Undetected: Loss of separation as controller bases separation on displayed data	3
OH 3.0.3-5B	Incorrect altitude information for one aircraft (altitude information integrity failure)	EC -1 EMM-1	Detected Workload increase	4
		EC-4	Undetected: Loss of separation as controller bases separation on displayed data	3
OH 3.0.3-6A	Loss of track information[65] for an aircraft under control in a sector	EC -1 EC-2 EMM-1	Detected: Workload increase	4
		EC-3 EC-4	Undetected Loss of separation as controller bases separation decisions on an incorrect traffic picture	2

[65] *Track information = ID + lat/long + altitude + speed*

OHA ref.	OH identification	EC	Worst Credible Operational Effect	Severity
OH 3.0.3-6B	Loss of track information[1] for all aircraft in a sector	EC -1 EC-2 EMM-1	Detected: Significant workload increase leading to possible loss of separation (for a short time)	3
			Undetected Not applicable	

Table 31: OSA - ADS-B-NRA Operational Hazard Assessment

For the reasons exposed in section REF, fault trees were developed during the ASOR for all those hazards except for OH3.0.3-4A.

C.4.2.1 External Mitigation means used in the assessment

The following table presents the mitigation means used in the current assessment along with the reference of corresponding safety requirements and the various OH they have an impact on.

External Mitigation Means	SR	OH
EMM-1 Fall-back procedures from Radar environment applies to ADS-B-NRA when necessary.	**SR-1**	OH3.0.3-2, OH3.0.3-3, OH3.0.3-4B, OH3.0.3-5A, OH3.0.3-5B, OH3.0.3-6A, OH3.0.3-6B

Table 32: OSA - ADS-B-NRA External Mitigation Means List

Note: Examples of procedures to be applied in ADS-B-NRA application based on PANS-ATM procedures for Radar environment:

Ex. Procedure 1: *Whenever it is observed on the situation display that the aircraft identification transmitted by an ADS-B equipped aircraft is different from that expected from the aircraft, the pilot shall be requested to confirm aircraft identification.*

When, after a pilot has been instructed to operate the aircraft's ADS-B transmitter on an assigned aircraft identification or to effect a call sign change, it is observed that the aircraft identification shown on the situation display is different from that assigned to the aircraft, the pilot shall be requested to re-enter the assigned aircraft identification.

Whenever it is observed that the aircraft identification of an aircraft as shown on the display is different from that assigned to the aircraft, and the application of the procedure described above has not resolved this discrepancy or is not warranted by circumstances (e.g. unlawful interference), the pilot shall be requested to confirm that the correct aircraft identification has been selected.

If the discrepancy continues to exist, following confirmation by the pilot that the correct aircraft identification has been set on the ADS-B identification feature, the following actions shall be taken by the controller:

a) informs the pilot of the persistent discrepancy;

b) when possible, correct the label showing the aircraft identification on the situation display; and

c) notify the erroneous aircraft identification transmitted by the aircraft to the next control position and any other interested unit using ADS-B for identification purposes.

Ex. Procedure 2: Verification of pressure altitude-derived level information displayed to the controller shall be effected at least once by each suitable equipped ATC unit on initial contact with the aircraft concerned or, if not feasible, as soon as possible thereafter. The verification shall be effected by simultaneous comparison with altimeter-derived level information received from the same aircraft by radiotelephony. The pilot of the aircraft whose pressure-altitude-derived level information is within the approved tolerance value

need not be advised of such verification. Geometric height information shall not be used to determine if altitude differences exist.

If the displayed level information is not within the approved tolerance value or when a discrepancy in excess of the approved tolerance value is detected subsequent to verification, the pilot shall be advised accordingly and requested to check the pressure setting and confirm the aircraft's level.

If following confirmation of the correct pressure setting the discrepancy continues to exist, the following action should be taken according to circumstances:

a) request the pilot to stop ADS-B altitude data transmission, provided this does not cause the loss of position and TBC - Operational +SPI + Emergency ?identity information and notify the next control positions or ATC unit concerned with the aircraft of the action taken; or
b) inform the pilot of the discrepancy and request that the relevant operation continue in order to prevent loss of position and identify information of the aircraft and, when authorized by the appropriate ATS authority, override the label-displayed level information with the reported level. Notify the next control position or ATC unit concerned with the aircraft of the action taken.

C.4.3 SAFETY OBJECTIVES ASSIGNMENT

As explained in OHA Step 4 section C.2.1.3.4 , a safety objective is assigned to each hazard based on its identified effects. For NRA the same Safety Objective has been assigned to all hazards having the same Hazard Class.

The Safety Objectives, calculated from the Safety Targets, are the following ones:

ATM Safety Targets		
ST	**fh**	**ATSU h**
ST1	1.00E-08	3.00E-07
ST2	1.00E-06	3.00E-05
ST3	1.00E-04	3.00E-03
ST4	1.00E-02	3.00E-01

ATM	NRA
$N_{max,i}$	**N° OH**
5	0
15	3
35	4
45	5

Safety Objectives per OH		
HC	**Pe**	**ATSU h**
1	-	-
2	1	2.E-06
3	0.1	9.E-04
4	0.1	7.E-02

OSA - Legend: Safety Objectives for NRA hazards

NOTE: a Pe of 1 has been considered for all the hazards with Hazard Class 2. This constitutes the most conservative approach for the most demanding hazards, i.e. it has been supposed that once one if these hazard occurs, the effects for which the OH has been classified is generated. For hazards with hazards Classes 3 and 4, a Pe of 0.1 has been considered as acceptable, i.e. one upon 10 the effects for which the OH has been classified are generated.

The Safety Objectives obtained are then:

SO ref.	Safety Objective	OHA ref.
SO-1	The likelihood that an aircraft is displayed with an incorrect position being detected shall be no greater than 7E-02 per ATSUh.	OH 3.0.3-2
SO-2	The likelihood that ATC services are provided to one aircraft based on corrupted position information shall be no greater than 2E-06 per ATSUh.	OH 3.0.3-2

SO ref.	Safety Objective	OHA ref.
SO-3	The likelihood all aircraft are displayed with an incorrect position being detected shall be no greater than 9E-04 per ATSUh.	OH 3.0.3-3
SO-4	The likelihood that ATC services are provided to all aircraft based on corrupted position information shall be no greater than 2E-06 per ATSUh.	OH 3.0.3-3
SO-5	The likelihood of losing altitude information for a single aircraft on the display shall be no greater than 7E-02 per ATSUh.	OH 3.0.3-4B
SO-6	The likelihood that an aircraft is displayed with an incorrect identification being detected shall be no greater than 7E-02 per ATSUh.	OH 3.0.3-5A
SO-7	The likelihood that ATC services are provided to one aircraft based on corrupted identification information shall be no greater than 9E-04 per ATSUh.	OH 3.0.3-5A
SO-8	The likelihood that one aircraft is displayed with an incorrect altitude being detected shall be no greater than 7E-02 per ATSUh.	OH 3.0.3-5B
SO-9	The likelihood that ATC services are provided to one aircraft based on corrupted altitude information shall be no greater than 9E-04 per ATSUh.	OH 3.0.3-5B
SO-10	The likelihood that track information[66] for an aircraft under control in a sector is loss being detected shall be no greater than 7E-02 per ATSUh.	OH 3.0.3-6A
SO-11	The likelihood of losing track information for an aircraft under control in a sector shall be no greater than 2E-06 per ATSUh.	OH 3.0.3-6A
SO-12	The likelihood that tracks information for all aircraft in a sector are loss being detected shall be no greater than 9E-04 per ATSUh.	OH 3.0.3-6B

Table 33: OSA - ADS-B-NRA Safety Objectives identified

C.4.4 LINK TO CLOSE APPROACH PROBABILITY CALCULATION

C.4.4.1 Introduction

One of the obvious differences between ADS-B and radar is that aircraft trajectory can be, with ADS-B, directly derived from the position, velocity vector, etc. provided by the avionics source. From the OPA, the accuracy, latency… requirements on those parameters were defined by comparison with the radar techniques. With the OSA, it was also possible to identify the requirements on position and quality indicator. However, none of these processes directly provide the minimum containment radius, applicable to the position transmitted by ADS-B, and required to support 5Nm separation minima safely. An additional analysis was therefore necessary and is summarized in the following section.

C.4.4.2 Summary of Close probability calculation

One of the operational hazards (OH303-2) potentially leads to loss of separation (class 2 hazard) [and could also lead to a collision (class 1)]. Loss of separation (or collision) can occur because it is assumed that the controller bases separation upon the surveillance position data.

[66] *Track information = ID + lat/long + altitude + speed*

All surveillance positions will have some error of some magnitude. For radar a certain measurement accuracy performance in normal operation, including some larger errors in the tails has been considered. For ADS-B, the errors will be a consequence of normal accuracy and also undetected fault conditions (i.e. loss of integrity effects).

The Close Approach Probability (CAP) is an ICAO accepted method of assessing surveillance risk. The CAP is the probability that, when the surveillance positions of two aircraft appear to be separated by a distance S, their true separation is actually within a distance A. The CAP is calculated from the assumed surveillance error distribution function.

The same CAP method can be applied to ADS-B position. In particular, the effects of certain undetected fault conditions are assessed (depending upon assumed position source integrity thresholds).

In the OSA, (fault tree analysis), the hazard of separation loss has a desired target level of safety (i.e. probability of occurring), [presently 10E-8?[67]]. How the hazard of "incorrect position for an aircraft" leads to the serious operation consequence of separation loss (or collision) depends upon the mitigation means that are present in between. For this, the CAP considerations are very relevant.

Minimum ADS-B surveillance requirements for 5 NM separation is:

SR 1 : The likelihood that the integrity of the maximum 2.0 NM containment radius is exceeded without detection shall be less than 1E-5 per flight hour.

These requirements provide an ADS-B to ADS-B separation operational margin of 2.1 NM for the Gaussian SSR error model, and 0.8 NM for the wide angle model. The CAP in this case is better than 3×10^{-12}, a considerable improvement relative to the current level. This same quality of ADS-B surveillance supports ADS-B to SSR separation at least as good as or better than that available today for SSR to SSR separation. Maximum coverage is determined by 95% confidence that the update interval is no greater than 12 seconds.

The full demonstration is provided in annex J

67 *"?" to be clarified*

C.5 ALLOCATION OF SAFETY OBJECTIVES AND REQUIREMENTS (ASOR)

C.5.1 IDENTIFICATION OF BASIC CAUSES

Functional architecture required to perform this NRA application is presented in Chapter 2 or 3 ??? . It has been used as the basis to allocated requirements on air and ground domains.

The following table identifies the various Basic Causes that have been identified during the development of the fault trees (based on this proposed functional system) along with the Operational Hazard they can generate.

Annex D presents these Basic Causes in the corresponding Fault trees.

Function	BC#	BC	OH
AC-ADSTransm	AC-AT-E02	Incorrect ADS-B transmission during operation (erroneous ID)	OH303-5A
AC-ADSTransm	AC-AT-E04	Incorrect ADS-B transmission during operation (erroneous position)	OH303-2
AC-ADSTransm	AC-AT-E06	Incorrect ADS-B transmission during operation (QI- lower than real level)	OH303-6A
AC-ADSTransm	AC-AT-E08	Incorrect ADS-B transmission during operation (QI higher than real level)	OH303-2
AC-ADSTransm	AC-AT-E09	Incorrect ADS-B transmission (erroneous altitude)	OH303-5B
AC-ADSTransm	AC-AT-I01	Incomplete ADS-B transmission during operation (no altitude)	OH303-4B
AC-ADSTransm	AC-AT-L02	Loss of ADS-B transmit function during operation	OH303-6A
AC-DataSourc	AC-DS-E01	Undetected common mode GPS integrity failure affecting all AC in the sector (QI lower than real one)	OH303-6B
AC-DataSourc	AC-DS-E02	Undetected common mode GPS integrity failure affecting all AC in the sector (QI higher than real one)	OH303-3
AC-DataSourc	AC-DS-E03	Incorrect data provided by Data Source function (QI lower than real one)	OH303-6A
AC-DataSourc	AC-DS-L01	Common mode GPS failure affecting all AC in the sector (no position)	OH303-6B
AC-DataSourc	AC-DS-L02	No data provided by Data Source function	OH303-6A

Function	BC#	BC	OH
ATCo	ATCo-D01	ATCo does not detect that one a/c is displayed with an incorrect altitude	OH303-5B
ATCo	ATCo-D03	ATCo does not detect ADS-B track loss for one aircraft	OH303-6A
FC	FC-F02	FC incorrectly enters ID into the A/C system	OH303-5A
GS-ADSRecept	GD-AR-E01	Gnd reception corrupts all ADS-B messages (erroneous position)	OH303-3
GS-ADSRecept	GD-AR-E02	Gnd reception corrupts all ADS-B messages (QI lower than real level)	OH303-6B
GS-ADSRecept	GD-AR-E03	Gnd reception corrupts all ADS-B messages (QI higher than real level)	OH303-3
GS-ADSRecept	GD-AR-L01	No ground reception of ADS-B messages during operation	OH303-6B
GS-Proc&Disp	GD-PD-E02	Gnd-Pro corrupts an ADS-B track during operations (erroneous ID)	OH303-5A
GS-Proc&Disp	GD-PD-E04	Gnd-Pro corrupts an ADS-B track during operations (erroneous position)	OH303-2
GS-Proc&Disp	GD-PD-E05	Gnd-Pro corrupts all ADS-B tracks (erroneous position)	OH303-3
GS-Proc&Disp	GD-PD-E07	Gnd-Pro corrupts an ADS-B track during operations (QI lower than real level)	OH303-6A
GS-Proc&Disp	GD-PD-E08	Gnd-Pro corrupts all the ADS-B tracks (QI lower than real one)	OH303-6B
GS-Proc&Disp	GD-PD-E10	Gnd-Pro corrupts an ADS-B track during operations (QI higher than real level)	OH303-2
GS-Proc&Disp	GD-PD-E11	Gnd-Pro corrupts all the ADS-B tracks (QI higher than real one)	OH303-3
GS-Proc&Disp	GD-PD-E12	Gnd-Pro corrupts an ADS-B track during operations (erroneous altitude)	OH303-5B
GS-Proc&Disp	GD-PD-I01	Gnd-Pro partially process an ADS-B track during operations (no altitude)	OH303-4B
GS-Proc&Disp	GD-PD-L02	No ground processing of one ADS-B track	OH303-6A
GS-Proc&Disp	GD-PD-L03	No ground processing of all ADS-B track	OH303-6B

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Function	BC#	BC	OH
G-Monitor	IM01-F01	Ground monitoring fails to detect loss of traffic information leading to system generated alert provided to controller	OH303-6A
G-Monitor	IM02-F01	Ground monitoring fails to detect hazard leading to system generated alert provided to controller when it relates to satellite error resulting in multiple position error	OH303-3
ATCo	IM03-F01	ATCo monitoring does not detect error in the positioning source resulting in unexpected changes to multiple AC tracks on the CWP	OH303-3
G-Monitor	IM04-F01	Ground monitoring fails to detect large single jumps in one AC position that is outside the probable position	OH303-2
ATCo	IM05-F01	ATCo monitoring does not detect a/c deviation from track	OH303-2
ATCo	IM08-F02	ATCo incorrectly correlates ADS-B information with FP (thus, he does not detect that one a/c is displayed with an incorrect ID)	OH303-5A
G-Monitor	IM09-F01	Site monitoring fails to detect hazard related to corruption of ADS-B messages received by Ground ADS-B Station	OH303-3

Table 34: OSA - ADS-B-NRA Basic Causes - From Functional Architecture

NOTE: Any of the basic causes listed in this table is used in more than one OH Fault tree. No common failures exist then between the identified AD-B NRA hazards. [68]

[68] Nevertheless, note that detected hazards failures are part of the same hazard when it is undetected (plus failure of the mitigation means).

C.5.2 SAFETY OBJECTIVES ALLOCATION

C.5.2.1 Compliance to Safety Objective

This table presents, per OH, the safety objective expected to be reached as determined in section C.4.3 and the results from the fault tree analysis (based on Fault trees presented in Annex D).

SO#	OH#	Safety Objective [ATSUh]	Top event results [ATSUh]
SO-1	OH303-2 detected	7E-02	8,00E-04
SO-2	OH303-2 undetected	2E-06	1,60E-06
SO-3	OH303-3 detected	9E-04	6,00E-04
SO-4	OH303-3 undetected	2E-06	1,20E-08
SO-5	OH303-4B detected	7E-02	3,00E-02
SO-6	OH303-5A detected	7E-02	5,92E-02
SO-7	OH303-5A undetected	9E-04	5,92E-04
SO-8	OH303-5B detected	7E-02	3,00E-02
SO-9	OH303-5B undetected	9E-04	3,00E-04
SO-10	OH303-6A detected	7E-02	2,42E-03
SO-11	OH303-6A undetected	2E-06	2,42E-08
SO-12	OH303-6B detected	9E-04	8,00E-04

Table 35: OSA - Safety Objective Compliance Matrix

C.5.2.2 Internal Mitigation Means

The following table presents the Safety Requirements related to the Internal Mitigation Means identified for NRA along with the hazards on which they have an impact. They have been obtained from the OHA sessions with Air Traffic Controllers and used during the development of the fault trees.

Internal Mitigation Means	SR#	OH
IMM1. Ground monitoring detects loss of track information leading to system generated alert provided to controller (controller monitoring assumed not to detect this scenario)	SR-2	OH303-6A
IMM2. Ground monitoring detects hazard leading to system generated alert provided to controller if it relates to satellite error resulting in multiple position error	SR-3	OH303-3

Internal Mitigation Means		SR#	OH
IMM3.	ATCo monitoring will detect the hazard if it relates to a frozen screen (current radar system mitigation)	SR-4	OH303-3
IMM4.	Ground monitoring detects large single jumps in one AC position that is outside the probable position	SR-5	OH303-2
IMM5.	ATCo monitoring will detect aircraft deviation from track (current radar system mitigation)	SR-6	OH303-2
IMM6.	ATCo monitoring will detect the loss of all tracks on the CWP (current radar system mitigation)	SR-7	OH303-6B
IMM7.	Gnd-Pro checks of QI for display and separation purpose	SR-8	OH303-2 OH303-3 OH303-6A OH303-6B
IMM8.	ATCo correlates ADS-B information with FP	SR-9	OH303-5A
IMM9.	Site monitoring detects hazard related to corruption of ADS-B messages received by Ground ADS-B Station	SR-10	OH303-3

Table 36: OSA - ADS-B-NRA Internal Mitigation Means List

C.5.3 SAFETY REQUIREMENTS DERIVED FROM BASIC CAUSES

This table lists of the Safety Objectives that have been derived from the allocation in the fault trees provided in Annex Annex D. Potential other safety requirements are also proposed.

BC#	Basic Cause	Value	SR#	Safety Requirements	Potential requirements for further mitigation
AC-AT-E02	Incorrect ADS-B transmission during operation (erroneous ID)	1,00E-03 fh	SR-11	The likelihood that an A/C-Av transmits an incorrect ID shall be less than 1E-3 per FH	
AC-AT-E04	Incorrect ADS-B transmission during operation (erroneous position)	1,00E-05 fh	SR-12	The probability of an undetected integrity failure affecting position for a single a/c shall be less than 1E-5 per FH	
AC-AT-E06	Incorrect ADS-B transmission during operation (QI- lower than real level)	3,00E-05 fh	SR-13	The likelihood that aircraft transmits incorrect quality indicator (QI lower that real level) shall be no greater than 3e-05 per FH	
AC-AT-E08	Incorrect ADS-B transmission during operation (QI higher than real level)	1,00E-05 fh	SR-14	The likelihood that aircraft transmits incorrect quality indicator (QI higher that real level) shall be less than 1e-05 per FH	
AC-AT-E09	Incorrect ADS-B transmission (erroneous altitude)	1,00E-03 fh	SR-15	The likelihood that an A/C-Av transmits an incorrect altitude shall be less than 1.E-3 per FH	
AC-AT-I01	Incomplete ADS-B transmission during operation (no altitude)	1,00E-03 fh	SR-16	The probability that an A/C-Av that is transmitting ADS-B messages with altitude does not continue to transmit messages containing altitude shall be less than 1E-3 per FH.	
AC-AT-L02	Loss of ADS-B transmit function during operation	3,00E-05 fh	SR-17	The likelihood that aircraft fails to transmit ADS-B messages shall be no greater that 3e-05 per FH	

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BC#	Basic Cause	Value	SR#	Safety Requirements	Potential requirements for further mitigation
			SR-18		FC shall notify ATCo of ADS-B transmitter failure once detected.
AC-DS-E01	Undetected common mode GPS integrity failure affecting all AC in the sector (QI lower than real one)	2,00E-04 h		Assumption	
AC-DS-E02	Undetected common mode GPS integrity failure affecting all AC in the sector (QI higher than real one)	2,00E-04 h		Assumption	
AC-DS-E03	Incorrect data provided by Data Source function (QI lower than real one)	1,00E-05 fh	SR-19	The probability of an incorrect QI being transmitted for a given aircraft shall be less than 1E-5 FH (QI lower than real one)	
AC-DS-L01	Common mode GPS failure affecting all AC in the sector (no position)	2,00E-04 h		Assumption	
AC-DS-L02	No data provided by Data Source function	1,00E-05 fh	SR-20	The likelihood that no position is provided by the avionics data source shall be less than 1e-05 per FH	

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BC#	Basic Cause	Value	SR#	Safety Requirements	Potential requirements for further mitigation
ATCo-D01	ATCo does not detect that one a/c is displayed with an incorrect altitude	1,00E-02 pATC	SR-21		Verification of pressure altitude-derived level information displayed to the controller shall be effected at least once by each suitable equipped ATC unit on initial contact with the aircraft concerned or, if not feasible, as soon as possible thereafter. The verification shall be effected by simultaneous comparison with altimeter-derived level information received from the same aircraft by radiotelephony. The pilot of the aircraft whose pressure-altitude-derived level information is within the approved tolerance value need not be advised of such verification. Geometric height information shall not be used to determine if altitude differences exist.
ATCo-D03	ATCo does not detect ADS-B track loss for one aircraft	1,00E-02 pATC	SR-22	The number of AC controlled in the sector by the same controller has to be determined taking into account that controller has to be able to detect the ADS-B track loss for one aircraft.	
ATCo-H01	ATCo does not perform sector transfer coordination	1,00E-02		Assumption	
FC-F01	FC does not contact ATCo when entering the new airspace	1,00E-03		Assumption	
FC-F02	FC incorrectly enters ID into the A/C system	1,00E-03 pAC	SR-23		Whenever it is observed on the situation display that the aircraft identification transmitted by an ADS-B equipped aircraft is different from that expected from the aircraft, the pilot shall requested to confirm aircraft identification

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BC#	Basic Cause	Value	SR#	Safety Requirements	Potential requirements for further mitigation
GD-AR-E01	Gnd reception corrupts all ADS-B messages (erroneous position)	1,00E-04 pH	SR-24	The likelihood that ground system corrupts ADS-B position for all messages received shall be no greater than 1e-04 per hour.	
GD-AR-E02	Gnd reception corrupts all ADS-B messages (QI lower than real level)	1,00E-04 pH	SR-25	The likelihood that Ground ADS-B Receive subsystem corrupts ADS-B messages for all the a/c (incorrect QI - lower than real level) shall be less than 1E-4 per H	
GD-AR-E03	Gnd reception corrupts all ADS-B messages (QI higher than real level)	1,00E-04 pH	SR-26	The likelihood that Ground ADS-B Receive subsystem corrupts QI (higher than real one) for all the aircraft in its region shall be less than 1E-4 per H.	
GD-AR-L01	No ground reception of ADS-B messages during operation	1,00E-04 pH	SR-27	The continuity risk of the ground ADS-B receivers shall be less than 1E-4 pH.	
GD-PD-E02	Gnd-Pro corrupts an ADS-B track during operations (erroneous ID)	1,00E-04 pH	SR-28	The likelihood that ground system corrupts ID for all aircraft received via ADS-B shall be no greater than 1e-04 per hour	
GD-PD-E04	Gnd-Pro corrupts an ADS-B track during operations (erroneous position)	1,00E-04 pH	SR-29	The likelihood that ground system corrupts the position of an aircraft received via ADS-B shall be no greater than 1e-04 per hour.	
GD-PD-E05	Gnd-Pro corrupts all ADS-B tracks (erroneous position)	1,00E-04 pH	SR-30	The likelihood that ground system corrupts position for all aircraft received via ADS-B shall be no greater than 1e-04 per hour.	
GD-PD-E07	Gnd-Pro corrupts an ADS-B track during operations (QI lower than real level)	1,00E-05 pH	SR-31	The likelihood that ground system corrupts quality indicator for an ADS-B track (QI lower than real level) shall be no greater than 1e-05 per hour.	
			SR-32		QI has to correctly be determined by ground system for each track based on ADS-B messages received from aircraft.
GD-PD-E08	Gnd-Pro corrupts all the ADS-B tracks (QI lower than real one)	1,00E-04 pH	SR-33	The likelihood that ground system corrupts quality indicator for all ADS-B track (QI lower than real level) shall be no greater than 1e-04	

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BC#	Basic Cause	Value	SR#	Safety Requirements	Potential requirements for further mitigation
				per hour.	
GD-PD-E10	Gnd-Pro corrupts an ADS-B track during operations (QI higher than real level)	1,00E-04 pH	SR-34	The likelihood that ground system corrupts quality indicator for all ADS-B track (QI higher than real level) shall be no greater than 1e-04 per hour.	
GD-PD-E11	Gnd-Pro corrupts all the ADS-B tracks (QI higher than real one)	1,00E-04 pH	SR-35	The likelihood that ground system corrupts quality indicator for all ADS-B track (QI higher than real level) shall be no greater than 1e-04 per hour.	
GD-PD-E12	Gnd-Pro corrupts an ADS-B track during operations (erroneous altitude)	1,00E-05 pH	SR-36	The likelihood that ground system corrupts altitude for an ADS-B track shall be no greater than 1e-05 per hour.	
GD-PD-I01	Gnd-Pro partially process an ADS-B track during operations (no altitude)	1,00E-04 pH	SR-37	The likelihood that ground system does not provide altitude for an ADS-B Track shall be no greater than 1e-04 per hour.	
GD-PD-L02	No ground processing of one ADS-B track	1,00E-04 pH	SR-38	The likelihood that ground system does not process and provide data for an ADS-B Track shall be no greater than 1e-04 per hour.	
			SR-39		ADS-B coverage shall be assured/known in the controlled airspace.
GD-PD-L03	No ground processing of all ADS-B track	1,00E-04 pH	SR-40	The likelihood that ground system does not process and provide information for all ADS-B tracks shall be no greater than 1e-04 per hour	
IM01-F01	Ground monitoring fails to detect loss of traffic information leading to system generated alert provided to controller	1,00E-03 pATC	SR-41	The probability that ground monitoring fails to inform controller of the loss of traffic information for one aircraft shall be no greater than 1e-03.	

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BC#	Basic Cause	Value	SR#	Safety Requirements	Potential requirements for further mitigation
IM02-F01	Ground monitoring fails to detect hazard leading to system generated alert provided to controller when it relates to satellite error resulting in multiple position error	1,00E-03 pATC	SR-42	The probability that ground monitoring fails to inform controller of a satellite error resulting in multiple position error shall be no greater than 1e-03.	
IM03-F01	ATCo monitoring does not detect error in the positioning source resulting in unexpected changes to multiple AC tracks on the CWP	1,00E-02 pATC	SR-43		The number of AC controlled in the sector by the same controller has to be determined taking into account that controller has to be able to detect error in the positioning source resulting in unexpected changes to multiple aircraft tracks on the CWP.
IM04-F01	Ground monitoring fails to detect large single jumps in one AC position that is outside the probable position	1,00E-03 pATC	SR-44	The probability that ground monitoring fails to detect large single jumps in one aircraft position that is outside the probable position shall be no greater than 1e-03.	
IM05-F01	ATCo monitoring does not detect a/c deviation from track	1,00E-03 pATC	SR-45		The number of AC controlled in the sector by the same controller has to be determined taking into account that controller has to be able to detect aircraft deviation from track displayed on the CWP.
IM08-F02	ATCo incorrectly correlates ADS-B information with FP (thus, he does not detect that one a/c is displayed with an incorrect ID)	1,00E-02 pATC	SR-46	The ATCo shall be able to identify and correlate ADS-B a/c to Flight Plan information.	
IM09-F01	Site monitoring fails to detect hazard related to corruption of ADS-B messages received by Ground ADS-B Station	1,00E-03	SR-47	The probability that ground monitoring fails to inform controller about the position corruption of ADS-B messages received on the ground station shall be no greater than 1e-03	

Table 37: OSA - ADS-B-NRA Safety Requirements

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C.5.4 OSA RESULTS

C.5.4.1 Main Assumptions

The main assumptions taken into account during the OSA process are:

Concerning the environment conditions:

EC-1: Direct Controller Pilot Communications (VHF)

EC-2: ATCo applies alternate separation (could simply be a vertical standard)

EC-3: System segregation of route structure (e.g. SID/STAR separation, one way routes, hemispherical levels). Although difficult to measure these can have a significant impact on the hazard if implemented into the environment concerned.

EC-4: Traffic density is medium/low

Concerning some external events having an impact on ADS-B-NRA application:

ASSUMP 5 : An undetected common mode GPS integrity failure affecting all AC in the sector (QI lower than real one) is supposed to be no greater than 2E-04 per hour.

ASSUMP 6 : An undetected common mode GPS integrity failure affecting all AC in the sector (QI higher than real one) is supposed to be no greater than 2E-04 per hour.

ASSUMP 7 : A common mode GPS failure affecting all AC in the sector (no position) 2E-04 per hour.

ASSUMP 8 : It is assumed that ATCo rarely fails to perform sector transfer coordination (probability used in the fault trees 1E-02).

ASSUMP 9 : It is assumed that FC very rarely fails to contact ATCo when entering the new airspace (probability used in the fault trees 1E-03).

C.5.4.2 Safety Objectives

The following table presents the Safety Objectives determined during the OSA process along with the main environmental assumptions considered during the assessment (EC), the identified safety requirements helping to achieve the corresponding safety objective, and the reference to the corresponding operational hazards (OH).

SO ref.	Safety Objective	EC	SR	OH ref.
SO-1	The likelihood that an aircraft is displayed with an incorrect position being detected shall be no greater than 7E-02 per ATSUh.	EC-1 EC-2	SR-1, SR-5, SR-6, SR-12, SR-14, SR-29, SR-34	OH 3.0.3-2
SO-2	The likelihood that ATC services are provided to one aircraft based on corrupted position information shall be no greater than 2E-06 per ATSUh.	EC-4	SR-12, SR-14, SR-29, SR-34, SR-44, SR-45	OH 3.0.3-2
SO-3	The likelihood all aircraft are displayed with an incorrect position being detected shall be no greater than 9E-04 per ATSUh.	EC-1 EC-2	SR-1, SR-3, SR-4, SR-10, SR-24, SR-26, SR-30, SR-35	OH 3.0.3-3
SO-4	The likelihood that ATC services are provided to all aircraft based on corrupted position information shall be no greater than 2E-06 per ATSUh.	EC-3 EC-4	SR-24, SR-26, SR-30, SR-35, SR-42, SR-43, SR-47	OH 3.0.3-3

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SO ref.	Safety Objective	EC	SR	OH ref.
SO-5	The likelihood of losing altitude information for a single aircraft on the display shall be no greater than 7E-02 per ATSUh.	EC-1	SR-1, SR-16, SR-37	OH 3.0.3-4B
SO-6	The likelihood that an aircraft is displayed with an incorrect identification being detected shall be no greater than 7E-02 per ATSUh.	EC-1	SR-1, SR-9, SR-11, SR-23, SR-28	OH 3.0.3-5A
SO-7	The likelihood that ATC services are provided to one aircraft based on corrupted identification information shall be no greater than 9E-04 per ATSUh.	EC-3 EC-4	SR-11, SR-23, SR-28, SR-46	OH 3.0.3-5A
SO-8	The likelihood that one aircraft is displayed with an incorrect altitude being detected shall be no greater than 7E-02 per ATSUh.	EC-1	SR-1, SR-15, SR-36	OH 3.0.3-5B
SO-9	The likelihood that ATC services are provided to one aircraft based on corrupted altitude information shall be no greater than 9E-04 per ATSUh.	EC-4	SR-15, SR-21, SR-36	OH 3.0.3-5B
SO-10	The likelihood that track information[69] for an aircraft under control in a sector is loss being detected shall be no greater than 7E-02 per ATSUh.	EC-1 EC-2	SR-1, SR-2, SR-13, SR-17, SR-18, SR-20, SR-31, SR-32, SR-38, SR-39	OH 3.0.3-6A
SO-11	The likelihood of losing track information for an aircraft under control in a sector shall be no greater than 2E-06 per ATSUh.	EC-3 EC-4	SR-13, SR-17, SR-18, SR-20, SR-22, SR-31, SR-32, SR-38, SR-39, SR-41	OH 3.0.3-6A
SO-12	The likelihood that tracks information for all aircraft in a sector are loss being detected shall be no greater than 9E-04 per ATSUh.	EC-1 EC-2	SR-1, SR-2, SR-7, SR-19, SR-25, SR-27, SR-33, SR-40	OH 3.0.3-6B

Table: OSA results: Safety Objectives

C.5.4.3 Safety Requirements

The following table lists ALL the safety requirements identified during the OSA process, along with the element from which each requirement is obtained and the safety objective for which the requirement is used.

[69] *Track information = ID + lat/long + altitude + speed*

Safety Requirements	Obtained from	Related to
SR 2 : Fallback procedures from Radar environment shall be applied to ADS-B-NRA when necessary.	EMM-1	SO-1, SO-3, SO-5, SO-6, SO-8, SO-10, SO-12
SR 3 : Ground monitoring detects loss of track information leading to system generated alert provided to controller (controller monitoring assumed not to detect this scenario)	IMM-1	SO-10, SO-12
SR 4 : Ground monitoring detects hazard leading to system generated alert provided to controller if it relates to satellite error resulting in multiple position error	IMM-2	SO-3
SR 5 : ATCo monitoring will detect the hazard if it relates to a frozen screen (current radar system mitigation)	IMM-3	SO-3
SR 6 : Ground monitoring detects large single jumps in one AC position that is outside the probable position	IMM-4	SO-1
SR 7 : ATCo monitoring will detect aircraft deviation from track (current radar system mitigation)	IMM-5	SO-1
SR 8 : ATCo monitoring will detect the loss of all tracks on the CWP (current radar system mitigation)	IMM-6	SO-12
SR 9 : Gnd-Pro checks of QI for display and separation purpose	IMM-7	SO-
SR 10 : ATCo correlates ADS-B information with FP	IMM-8	SO-6
SR 11 : Site monitoring detects hazard related to corruption of ADS-B messages received by Ground ADS-B Station	IMM-9	SO-3
SR 12 : The likelihood that an A/C-Av transmits an incorrect aircraft identification (or mode A) shall be less than 1E-3 per fh.	AC-AT-E02	SO-6, SO-7
SR 13 : The probability of an undetected integrity failure affecting position shall be less than 1E-5 per fh.	AC-AT-E04	SO-1, SO-2
SR 14 : The likelihood that aircraft transmits incorrect quality indicator (QI lower that real level) shall be no greater than 3E-05 per fh.	AC-AT-E06	SO-10, SO-11
SR 15 : The likelihood that aircraft transmits incorrect quality indicator (QI higher that real level) shall be less than 1E-05 per fh.	AC-AT-E08	SO-1, SO-2
SR 16 : The likelihood that an A/C-Av transmits an incorrect altitude shall be less than 1E-03 per fh.	AC-AT-E09	SO-8, SO-9

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Safety Requirements	Obtained from	Related to
SR 17 : The probability that an A/C-Av does not continue to transmit messages containing altitude shall be less than 1E-3 per fh.	AC-AT-I01	SO-5
SR 18 : The likelihood that aircraft fails to transmit ADS-B messages shall be less than 3E-05 per fh.	AC-AT-L02	SO-10, SO-11
SR 19 : FC shall notify ATCo of ADS-B transmitter failure once detected	AC-AT-L02	SO-10, SO-11
SR 20 : The probability of an incorrect QI being transmitted by the avionics source shall be less than 1E-5 per fh. (QI lower than real one)	AC-DS-L01	SO-12
SR 21 : The likelihood that the avionics data source does not provide position shall be less than 1E-05 per fh.	AC-DS-L02	SO-10, SO-11
SR 22 : Verification of pressure altitude-derived level information displayed to the controller shall be effected at least once by each suitable equipped ATC unit on initial contact with the aircraft concerned or, if not feasible, as soon as possible thereafter. The verification shall be effected by simultaneous comparison with altimeter-derived level information received from the same aircraft by radiotelephony. The pilot of the aircraft whose pressure-altitude-derived level information is within the approved tolerance value need not be advised of such verification. Geometric height information shall not be used to determine if altitude differences exist.	ATCo-D01	SO-9
SR 23 : The number of AC controlled in the sector by the same controller has to be determined taking into account that controller has to be able to detect the ADS-B track loss for one aircraft.	ATCo-D03	SO-11
SR 24 : Whenever it is observed on the situation display that the aircraft identification transmitted by an ADS-B equipped aircraft is different from that expected from the aircraft, the pilot shall requested to confirm aircraft identification	FC-F02	SO-6, SO-7
SR 25 : The likelihood that ground system corrupts ADS-B position for all messages received shall be no greater than 1E-04 per hour.	GD-AR-E01	SO-3, SO-4
SR 26 : The likelihood that Ground ADS-B Receive subsystem corrupts ADS-B messages for all the a/c (incorrect QI - lower than real level) shall be less than 1E-4 per hour.	GD-AR-E02	SO-12
SR 27 : The likelihood that Ground ADS-B Receive subsystem corrupts QI (higher than real one) for all the	GD-AR-E03	SO-3, SO-4

Safety Requirements	Obtained from	Related to
aircraft in its region shall be less than 1E-4 per hour.		
SR 28 : The continuity risk of the ground ADS-B receivers shall be less than 1E-4 per hour.	GD-AR-L01	SO-12
SR 29 : The likelihood that ground system corrupts ID for all aircraft received via ADS-B shall be no greater than 1E-04 per hour.	GD-PD-E02	SO-6, SO-7
SR 30 : The likelihood that ground system corrupts the position of an aircraft received via ADS-B shall be no greater than 1E-04 per hour.	GD-PD-E04	SO-1, SO-2
SR 31 : The likelihood that ground system corrupts position for all aircraft received via ADS-B shall be no greater than 1E-04 per hour.	GD-PD-E05	SO-3, SO-4
SR 32 : The likelihood that ground system corrupts quality indicator for an ADS-B track (QI lower than real level) shall be no greater than 1E-05 per hour.	GD-PD-E07	SO-10, SO-11
SR 33 : QI has to correctly be determined by ground system for each track based on ADS-B messages received from aircraft.	GD-PD-E07	SO-10, SO-11
SR 34 : The likelihood that ground system corrupts quality indicator for all ADS-B track (QI lower than real level) shall be no greater than 1E-04 per hour.	GD-PD-E08	SO-12
SR 35 : The likelihood that ground system corrupts quality indicator for all ADS-B track (QI higher than real level) shall be no greater than 1E-04 per hour.	GD-PD-E10	SO-1, SO-2
SR 36 : The likelihood that ground system corrupts quality indicator for all ADS-B track (QI higher than real level) shall be no greater than 1E-04 per hour.	GD-PD-E11	SO-3, SO-4
SR 37 : The likelihood that ground system corrupts altitude for an ADS-B track shall be no greater than 1E-05 per hour.	GD-PD-E12	SO-9
SR 38 : The likelihood that ground system does not provide altitude for an ADS-B Track shall be no greater than 1E-04 per hour.	GD-PD-I01	SO-5
SR 39 : The likelihood that ground system does not process and provide data for an ADS-B Track shall be no greater than 1E-04 per hour.	GD-PD-L02	SO-10, SO-11
SR 40 : ADS-B coverage shall be assured/known in the controlled airspace	GD-PD-L02	SO-10, SO-11

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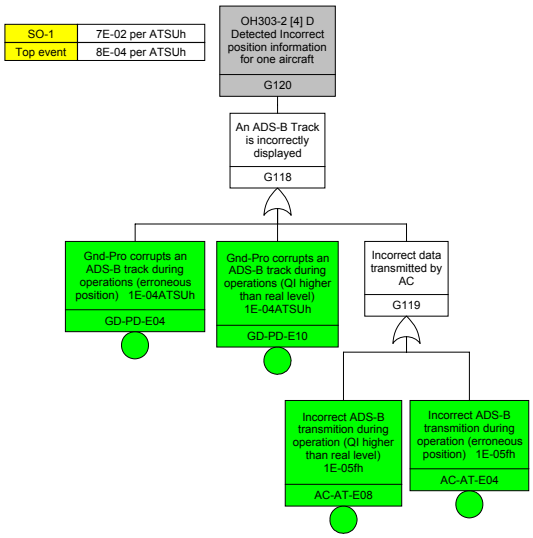
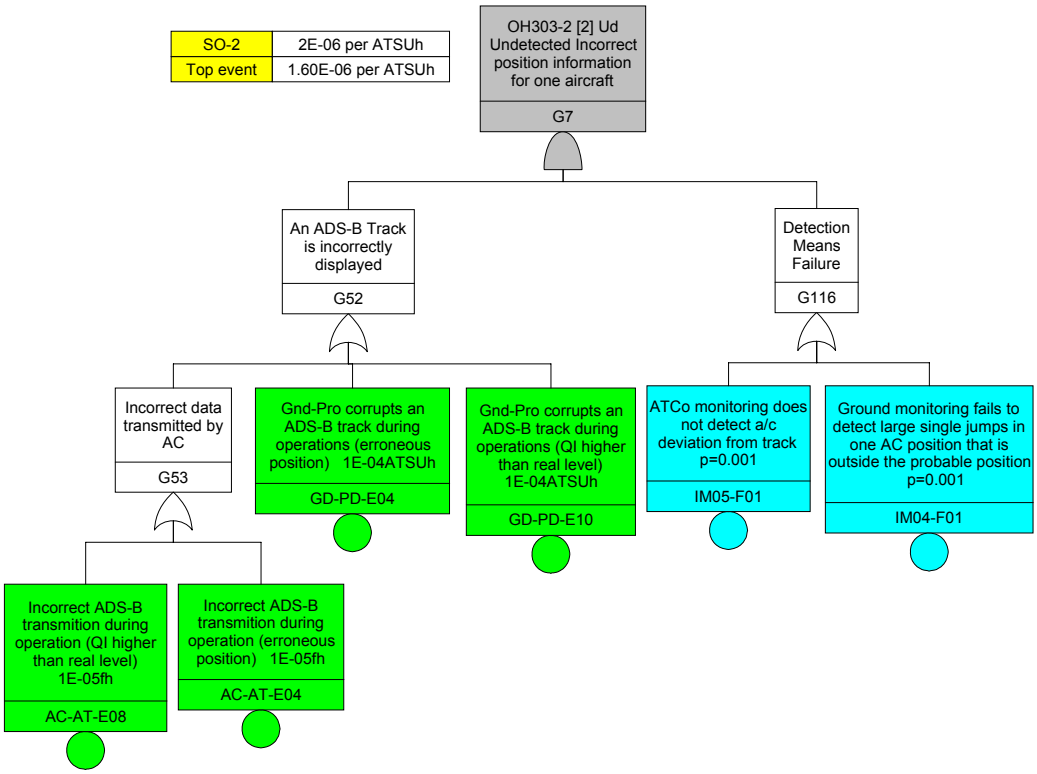
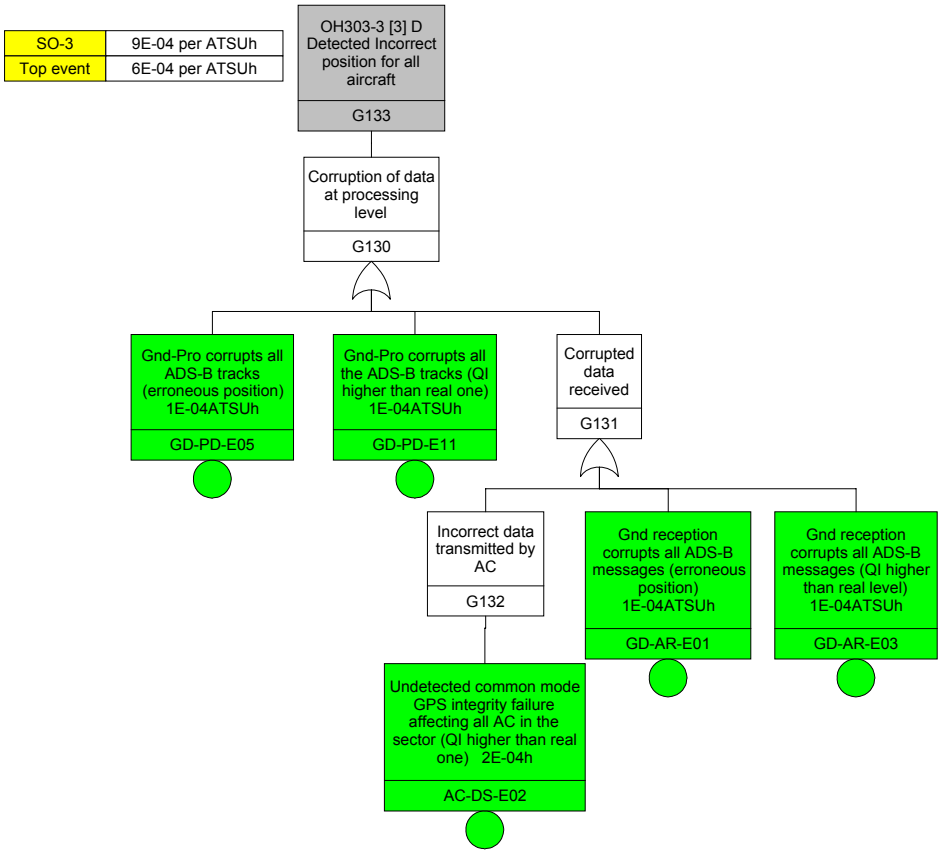
Safety Requirements	Obtained from	Related to
SR 41 : The likelihood that ground system does not process and provide information for all ADS-B tracks shall be no greater than 1E-04 per hour.	GD-PD-L03	SO-12
SR 42 : The probability that ground monitoring fails to inform controller of the loss of traffic information for one aircraft shall be no greater than 0.001.	IM01-F01	SO-11
SR 43 : The probability that ground monitoring fails to inform controller of a satellite error resulting in multiple position error shall be no greater than 0.001.	IM02-F01	SO-4
SR 44 : The number of AC controlled in the sector by the same controller has to be determined taking into account that controller has to be able to detect error in the positioning source resulting in unexpected changes to multiple aircraft tracks on the CWP.	IM03-F01	SO-4
SR 45 : The probability that ground monitoring fails to detect large single jumps in one aircraft position that is outside the probable position shall be no greater than 0.001.	IM04-F01	SO-2
SR 46 : The number of AC controlled in the sector by the same controller has to be determined taking into account that controller has to be able to detect aircraft deviation from track displayed on the CWP.	IM05-F01	SO-2
SR 47 : The ATCo shall be able to identify and correlate ADS-B a/c to Flight Plan information.	IM08-F02	SO-7
SR 48 : The probability that ground monitoring fails to inform controller about the position corruption of ADS-B messages received on the ground station shall be no greater than 0.001.	IM09-F01	SO-4

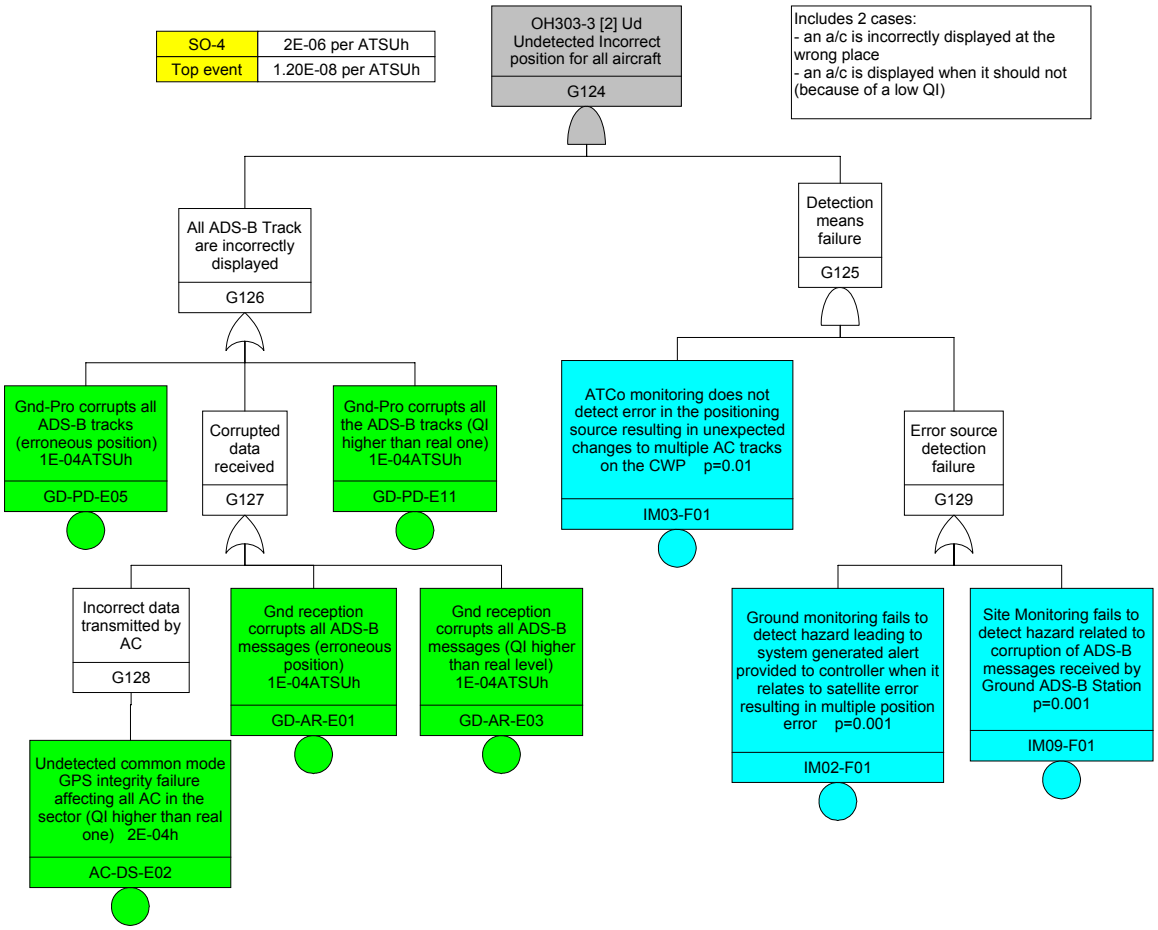
Table: OSA: results: Safety requirements list

Annex D Fault Trees




SO-2
2E-06 per ATSUh
Top event
1.60E-06 per ATSUh
OH303-2 [2] Ud Undetected Incorrect position information for one aircraft
G7
An ADS-B Track is incorrectly displayed
G52
Detection Means Failure
G116
Incorrect data transmitted by AC
G53
Gnd-Pro corrupts an ADS-B track during operations (erroneous position) 1E-04ATSUh
GD-PD-E04
Gnd-Pro corrupts an ADS-B track during operations (QI higher than real level) 1E-04ATSUh
GD-PD-E10
ATCo monitoring does not detect a/c deviation from track p=0.001
IM05-F01
Ground monitoring fails to detect large single jumps in one AC position that is outside the probable position p=0.001
IM04-F01
Incorrect ADS-B transmition during operation (QI higher than real level) 1E-05fh
AC-AT-E08
Incorrect ADS-B transmition during operation (erroneous position) 1E-05fh
AC-AT-E04


SO-3
9E-04 per ATSUh
Top event
6E-04 per ATSUh
OH303-3 [3] D Detected Incorrect position for all aircraft
G133
Corruption of data at processing level
G130
Gnd-Pro corrupts all ADS-B tracks (erroneous position) 1E-04ATSUh
GD-PD-E05
Gnd-Pro corrupts all the ADS-B tracks (QI higher than real one) 1E-04ATSUh
GD-PD-E11
Corrupted data received
G131
Incorrect data transmitted by AC
G132
Gnd reception corrupts all ADS-B messages (erroneous position) 1E-04ATSUh
GD-AR-E01
Gnd reception corrupts all ADS-B messages (QI higher than real level) 1E-04ATSUh
GD-AR-E03
Undetected common mode GPS integrity failure affecting all AC in the sector (QI higher than real one) 2E-04h
AC-DS-E02



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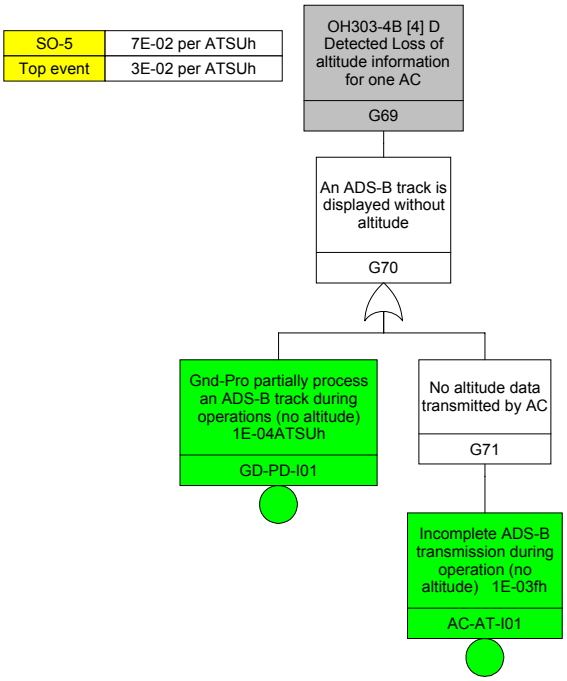

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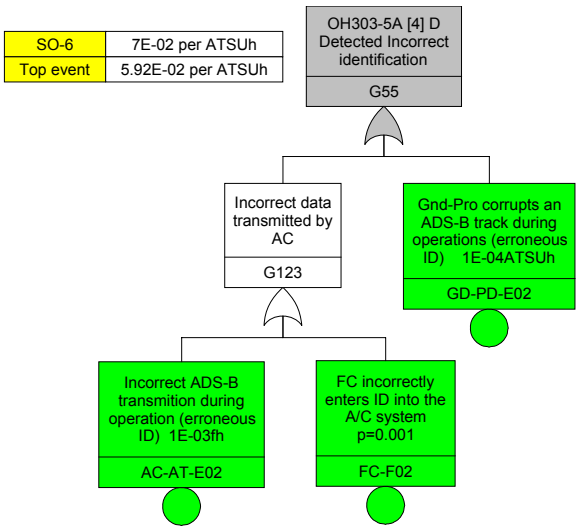
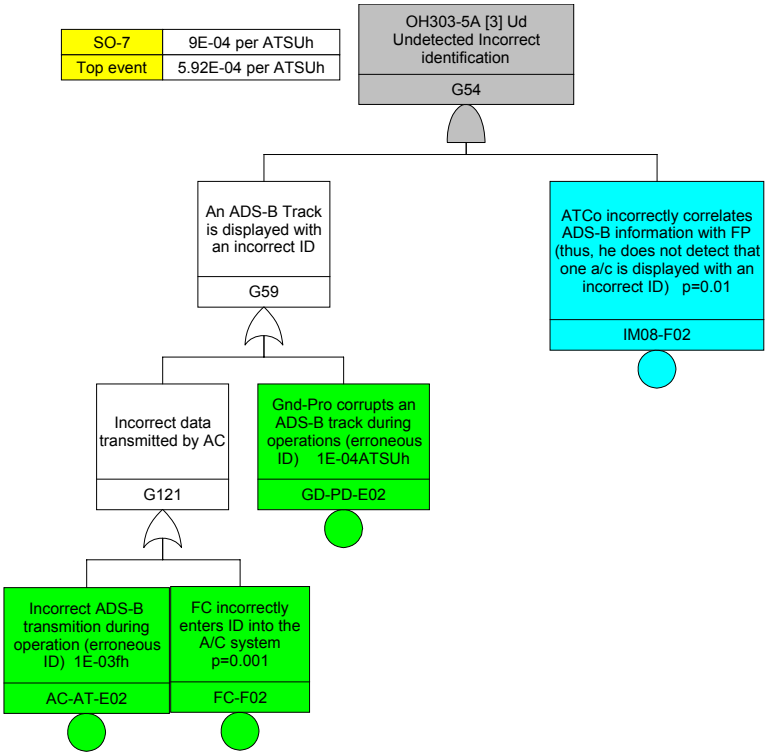

SO-6
7E-02 per ATSUh
Top event
5.92E-02 per ATSUh
OH303-5A [4] D Detected Incorrect identification
G55
Incorrect data transmitted by AC
G123
Gnd-Pro corrupts an ADS-B track during operations (erroneous ID) 1E-04ATSUh
GD-PD-E02
Incorrect ADS-B transmition during operation (erroneous ID) 1E-03fh
AC-AT-E02
FC incorrectly enters ID into the A/C system p=0.001
FC-F02



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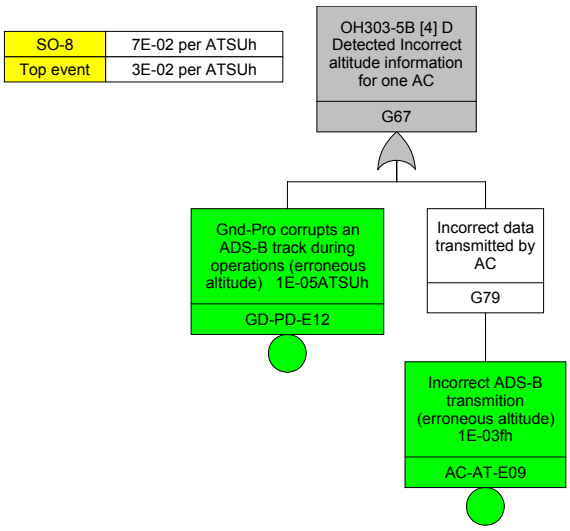

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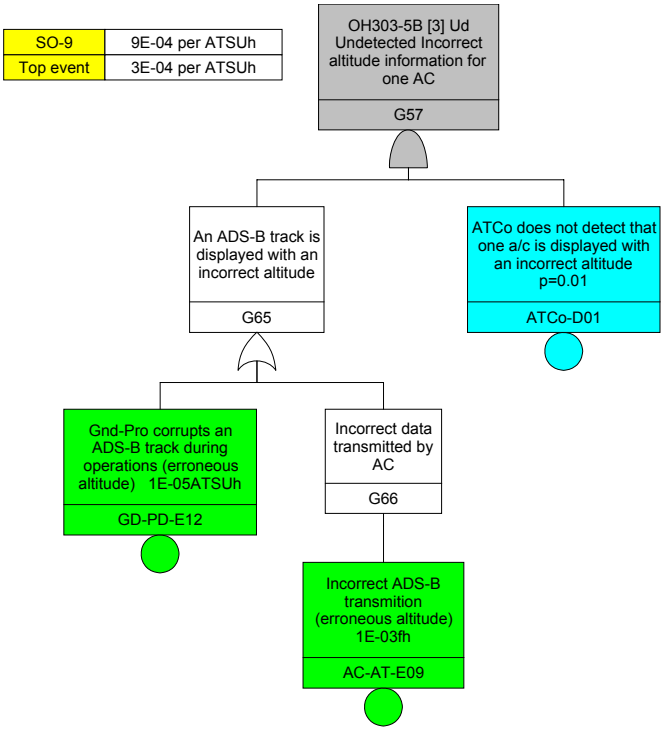

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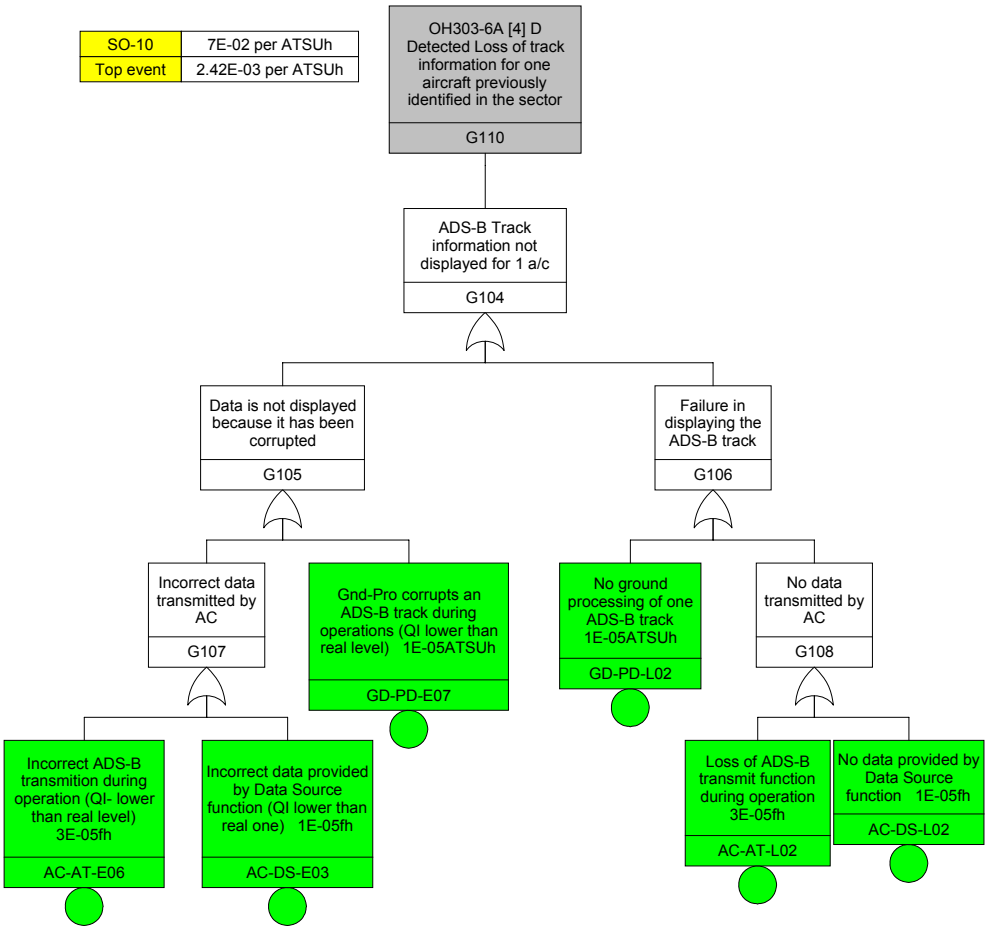

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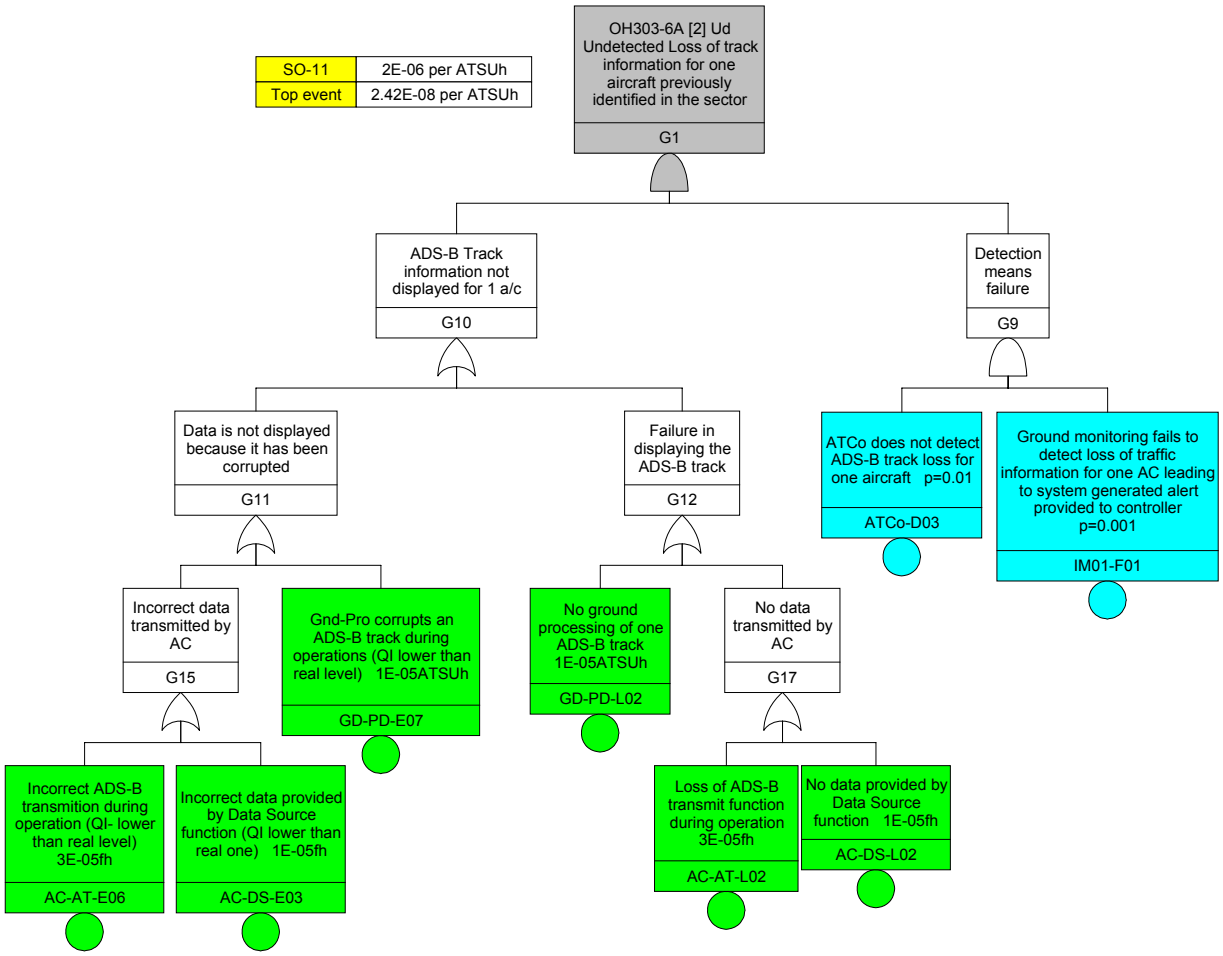

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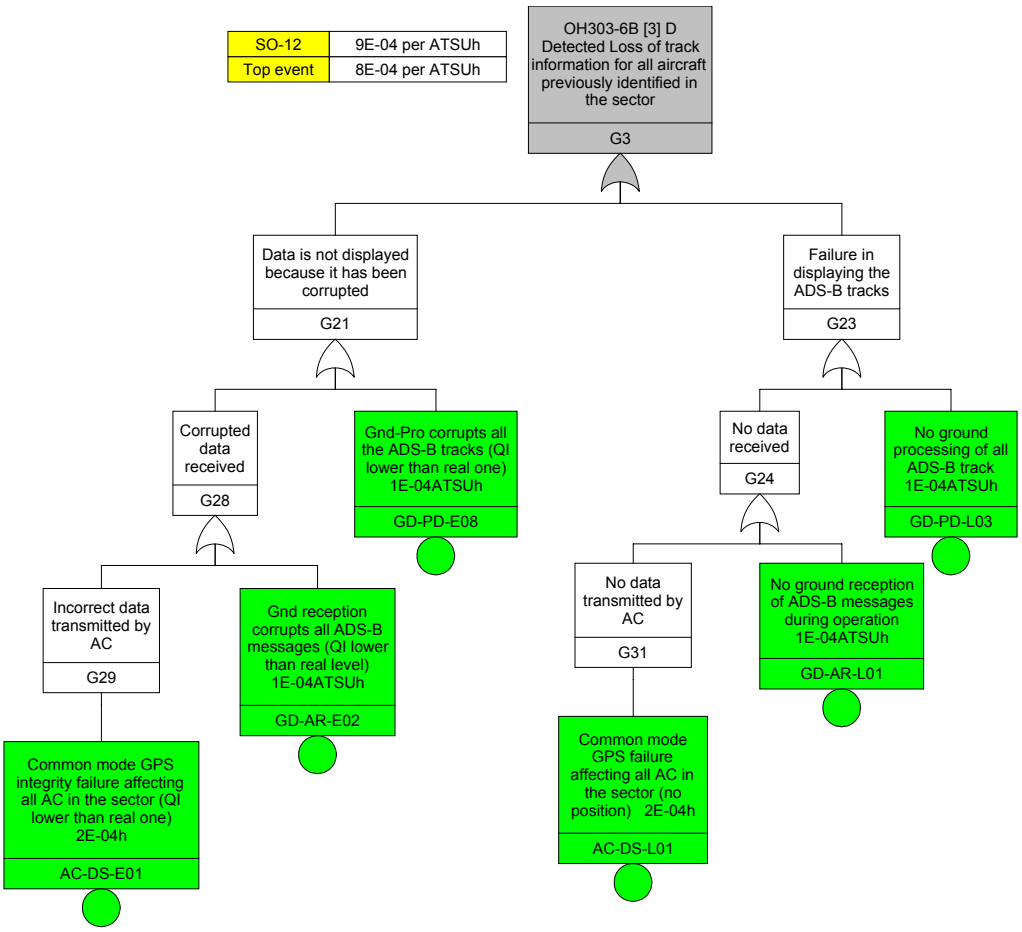

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Annex E Summary from ADS-B-NRA expert analysis

E.1 SCOPE

The OHA was run within the scope of the NRA OSED. Failures that could occur prior to an aircraft receiving an ATC service within the ADS-B-NRA airspace were not considered in the exercise (e.g. failed coordination procedures for aircraft entering the ADS-B-NRA area possibly resulting in risk of the aircraft transiting the airspace without ATC knowledge). These hazards are present in the current system and current ICAO procedures sufficiently mitigate the risks. Hence the assumption is that the ATC is aware of the aircraft as it enters the NRA area concerned and is in normal communications with the pilot/s.

An important note in regards to listed Internal Mitigation Means listed against and their allocation alongside hazards were not used in designating the hazard class however, they were identified as requirements to the detection of the hazards and as such you will not find IMM's against any undetected hazards.. These IMM's are represented as operational requirements in the NRA OSED.

This allocation does not say that all means shall be required to reduce the hazard to ALARP levels. In other words the operational participants do not want to mandate all identified mitigation means listed, these are merely noted as possible external mitigators and may in fact not be required once internal mitigating means are affected.

An 'Important Notes' section has been included at the end of this document to detail further information relating to the hazards and should be read in conjunction with this table.

OSA ref #	OH#	OH	EMMMitigations	Worst Credible Effects (ATC)	Hazard Class
3.0.3-6	OH1	Loss of track information[70] for one aircraft previously identified in the sector	EMM -1 IM - 1 EMM-2	Detected: workload increase	4
3.0.3-6			EMM-3	Undetected[71]: Loss of separation as controller bases separation decisions on an incorrect traffic picture	1-2
3.0.3-6	OH2	Loss of track information[1] for all aircraft previously identified in the sector (similar to detected version of OH9)	EMM -1 IM - 4 EMM-2	Detected Only: Significant workload increase leading to possible loss of separation (for a short time)	3
3.0.3-3	OH3	Incorrect position information for all aircraft.	EMM -1 EMM-2 IM –2a IM- 2b[72]	Detected: Significant workload increase leading to possible loss of separation	3

[70] *Track information = ID + lat/long + altitude + speed*

[71] Difference between 1 and 2 relates to undetected exposure time.

[72] There are two operational scenarios to consider (a) relates to the IM for a general position error affecting a wide area (e.g. error at radar head or error in GNSS position source) and (b) relates to a frozen screen depicting all aircraft position on the CWP incorrectly. Each of these has different IM's; 2a and 2b respectively.

OSA ref #	OH#	OH	EMMMitigations	Worst Credible Effects (ATC)	Hazard Class
3.0.3-3			EMM-3	Undetected[2] Multiple Loss of separation	**1-2**
3.0.3-2	**OH4**	Incorrect position information for one aircraft		Undetected: Loss of separation as controller bases separation on displayed data	**1-2**
3.0.3-2			EMM -1 IM– 3a IM- 3b[73] EMM-2	Detected Workload increase	**4**
3.0.3-5	**OH5**	Incorrect identification	EMM-3	Undetected: Loss of separation as controller bases separation on displayed data	**3**
3.0.3-5			EMM -1	Detected Workload increase	**4**
3.0.3-5	**OH6**	Incorrect altitude information for 1 a/c		Undetected: Loss of separation as controller bases separation on displayed data[74]	**3**
3.0.3-5			EMM -1	Detected Workload increase	**4**
3.0.3-4	**OH7**	Loss altitude information for 1 a/c	EMM -1	Detected Only: Workload increase to establish current altitude, and increased monitoring to account for loss of system supported level monitoring.	**4**
Not referred	**OH8**	Incorrect speed information transmitted by the a/c (where GSP is not calculated by ground RDPS)		Undetected: Loss of separation where controller/ground system use velocity vector and data to identify faster following conflicts	**3**
			EMM - 1	Detected workload increase due to reduced confidence in the system	**4**
	OH9	Loss of emergency mode that has been selected by the pilot but not displayed to ATCO		Undetected: (1) Loss of separation as track/level changes resulting from the emergency are unexpected by ATC and separation assurance is not possible.	**1**
				Detected workload increase due to response actions	**4**
	OH10	Incorrect emergency mode displayed to ATC when another mode has been selected by the Pilot		Undetected (i.e. an emergency is detected but not the correct one): workload increase due to response actions (2)	**4**

[73] There are two operational scenarios to consider that are detailed in the 'Important Notes' section (Each of these has different IM's; 3a and 3b respectively.

[74] The severity is lower than other undetected hazards as current approved airborne radar transponder requirements show that severity class 3 is applied in this scenario

OSA ref #	OH#	OH	EMMMitigations	Worst Credible Effects (ATC)	Hazard Class
				Detected workload increase due to response actions	**4**

E.2 EXTERNAL MITIGATION MEANS:

EMM-1 – Direct Controller Pilot Communications

EMM-2 – ATCo applies alternate separation (could simply be a vertical standard – *See 'Important Notes' below*).

EMM-3 –System segregation of route structure (e.g. sid/star separation, one way routes, hemispherical levels). Although difficult to measure these can have a significant impact on the hazard if implemented into the environment concerned.

E.3 INTERNAL MITIGATION MEANS:

The Internal Mitigation Means listed below have been assigned against various hazards but were not used in designating the hazard class however, they were identified as requirements to the detection of the hazards and as such you will not find IMM's against any undetected hazards. These IMM's are represented as operational requirements in the NRA OSED.The following IM's are provided to assist with the ASOR process in identifying the mitigations that internally will assist with reducing the likelihood of the hazard being detected. They do not reduce the severity. In relation to the controller monitoring IM's, the expert opinion is that these shall occur given the specific hazard scenario that each IM relates to (see table).

IM-1 – Real time ground system monitoring detects loss of track information leading to system generated alert indication provided to controller (controller monitoring assumed not to detect this scenariocurrent radar system mitigation e.g. track coasting symbol)

IM-2a –Real time ground system monitoring detects a satellite satellite position information error resulting in multiple position error leading to system generated alert provided to controller.

IM-2b -Controller monitoring will detect the hazard either if it relates to a frozen screen (current radar system mitigation) or where the error in positioning source results in unexpected changes to multiple aircrafts tracking on the CWP (but is not filtered by the ground system as it is within the probable ranges from previous positions)

IM-3a –Real time ground monitoring detects aircraft deviating from cleared flight planlarge single jump in the aircrafts position that is outside its probable position range leading to system generated alert provided tofiltering of the data (similar to radar) and indication provided to the controller (e.g. track coasting symbol) controller.

IM-3b –Controller monitoring will detect the hazard where the error in position data results in an unexpected change to aircrafts tracking on the CWP (but is not filtered by the ground system as it is within the probable ranges from previous positions) aircraft deviation from track (current radar system mitigation).

IM-4 –Controller monitoring will detect the loss of all tracks on the CWP (current radar system mitigation)

E.4 IMPORTANT NOTES:

- See and avoid - See and avoid as a mitigation means has not been utilised as it cannot be assured and is reliant on providence.
- OH3 Incorrect Position (all aircraft in a wide area region):
  - Undetected – This variance refers to the case where the same incorrect positioning source is being used for both the navigation and surveillance by all aircraft (i.e. both are incorrect but the same) and as such any errors in position data will not be detected by the

ATC.[75] This would be the case where the corruption of the data is occurring at the source (e.g. GNSS satellite) and is undetected by the system (for errors in the individual aircraft position information see OH4).

- Detected – This variance contains three scenarios,
  - (a) IM-2a: Where the error at the source of position data is detected and filtered by the ground system (i.e. ground monitoring of the data source) leading to an alert provided to the controller (similar to radar), and
  - (b) IM-2b:
    Where the incorrect position information relates to a frozen picture on the CWP and no updates are being received for all aircraft. This will be detected by the controller.

    This mitigation also applies where the position information being used for navigation is not the same as that being used for surveillance the controller will detect the apparent deviation on the CWP of multiple aircraft from their cleared routes.

- OH4 Incorrect Position (one aircraft):
  - This hazard does not include the scenario where the aircraft system detects degradation in position quality and this reduced quality indication is received by the ground system and indicated to the controller. In this case the system is considered to be operating correctly and no hazard exists.
  - Undetected – This variance refers to the case where the same incorrect position information is being used for both the navigation and surveillance (i.e. both are incorrect but the same) and as such any errors in position data will not be detected by the ATC.[6] This could be the case where the corruption of the data is occurring on the aircraft (e.g. transmission of an incorrect NUC value being higher than it should be) and the corruption is therefore undetected (for errors in the position source see OH3).
  - Detected – This variance contains two scenarios,
    - (a) IM-3a: Where the error in position data causes a large single jump in the aircrafts position that is detected and filtered by the ground system (similar to radar) and
    - (b) IM-3b: Where the error in position data is within probable ranges of the aircrafts position (i.e. not filtered by the ground system) but is not affecting the navigation of the aircraft. In this case it is reasonable to assume that the controller will detect the aircrafts apparent deviation from its cleared route on the CWP (and attempt to resolve the problem using controller pilot communications).

      This hazard assumes the position information is not the same for the navigation and the surveillance (see the undetected case for the scenario regarding common data source)

- 20/08/05 - ATCo 'skill' for procedural separation –EMM-2 has been reduced to a simple fallback of 'alternate separation':
  - Although some implementations may result in ATCO's providing both a surveillance and procedural service and as such procedural skill is easy to maintain, there is no desire to apply this requirement for ATCo's to be capable of the complete procedural service.

    Where NRA is implemented into airspace which will compare to radar (in terms of reliability and availability) whereby the ATCo applies a surveillance separation service for

[75] Current ATC requirements for monitoring radar tracks and advising pilots of detected deviations assume that the position information on the controllers CWP is not the same as that being used by the pilot to navigate. These requirements are designed to mitigate only errors in navigation of the aircraft such that the controller detects unexpected deviations and informs the pilot. Subsequent navigation assistance from the controller may be required (i.e. radar vectors). Where the positioning information is the same for both navigation and surveillance

all traffic the fallback mitigation is often simply vertical separation until either the failure is rectified or traffic is cleared from the concerned airspace volume.

- 7/10/05 - [OH4] After OPS team review of two different scenarios (a) both ATCO CWP and Pilot have the wrong position information (but the same between them) and (b) only the ATCO CWP track position is incorrect, the hazard was re-classified as 1-2 for both cases (same HC as for 3.0.3-3/3.0.3-6

- 7/10/05 - [OH5] After OPS team review of three different scenarios (a)two aircraft with swapped ident and (b)Two aircraft with same Ident and (c)one aircraft with incorrect ident the team found no change in hazard class for the undetected situation however agreed that detection time would be different with (a) being more difficult to detect than (b) which is more difficult to detect than (c)

E.5 PARTICIPATION:

Participation was limited to identification of hazards and, where extra explanatory details were required, in the drafting of 'dated' Important Notes. 'Undated' Important Notes have been added after the formal OHA workshops to assist with clarification of the hazards

Annex F Automatic Dependent Surveillance—Broadcast Surveillance Requirements to Support Air Traffic Control Separation Standards (Summary) - S. R. Jones, MITRE/CAASD

F.1 INTRODUCTION

This paper summarizes the analytic basis for Automatic Dependent Surveillance—Broadcast (ADS-B) surveillance to support the currently used three nautical mile (NM) separation standard in the terminal area, and the en route area 5 NM separation standard. The separation risk assessment is based on an extension of an International Civil Aviation Organization (ICAO) accepted comparative methodology and use of available surveillance data. The analysis considers only horizontal separation risk, as altitude is assumed to be the same with ADS-B (barometric based) as it is for existing radar-based separation. Details of the treatment are given in [1].

ADS-B equipped aircraft broadcast onboard derived state vector (horizontal position in World Geodetic System-84 (WGS-84) coordinates, velocity, barometric altitude, and identification) along with other data, at high update rates. Lateral position and velocity are of primary interest in air traffic control (ATC) separation of adjacent co-altitude aircraft, and this data, when derived from an accurate navigation source such as GPS is very accurate under normal conditions. ADS-B reports delivered to ATC contain indicators of this position accuracy (Navigation Accuracy Category for Position (NACp)), and integrity of the reported position (Navigation Integrity Category, (NIC)).

Unlike radar, this ADS-B reported accuracy is independent of the aircraft distance from the receiving ground station (although the ground station received update rate degrades with distance, particularly in higher co-channel interference environments). Another significant difference from radar is that ADS-B position integrity, the error containment bound at a certain risk level (indicated by the transmitted NIC value), is primarily determined by onboard monitoring of the navigation source rather than assured by ATC monitoring practices.

ICAO Document 9689-AN/953, “Manual for the Determination of Separation Minimum” [2], identifies two safety assessment alternatives: comparison of the proposed surveillance system risk with a reference system that has previously been accepted as safe, or evaluation of the proposed system risk against an absolute safety threshold. Evaluation against a threshold is an absolute method required when a radical change is proposed; an example of this method is given in Appendix 8 of Document 9689 for use of ADS-Addressed for reduced procedural separation in the North Atlantic. The comparative assessment is appropriate when the proposed system is sufficiently similar to the reference system. A comparative assessment, based on the CAP Model [3] used by the Japanese to extend radar coverage for 5 NM separation over the ocean, is described in Appendix 6 of the manual.

In order to apply the ICAO comparative approach, the following requirements must be met: the separation minima must not be less in the proposed system; the proposed communication and surveillance must not be worse in terms of accuracy, reliability, integrity, and availability; the frequency and duration of the application of minimum separation between aircraft must not be greater in the proposed system; and the navigation performance of aircraft in the proposed system should be no worse in its effect on collision risk in any dimension.

For the proposed use of ADS-B surveillance, all factors except surveillance are assumed to be unchanged. This assumption requires mitigation of a new dependent failure mode associated with the use of GPS for both the navigation source and the ADS-B position source, whereas previously, failures in navigation and secondary surveillance radar (SSR) were independent. Avionics and ground receiver infrastructure redundancy limit this new concern to the issue of

potential local and area-wide GPS outages. Continuity of operation in this event is assured by requiring an onboard backup navigation capability in specified airspace (Inertial Navigation System, VOR, Distance Measuring Equipment, etc.) for procedural recovery just as with a wide area radar outage today. The analysis given here does not address failure mode recovery and is only concerned with risks associated with the use of ADS-B surveillance in lieu of or in conjunction with SSR data.

F.2 REFERENCE SYSTEM RADAR BASELINE

The surveillance risk assessment issue is how to evaluate safety when displayed position measurement uncertainty is the limitation on separation of adjacent aircraft. This analysis is based on the ICAO referenced CAP model for radar separation. The model determines the probability that an aircraft pair will actually overlap when the apparent distance between them is some given value. We optimistically assume for this baseline reference that this measurement uncertainty is the only risk element for radar surveillance. That is, we exclude the probability of accepting false targets due to undetected failures associated with such effects as multipath, target splits, and side lobe detections (i.e., the SSR integrity risk is zero). This best case assumption for the radar baseline capability assures the ADS-B comparative assessment (including the integrity risk result) is conservative.

The probability of close approach (Pca) for radar separation is evaluated for an assumed worst case where co-altitude adjacent aircraft position estimates are limited by the radar azimuth accuracy at the maximum service range of 40 NM from a single-sensor mode terminal area SSR. Surveillance performance is adequately represented in this case by the cross-range azimuth accuracy since the relative separation estimate is unbiased when both aircraft are viewed by the same radar. The measurement is unbiased since both aircraft are considered to be in the same radar environment and viewed essentially at the same time. Since our interest is in the characteristics of a reference surveillance system with demonstrated safety, the baseline azimuth accuracy considered is that of the sliding window SSR (SWSSR), the cooperative surveillance system that has a well established safety record over more than 40 years.

CAP is the probability, Pca, that two adjacent aircraft each of width, Aw, actually overlap when the apparent separation is some value, So. For a cross-range separation, y, this conditional probability is Pca = Probability [y < Aw | So]. With some math, Pca is given by

$$Pca = 2Aw\int_{-\infty}^{\infty} p1(y)\,p1(y-So)\,dy$$

where p1(y) is the cross range pdf for aircraft 1 position error at reference y = 0, and p2(y) = p1(y-So) is the shifted pdf for aircraft 2 position error when apparently separated by y = So.

F.2.1 TERMINAL AREA 3 NM SEPARATION BASELINE

We first determine So for a value of Pca no greater than the value accepted by ICAO when p1 is the SWSSR cross range error pdf at a the maximum coverage range of R = 40 NM. Since dy = R dφ, the pdf of y is determined by the SSR angular error distribution with standard deviation, σφ. An aircraft width of 200 feet, or Aw = 0.033 NM is used.

Available data [4] shows σφ = 0.23 degrees for SWSSRs in the NAS, but details on the shape of the wider angle azimuth error distribution away from bore-sight are not well quantified. The most demanding requirement for ADS-B to ADS-B separation is to optimistically assume a normal distribution for this reference system pdf since this produces the smallest acceptable value for the reference separation, So. A higher probability of wide angle SSR errors, as well as a registration bias error between the two systems, are also examined to determine the sensitivity of ADS-B requirements for separation of ADS-B to SSR targets. Results for both distributions are shown parametrically in [1].

Our basic reference for ADS-B comparison to radar is then the minimum azimuth separation required for two adjacent SWSSR targets at a range of 40 NM from the radar to provide a Pca on the order of the 2×10^{-12} accepted by ICAO. With an angular uncertainty standard deviation of 0.23 degrees, the width of the cross-range standard deviation at 40 NM is 0.16 NM. In

computing the baseline reference separation, So, two cross-range error models are used: a Gaussian model resulting in Ss, and a wide angle error linear combination model resulting in Sw. For the cross-range Gaussian error distribution, ps, the minimum acceptable apparent separation (So is set to Ss for this case) is shown to be Ss = 1.6 NM for Pcs = 1.9×10^{-12}. The difference in Ss and the 3 NM separation standard is 1.4 NM. This is considered the operational margin, Ms, allowing for reaction time related to other separation risk factors. Similar calculations for the wide angle SSR error model yield a minimum baseline separation, Sw = 2.4 NM with an operational margin, Mw = 0.6 NM.

In addition to the surveillance risk factors described here, terminal area automation systems require a surveillance update interval (determined by the antenna scan rate for radar updates) of 5 seconds with 95% confidence. For ADS-B to satisfy this part of the baseline requirement, this determines the minimum acceptable probability of message reception for the ADS-B link of interest. For example, with a universal access transceiver (UAT) state vector broadcast rate of once per second, the minimum probability of reception assuring a 5 second state vector update with a 95% probability is 0.45 with independent decode failures. Since probability of reception degrades with range, the maximum service range from the ground receive station for this link is limited by this value. Similar arguments determine the maximum service range from a 1090ES receiver.

F.2.2 EN ROUTE 5 NM SEPARATION BASELINE

Close approach probabilities associated with the current SSR en route separation standard of 5 NM can be derived for the two cross range error distribution models by setting the separation to 5 NM (assuming the total separation margin is allocated to surveillance risk), and solving for Pca as a function of range. The optimistic Gaussian error model yields Pcas = 10^{-6} at R = 200 NM; the more conservative model CAP is Pcaw = 3×10^{-5} at this range. Notice, too, that the above estimates have further assumed no registration bias errors in the mosaic support of en route applications.

Although 5 NM separation of traffic at R = 200 NM from the SSR has proven over the years to be safe, we may consider a slight modification to our 5 NM reference baseline in order to assure that ADS-B provides an increased level of surveillance confidence (a CAP= 3×10^{-12}) and enhanced operational capability (an operational margin, M = H). This is done, by determining the 5 NM baseline minimum separation requirement from scaling the operational margin, M, available with 3 NM separation to preserve that ratio for 5 NM separation. In addition to the radar estimate uncertainty for the two error models, this treatment also includes an assumed en route mosaic bias error allocation, μm = 0.21 NM. This estimated cross-range bias margin is determined by a typical 0.06 degree relative azimuth bias at 200 NM range. No coordinate conversation error margin is included since these differential errors are negligible for nearby targets.

The resulting reference baselines for defining ADS-B to ADS-B requirements for the 5 NM separation standard with this approach are minimum acceptable separations of Ds = 2.9 NM for the Gaussian error assumption, and Dw = 4.2 NM for the wide angle error model. This assures en route operational margins of Hs = 2.1 NM and Hw = 0.8 NM respectively, considerably better capability than that available today with radar.

As with 3 NM separation, the required update rate for 5 NM separation limits the maximum coverage range for an equivalent ADS-B capability. En route area automation systems require a surveillance update interval of 12 seconds with 95% confidence; this determines the minimum acceptable probability of message decode for the ADS-B link.

F.3 COMPARATIVE ASSESSMENT FOR ADS-B

GPS, the usual navigation source of ADS-B state vector data, is highly accurate in the normal “no fault” condition. Horizontal position accuracies (95%) for unaided GPS with selective availability off are on the order of tens of meters; monitored values for the Wide Area Augmentation System (WAAS) are on the order of meters. Integrity monitoring assuring the error in a GPS “fault” condition is no greater than a certain value without a fault alarm is also

provided to WAAS receivers within WAAS coverage. Since the ADS-B navigation source is not limited to WAAS, nor even to GPS, we take a more general view concerning the potential quality of ADS-B reported data. We do assume the navigation source for ADS-B has integrity monitoring capability, and can report the Horizontal Protection Level (HPL) defined at a 10^{-7}/hr integrity risk level as well as the 95% horizontal accuracy bound as the NACp category. Although the GPS HPL could be encoded as the NIC category at a Surveillance Integrity Level (SIL) corresponding to this 10^{-7}/hr (SIL = 3), due to 1090 Extended Squitter format requirements that both the signal in space and the equipment integrity levels (SIL_E) be combined, we use the more conservative level of 10^{-5}/hr, or a SIL = 2.

In the interest of supporting the most flexible implementation of ADS-B, and to impose the fewest restrictions on navigation backup requirements, our approach is to first determine the minimum separation requirements on ADS-B NIC and NACp that assure a risk level no greater than that associated with the use of SWSSR today. To provide similar ADS-B support for any automation application, these NACp accuracy values are then compared with SWSSR or monopulse (MSSR) target display accuracy or jitter characteristics as a function of range from the radar. Recommended minimum performance parameters for ADS-B are the more demanding of these two evaluation criteria. ADS-B surveillance safety is assured by the NIC/SIL integrity parameters derived in the comparative risk assessment.

F.3.1 COMPARATIVE RISK ASSESSMENT

A number of conservative assumptions are made:

- Although, as mentioned above, SSRs can exhibit comparatively high false target probabilities under some conditions (e.g., undetected erroneous information), we assume no integrity risk for the baseline system, but assume any integrity failure in ADS-B induces an error that reduces separation with the nearby aircraft.
- While ADS-B reported horizontal position errors, and the bias error associated with a fault condition or equipment error, are randomly oriented in the horizontal plane, we assume bias errors to be in the worst case direction (that of the adjacent aircraft) in this assessment.
- Adjacent aircraft are assumed to be in close proximity for 30 minutes so that hourly fault rates can be converted to event probabilities.
- Although the low ADS-B channel occupancy experienced in initial ATC automation configurations assures a high received message update rate, we allow for future circumstances when the time between asynchronously received reports from adjacent aircraft may be as long as the currently used update intervals of 5 seconds (terminal) and 12 seconds (en route). In this case, the earlier received report from one aircraft is updated with its velocity (part of the state vector report) to be in time registration with the later report from the adjacent aircraft. The CAP for this no fault condition includes a worst case separation margin allowing for one aircraft to turn toward the adjacent aircraft just after its previous report was received. A speed of 300 knots and turn rate of 6 degrees/sec is assumed in the terminal area; 600 knots and 3 degrees/sec is assumed en route areas.
- Any residual registration error between ADS-B and SSR targets after registration bias error correction is assumed to be limited by the root sum square of the standard deviations of each target, and this value is reduced by averaging several estimates. The GPS, or other navigation source, error distribution in the direction of the adjacent aircraft, is assumed to be upper- bounded by a Gaussian pdf covering the tails of the actual distribution (if it is not Gaussian).

The general assessment approach is summarized in Figure 3-1. The “no fault condition” CAP is computed for the minimum baseline separation reduced by the cross-track turn maneuver margin. The “conditional CAP given a fault condition” is next computed for the baseline separation reduced by the integrity risk error containment bound, Rc. The undetected fault risk is this conditional value multiplied by the probability the fault occurs and is undetected. The total CAP is the sum of these values for independent statistics.

The process is described for GPS, but is equally suitable for any integrity monitored Navigation source. No fault condition error distributions for GPS and flight management computer (FMC) source data for ADS-B are generally represented as bi-variant Gaussian with a circular Rayleigh radial distribution in the horizontal plane. The 95% NACp bound on these Rayleigh distributed errors is given by ra = 2.45σ where σ is the standard deviation of the Gaussian error distribution in the direction of the adjacent aircraft.

Since the associated Rc can vary over a considerable range for a selected horizontal position error standard deviation, the process basically is to iteratively determine the maximum value of Rc satisfying the acceptable CAP value. The probability, Io, that an error no greater than this occurs during an assumed close approach interval of 30 minutes without an alert is then the signal in space risk factor times 30 minutes. However, due to the noted 1090 ES format limitation, this value is degraded to Io = 5 x 10^{-6} since there is no sure way to convey a better value.

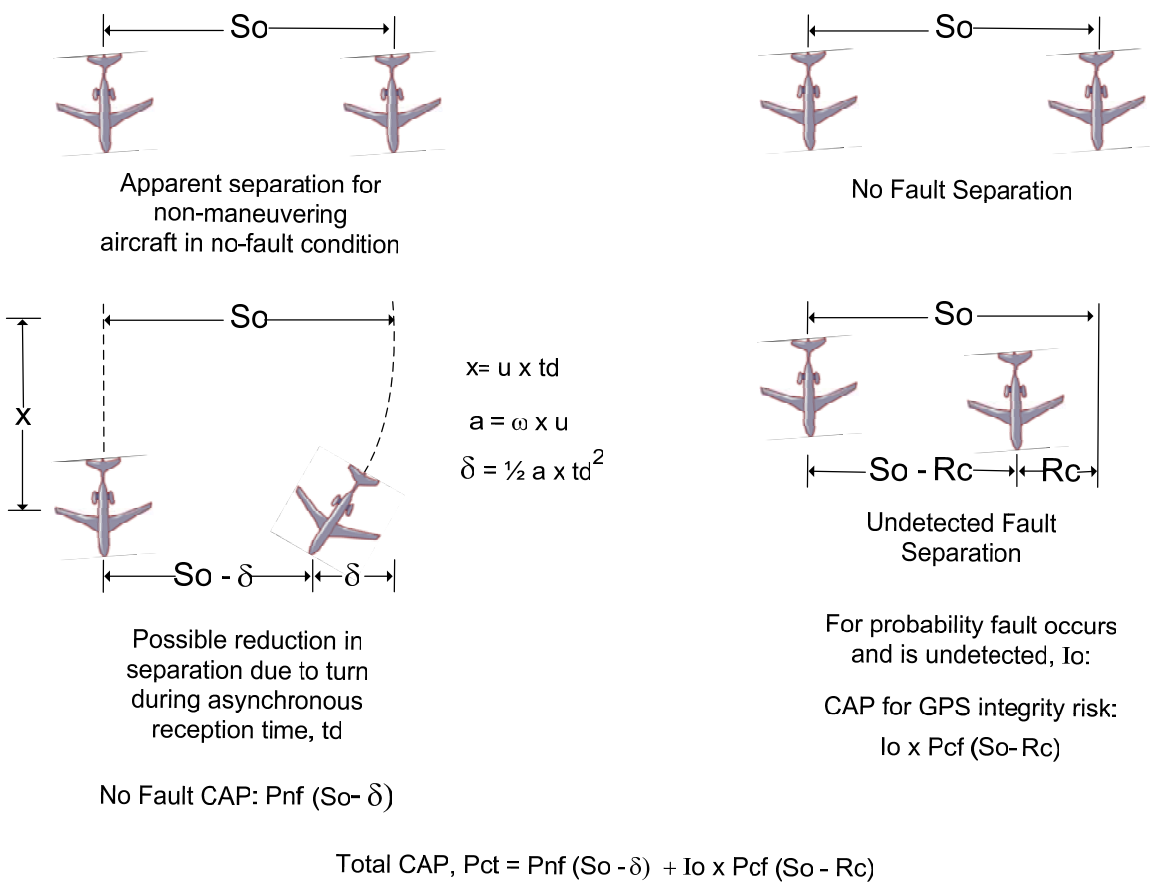

Figure 3-18. CAP Evaluation Approach for ADS-B Risk Assessment

The final potential fault mechanism considered is the probability that the reported position is in error due to an undetected fault in equipment or software. Here we follow the "data reasonableness test" outlined in Required Navigation Performance (RNP) Minimum Operational Performance Standards (MOPS) [5], and commonly referred to as the correlation bin surveillance update outlier rejection test in most radar trackers. The fault detection capability is based on a threshold setting that would be exceeded only by a random position error greater than a reasonable upper bound on any target maneuver since the last received update. The test is centered on the along track extrapolated expected position, but is wide enough in the cross track direction to accept updates from any unexpected turns during the update interval. These various risk level probabilities are additive since they are associated with independent events and the assessment is completed by summing the various CAP components to yield the total CAP (Pet) for these assumptions.

Assessment of ADS-B to SSR target separation requirements follows the above example with the SSR target pdfs and baseline separation references defined first for the Gaussian, then the wide angle error model. Additionally, a residual bias error between ADS-B and SSR reported positions is included. In practice, this bias is minimized by correcting the relative radar bias error on targets that are also ADS-B equipped. This correction is basically limited by noise in the SSR and ADS-B position estimates. Results of this risk evaluation are summarized in the two tables below.

Table 3-38. ADS-B Surveillance Requirements for 3 NM Separation Standard at a CAP = 3 x 10^{-12})

SSR Error Model	Operational Margin (NM)	NACp for ADS-B to ADS-B	NACp for ADS-B to SSR	NIC for ADS-B to ADS-B	NIC for ADS-B to SSR	SIL
Gaussian	1.4	**7** (σ = 76 m)	**7** (σ = 76 m)	**5** (Rc = 1 NM)	**6** (Rc = 0.6 NM)	**2** (10^{-5}/hr)
Wide angle	0.6	**6** (σ = 228 m)	**7** (σ = 76 m)	**5** (Rc = 1 NM)	**6** (Rc = 0.6 NM)	**2** (10^{-5}/hr)

Table 3-39. ADS-B Surveillance Requirements for 5 NM Separation Standard at a CAP = 3 x 10^{-12})

SSR Error Model	Operational Margin (NM)	NACp for ADS-B to ADS-B	NIC for ADS-B to ADS-B	SIL
Gaussian	2.1	**6** (σ = 228 m)	**4** (Rc = 2 NM)	**2** (10^{-5}/hr)
Wide angle	0.8	**5** (σ = 380 m)	**4** (Rc = 2 NM)	**2** (10^{-5}/hr)

As in the case of long range SSR to SSR separation, the relatively wide cross-range radar error distribution limits ADS-B effectiveness in supporting the above minimum required separation values of 2.9 NM or 4.2 NM. Assurance that ADS-B based surveillance risk is at least as good as that of radar when separating ADS-B targets from radar targets requires defining ADS-B requirements so they are at least the CAP level obtained for radar to radar 5 NM separation. Using the above conservative values of NACp = 6 and NIC = 4 for ADS-B performance, and defining the radar cross-range error distribution as before, we get the results (Ccax where "x" is "s" or "w" depending on the Gaussian or wide angle error model) plotted in Figure 3-2 in comparison to the reference values (Pcax) for SSR to SSR separation. Although ADS-B provides improved capability over the SSR baseline for the Gaussian SSR case, the SSR wide angle errors at long ranges for the alternate assumption limit the incremental effectiveness of ADS-B in this case.

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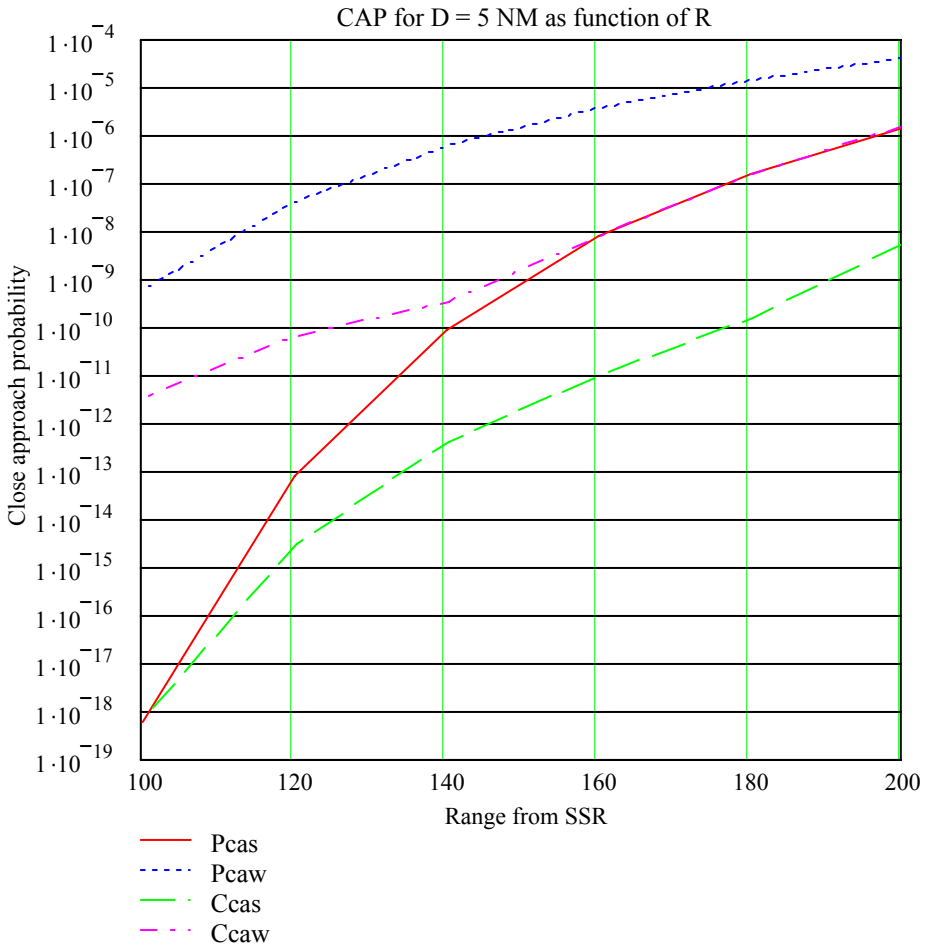

Figure 3-2. Comparison of ADS-B to SSR CAP (Ccax) with SSR to SSR CAP (Pcax) as Function of Range from SSR for Two SWSSR Error Models (Minimum ADS-B Surveillance Quality is given by NACp = 6 and NIC = 4 at SIL = 2)

F.3.2 COMPARISON OF ACCEPTABLE ADS-B ACCURACIES WITH SWSSR AND MSSR ACCURACIES

Requirements defined above on the basis of a comparative risk assessment assure the safety of ADS-B based surveillance for ATC separation service if the ADS-B data quality meets these defined minima for accuracy and integrity. A separate consideration, and one that accounts for at least some of the user interest in the initial implementations of ADS-B, is the fact that GPS based ADS-B reports generally display greater accuracy than associated radar estimates for the same aircraft. The upper sloping line in Figure 3-3 is the approximate cross-range standard deviation (in meters) as a function of range from the radar for SWSSR; the lower sloping line reflects the nominal factor-of-three improvement in this core estimate with MSSR. Standard deviations for NACp values of 6 and 7 (minimum requirements for 5 and 3 NM separation) are

shown for comparison as the top two horizontal lines in the figure. While the 5 NM minimum requirement of NACp = 6 is better than SWSSR performance at ranges exceeding 30 NM, current radar configurations using MSSR have better accuracy within 90 NM. The minimum 3 NM requirement of NACp = 7 is seen to be better than even MSSR at ranges greater than 30 NM from the radar. For reference, a NACp = 8 (still less accurate than typically achieved GPS based NACp horizontal accuracy levels of 9 or 10) is also shown as the bottom horizontal line.

While operational experience may thus modify the minimum desired NACp levels to values more restrictive than those assessed here only in terms of safety risk, the derived integrity containment bounds given by NIC = 6 for 3 NM separation, and NIC = 4 for 5 NM separation are unchanged. They assure any undetected ADS-B position errors are within acceptable risk limits when aircraft are at the reference system minimum baseline separation values.

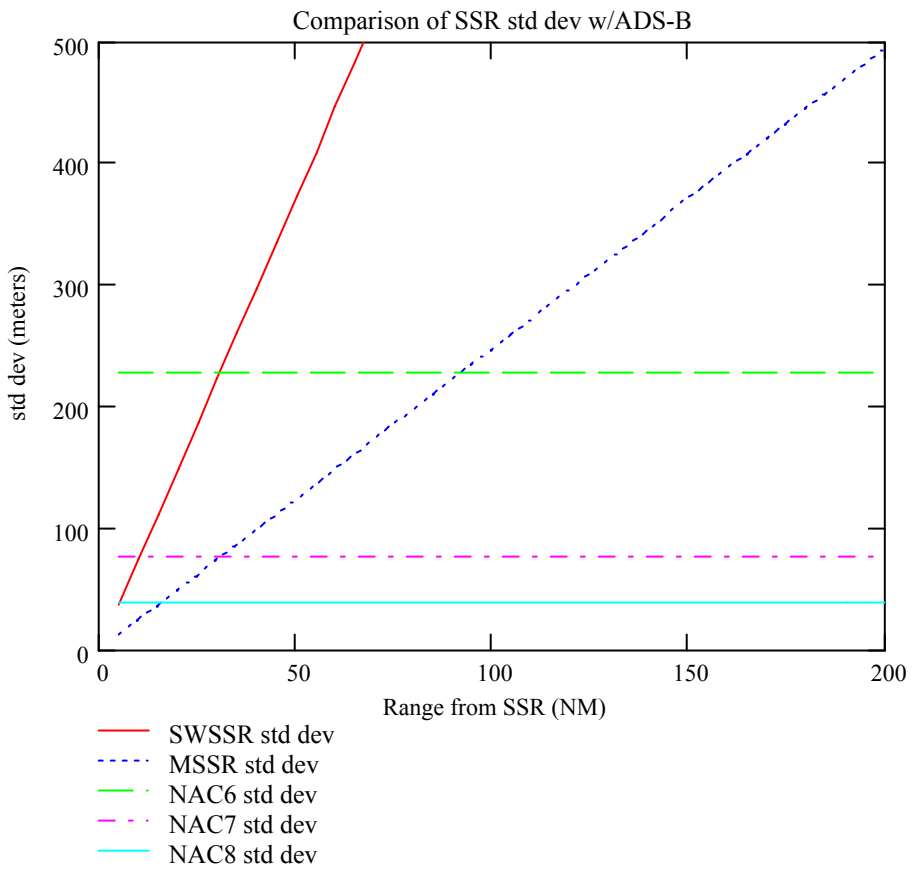

Figure 3-3. Comparison of SWSSR and MSSR Accuracies (Meters) as a Function of Range from Radar (NM) with Several ADS-B Reported NACp Categories

F.4 SUMMARY

Minimum surveillance requirements supporting ADS-B use for 3 NM and 5 NM traffic separations have been determined based on the comparative risk assessment approach. Conservative margins were derived to accommodate certain differences in ADS-B and SWSSR, the baseline reference for the comparative assessment. The CAP model accepted by ICAO for safety assessments shows the proposed use of ADS-B, with

minimum values at least as good as the values given here, preserves or improves the existing surveillance risk level with a preserved or improved operational margin.

Minimum requirements for ADS-B accuracy are NACp = 7 for 3 NM separation, and NACp = 6 for 5 NM separation. These risk related minimum accuracies are considerably lower (less demanding) than values typically available with GPS-based ADS-B reports, and some operational activities may desire more restrictive values to provide ADS-B accuracy equivalent to MSSR performance at shorter ranges. Surveillance integrity considerations, at a SIL = 2 risk level without an alarm, require error bounds of NIC = 6 and NIC = 4 for 3 NM and 5 NM separation respectively. Table 4-1 summarizes these results for time registered state vector updates. These minima are relatively insensitive to specific baseline assumptions, but may vary slightly with operational considerations such as limiting capability to only ADS-B to ADS-B separation.

Table 4-1. Summary of ADS-B Surveillance Requirements for Support of 3 NM and 5 NM Separation Standards

Separation Standard	**NACp (std dev)**	**NIC (Rc)**	**SIL**	**Operational Margin @ CAP = 3 x 10^{-12} (Minimum Separation)**
3 NM	**7** (76 m or 0.04 NM)	**6** (0.6 NM)	**2** (10^{-5}/hr)	1.4 NM (Ss = 1.6 NM)
5 NM	**6** (228 m or 0.12 NM)	**4** (2 NM)	**2** (10^{-5}/hr)	2.1 NM* (Ds = 2.9 NM)

* This margin applies to ADS-B to ADS-B 5 NM separation. ADS-B to Secondary Surveillance Radar (SSR) CAP as a function of radar range is given in Figure 3-2.

F.5 LIST OF REFERENCES

1. Stanley R. Jones, “Automatic Dependent Surveillance – Broadcast Surveillance Requirements to Support Air Traffic Control Separation Standards,” MITRE Technical Report MTR 05W0000008, August 2005

2. 1998, “Manual for the Determination of Separation Minimum,” ICAO Document 9689-AN/953, First Edition.

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4. December 13, 1999, “Mosaic Display Target Accuracy Study,” ARCON Final Report for FAA under Contract DTFA01-97-C-00046.

5. October 28, 2003, “Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation,” RTCA/DO-283A.

Annex G Mapping between integrity and NUC/NIC/NAC

G.1 NUCP, NIC, NACP RELATIONSHIPS AND SUMMARY OF SEPARATION REQUIREMENTS

Relationships between received NUCp values and comparable NIC and NACp values are given in Table XX. These associated levels assume the transmitted NUCp encoding is based on the navigation source Horizontal Protection Level (HPL) integrity containment radius, Rc, and not the Horizontal Figure of Merit (HFOM) 95% error limit, rac. On this assumption, the NUCp containment radius is converted to the corresponding NIC radius. Where the NIC radius does not directly correspond to the NUCp radius, the next higher NIC level is used. NACp accuracy values, rac, associated with the converted NIC values are then half the NIC Rc values, based on the defined NUCp relationships. These NUCp converted NACp error bounds will generally overestimate the navigation source error bound that otherwise might have been directly encoded as NACp values.

The NACp horizontal plane error distribution for a GNSS navigation source is represented by a radial Rayleigh probability density function (pdf). Reference [SRJ] shows the standard deviation for this pdf is the 95% error bound divided by 2.45. This standard deviation in a single direction Gaussian distribution may be related to radar cross range accuracy to compare ADS-B with radar for general support of automation applications.

Minimum acceptable NIC and NACp values for ADS-B support of both 3 NM and 5 NM separation standards are derived in reference [SRJ] and summarized below the table. Corresponding NUCp values for the assumed encoding based on HPL are also shown. Determination of these NUCp values follows reference [SRJ], but uses the NUCp relationship of 95% accuracy limited by half the integrity containment radius. This generally wider error distribution limits the NUCp encoded HPL to 1 NM for 5 NM separation (but supporting a 2.1 NM operational margin), whereas a direct NIC encoding of Rc = 2 NM is acceptable if combined with a more accurate NACp = 6. NIC and NACp encoding quantization intervals mask any such effect for 3 NM separation and the resulting NUCp = 5 (with a 1.4 NM operational margin) is just rounded up to NIC = 6 in this case.

Table – xx NUCp conversion to NIC and NACp for Receive Output (assumes NUCp encoded from NAV source HPL)

NUCp (max Rc NM)	NIC (max Rc NM)	NACp (95% bound - std dev)
9 (0.003)	**11** (0.004)	**11** (3 m – 1.2 m)
8 (0.01)	**10** (0.013)	**10** (10 m – 4.1 m)
-	**9** (0.04)	**9** (30 m – 12.2 m)
7 (0.1)	**8** (0.1)	**8** (0.05 NM – 38 m)
6 (0.2)	**7** (0.2)	**7** (0.1 NM – 76 m)
5 (0.5)	**6** (0.6)	**6** (0.3 NM – 227 m)
4 (1.0)	**5** (1.0)	**5** (0.5 NM – 378 m)
3 (2.0)	**4** (2.0)	**4** (1 NM- 756 m)
-	**3** (4.0)	**3** (2 NM – 1.512 km)
-	**2** (8.0)	**2** (4 NM – 3.024 km
2 (10)	**1** (20)	**1** (10 NM – 7.559 km)
1 (20)	**1** (20)	**1** (10 NM – 7.559 km)
0 (no integrity)	**0** (> 20)	**0** (unknown)

Note 1 : 95% error bound in NM converted to std dev in meters by factor of 1852 / 2.45

Note 2: NIC containment values are defined in GNSS at a 10^{-7} / hr risk level, but format encoding limits the reported level to that of the equipment and software level of 10^{-5} / hr or a SIL = 2.

G.2 MINIMUM ADS-B REQUIREMENTS BASED ON SSR COMPARATIVE RISK ASSESSMENT

En route 5 NM separation (So = 2.9 NM, or operational margin = 2.1 NM):

NIC = 4 (Rc = 2.0 NM) NACp = 6 [rac = 0.3 NM, std dev = 227 m (MSSR @ 90 NM)]

Or, NUCp = 4

TMA 3 NM separation (So = 1.6 NM, or operational margin = 1.4 NM):

NIC = 6 (Rc = 0.6 NM) NACp = 7 [rac = 0.1 NM, std dev = 76 m (MSSR @ 30 NM)]

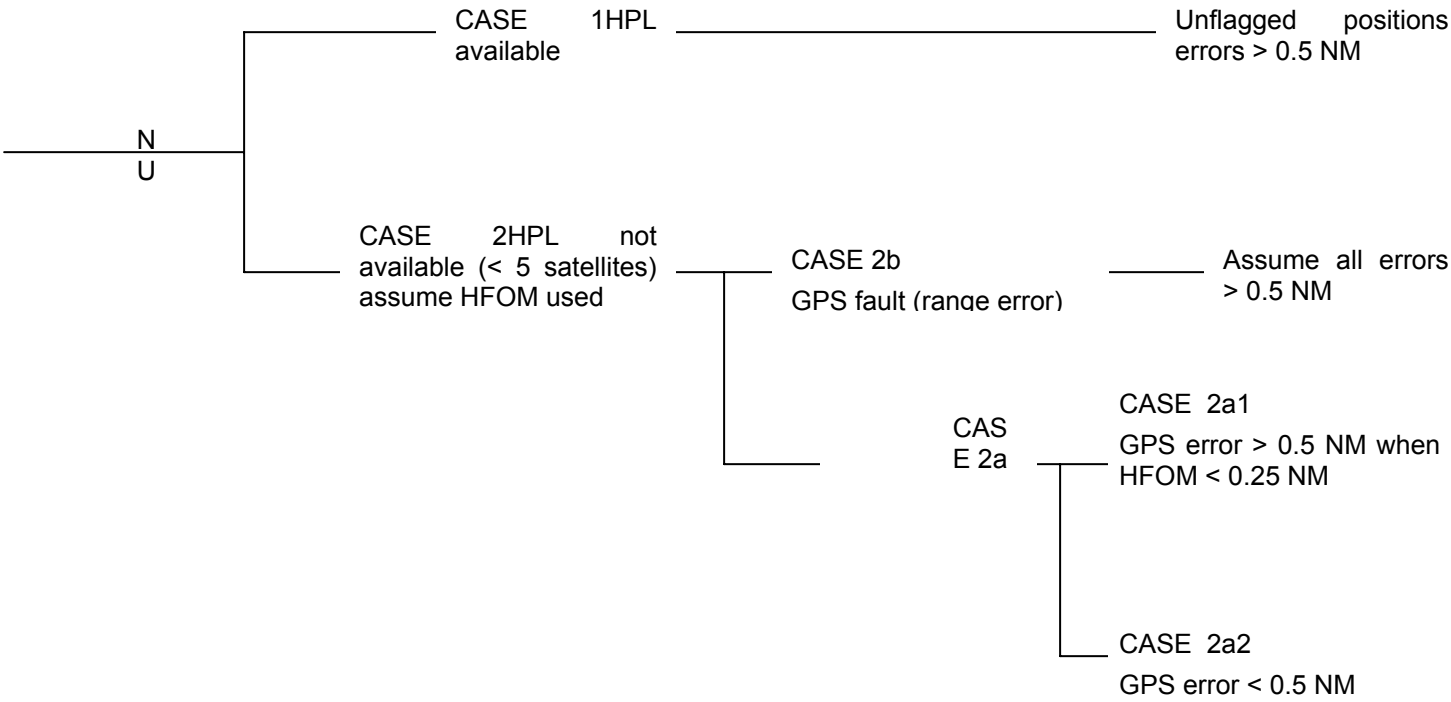
Or, NUCp = 5

Annex H Analysis of NUCp use risk

H.1 INTRODUCTION

This appendix examines the risk of the ATC system receiving a position report marked as NUC ≥ 5 when the positional data is more than 0.5 NM from the true aircraft position and assuming that HPL and HFOM are provided to the transponder by design.

The analysis considers a number of cases described below and shown diagrammatically as follows



<u>CASE 1 : Baseline case (with HPL)</u>

In this case HPL is available from the GNSS receiver. The GNSS receiver has at least 5 satellites in view to achieve this result [76]

[76] It can also be achieved by 4 satellites and barometric aiding. The more stringent case where barometric aiding is not available is used in this paper.

The accepted probability of failure of the RAIM algorithm is $1*10^{-7}$ made up from $1*10^{-4}$ probability of GPS ranging error, i.e. P3=1*10-7

In other words, there is 1*10-7 chance of the reported position being more than 0.5 NM from the real aircraft position.

CASE 2: HPL and HFOM provided but HPL not available

In this case HPL is not available to the transponder and it is assumed that HFOM is used to encode NUCp. Since NUC ≥ 5 the HFOM value is <0.25 NM (95%)

Examining each of the probabilities in the tree:

P1: This expresses the likelihood that HPL will not be available. The only envisaged relevant cause is that less than 5 satellites are visible to the receiver [77]

There are 28 satellites operational. During the last 4 years, the guaranteed minimum of 24 satellites has been maintained without loss.

A visibility analysis using a simulation was conducted using:

- Martinez 24 Almanac specified in RTCA/DO-229c
- Using a mask angle of 5 degrees

This analysis shows that with 24 satellites operational 5 satellites are always visible to a receiver. If only 23 satellites are available, 0.005% of the time there are less than 5 satellites available to a receiver, i.e. the probability of less than 5 satellites available to a receiver when there 23 operational is $5*10^{-5}$. Taking into account that 24 satellites are available most of the time, 1*10-5 is used as the acceptable value for this analysis.

P2: This expresses the probability of a GPS ranging error (GPS fault). The announced GPS probability is 1*10-4 although in practice much better performance has been achieved. The 1*10-4 value is used.

P4: This expresses the probability that a position report will fall outside 0.5 NM bound, assuming GPS is operating correctly and that the HFOM 95% value is less than 0.25 NM. A probability of 1% is used i.e. $P4=1*10^{-2}$

Analysis Result:

Finally examining each case

BASE CASE 1: (HPL available, but unflagged error > 0.5 NM)

[77] It can also be achieved by 4 satellites and barometric aiding. The more stringent case where barometric aiding is not available is used in this paper.

P3 = $1*10^{-7}$ (footnote : The use $1*10^{-7}$ is conservative. Stan Jones paper assumes 10^{-5})

CASE 2A1: (HPL not available, no GPS fault, but error > 0.5 NM)

P=P1*(1-P2)*P4

Assume 1-P2=1 since this is worst case

P = P1*P4 $=10^{-5}*1*10^{-2}$ $=1*10^{-7}$

This is equivalent risk to the base case

CASE 2A2: (HPL not available, GPS fault, but error >0.5 NM)

P = P2*P1 $=10^{-4}*10^{-5}$ $=10^{-9}$

This is lower risk than the base case

Conclusion:

Due to the very small time that less than 5 satellites will be available, the use of NUC formed from HFOM is acceptable, provided HPL is provided to the transponder by design.

H.2 FURTHER MITIGATIONS

Whilst the above shows that the use of HFOM during periods of HPL non availability does not pose an additional risk, there are available a number of mitigations which could lower the risk further during these periods if required:

a. **Site monitoring** can be implanted to detect satellite ranging errors independent of the aircraft. ATC separation services using ADS_B could be suspended follow such detection, sometimes before the aircraft detects the error.
b. **A RAIM prediction service** can identify predict loss of adequate satellite coverage and associated loss of HPL reducing the risk of unflagged errors.

H.3 OTHER CONSIDERATIONS

The following could be included in the above analysis if required and would further strengthen the argument.

a. Some ADS-B transponders will transmit NUC when HPL is not available. These transponders lower the risk of misleading data.

b. The analysis could consider a reduced risk of ranging error by considering that the ranging error needs to occur on one of the 4 visible satellites, rather than on any satellite.

c. Some positional errors triggered by a faulty ranging signal will be detected by the air traffic controller as by the ATC processing system (eg route adherence monitoring)

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Annex I INTEROPERABILITY STANDARD

I.1 INTRODUCTION

This document provides the interoperability requirements (INTEROP) standard for the implementation of the "Enhanced Air Traffic Services in Non-Radar Areas using ADS-B surveillance" application, henceforth referred to ADS-B-NRA. This application is one of the set of applications grouped under the name Package I of Air Surveillance Applications/Ground Surveillance Applications (ASA/GSA).

This document was developed in accordance with the criteria for INTEROP standards set forth in EUROCAE ED-78A/RTCA DO-264, "Guidelines for Approval of the Provision and Use of Air Traffic Services Supported by Data Communications".

This document specifies the minimum set of interoperability requirements and allocations necessary to provide assurance that the elements of the communication, navigation, and surveillance/ air traffic management (CNS/ATM) system are compatible with each other and will perform their intended function for ADS-B-NRA. The system elements are composed of the aircraft system, the air traffic service provider (ATSP) system, and the operator's provisions to use the air traffic services.

I.1.1 PURPOSE

The purpose of this document is to define the set of requirements for the interoperability aspects of the ADS-B-NRA application. It is intended for use in conjunction with a consistent safety and performance requirement standard, other INTEROP standards, and the guidelines described in ED-78A/DO-264 for each approval type associated with the elements of the CNS/ATM system.

NOTE 1: *Based on ED-78A/DO-264, INTEROP and SPR standards provide recommendations intended for government organizations, conferences of governments, or agencies having statutory jurisdiction over the use and provision of air traffic services supported by data communications. These recommendations are for use by such government organizations to enunciate official policy, related to such matters, in aeronautical information publications (AIPs), notices to airmen (NOTAMs), airplane flight manuals (AFMs), and operator specifications.*

NOTE 2: *This standard is not intended to contain detailed requirements on avionics and/or ground equipment. Such requirements can be found in specialised documents (e.g.: MOPS and Interface Control documents).*

I.1.2 SCOPE

The scope of the application and this document is for ATS use of ADS-B in Non Radar Areas.

ADS-B is an aircraft system that periodically transmits a state vector (horizontal and vertical position, horizontal and vertical velocity) and other information. ADS-B is *automatic* because no external stimulus is required; it is *dependent* because it relies on on-board navigation sources and on-board broadcast transmission systems to provide surveillance information to other users. The aircraft originating the broadcast may or may not have knowledge of which users are receiving its broadcast; any user, either aircraft or ground based, within range of this broadcast, may choose to receive and process the ADS-B surveillance information.

NOTE 1: *During the course of the SPR analysis of the ADS-B-NRA application it was found that DO-242 requirements are sufficient, under the conditions specified below, to support the NRA application.*

It is important for users of this document to be aware that DO-242 is not satisfactory for many other envisioned applications of ADS-B.

While DO-242 compliant equipment will be satisfactory for the NRA application for the very near term, the committee strongly recommends that users, regulators, and manufacturers move forward with implementations and approvals of DO-242A requirements in the most expeditious manner possible.

***NOTE 2** :The US programme for the use of ADS-B plans to require fitting with DO-242A compliant equipment starting in 2008.*

I.1.3 RELATIONSHIP TO OTHER DOCUMENTS

This INTEROP standard is based upon the guidance of ED-78A/DO-264. This INTEROP standard can be used as evidence of the interoperability assessment, which is part of the coordinated requirements determination process. This evidence provides the basis for qualifying the interoperability aspects of elements of the CNS/ATM system. Additional criteria for qualifying the interoperability aspects of an element of the CNS/ATM system to the INTEROP standard can be found in ED-78A/DO-264.

This INTEROP document does not address safety or performance. These types of requirements are covered in the safety and performance requirements standard (SPR), which are the products of the operational safety assessment (OSA) and the operational performance assessment (OPA), and are based on the operational services and environment definition (OSED). The OSA determines, validates, and allocates requirements to ensure that the CNS/ATM system, as described in the OSED, is acceptably safe. The OPA derives and/or validates required surveillance performance. Applicants will have to show for approval that this INTEROP standard is viable for the relevant SPR standards per Section 5 and 6 of ED-78A/DO-264.

I.1.4 HOW TO USE THIS DOCUMENT

I.1.4.1 Mandating and Recommendation Phrases[78]

The document contains "shall" and "should" statements with the following meanings:

- *The document provides "shall" statements to ensure compatible and interoperable systems for the ADS-B-NRA application. The use of the word "shall" indicates a mandated criterion; i.e. compliance with the criterion is mandatory and no alternative may be applied;*
- *The use of the word "should" indicates that though the criterion is regarded as the preferred option, alternative criteria may be applied. In such cases, alternatives should be identified in appropriate approval plans and agreement sought from the approval authority; and*
- *The use of the word "will" describes expected system behaviour when the system complies with the references requirements, and/or this document's requirements.*

I.1.4.2 Document Organization

In this Annex I, section 1 provides an introduction to the Interoperability Requirements Standard for ADS-B-NRA (INTEROP ADS-B-NRA).

Section 2 describes ADS-B-NRA in terms of its main components and functions.

Section 3 defines the air and ground interoperability requirements for the ADS-B-NRA application.

Annex J provides the interoperability specifications for the ADS-B-NRA application utilizing 1090 MHz Mode-S extended squitter.

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[78] Recommendations in the IR document have no definition to refer to. There should be a definition that says ‘all new airframes should comply with the recommendations’

NOTE 1: *This technology is proposed by ICAO for global use in the near-term ADS-B applications, see the recommendation from the ICAO Eleventh Air Navigation Conference (ANC/11) in Montreal, 22 September to 3 October 2003*

'Recommendation 7/1 — Strategy for the near-term introduction of ADS-B

That States:

a) note that a common element in most of the approaches currently adopted for early implementation of ADS-B is the selection of the SSR Mode S extended squitter as the initial data link; and

take into account this common element to the extent possible in their national and regional implementation choices in order to facilitate global interoperability for the initial introduction of ADS-B'.

NOTE 2*: Other technologies may be applied on a regional basis.*

NOTE 3: *The airborne system hardware supporting this application can be a stand-alone ADS-B unit, or alternatively, ADS-B may be incorporated within other on-board equipment.*

I.1.4.3 Acronyms and Abbreviations

The following list gives an inventory of acronyms frequently used in documents dealing with the context of ADS-B and Mode S, not all necessarily appear in this document:

1090ES - 1090Mhz Extended squitter
AC - Advisory Circular
ACARS - Aircraft Communications, Addressing and Reporting System
ADS - Automatic Dependent Surveillance
ADS-B - Automatic Dependent Surveillance-Broadcast
AIP - Aviation Information Publications
ANC - (ICAO) Air Navigation Conference
ARINC - ARINC Incorporated (formally Aeronautical Radio Incorporated)
ASA - Air Surveillance Applications
ATM - Air Traffic Management
ATS - Air Traffic Services
ATIS - Automatic Terminal Information Service
BDS - Comm-B Data Selector
BER - Bit Error Rate
BNR - Binary Numbers
BW - Bandwidth
CNS - Communications, Navigation and Surveillance
CDTI - Cockpit Display of Traffic Information
CRC - Cyclic Redundancy Check
EPU - Estimated Position Uncertainty
ETA - Estimated Time of Arrival
EUROCAE - European Organization for Civil Aviation Equipment

FAA - Federal Aviation Administration
FAR - Federal Aviation Regulation
FD - Fault Detection
FDE - Fault Detection and Exclusion
FMS - Flight Management System
GNSS - Global Navigation Satellite System
GPS - Global Positioning System
GSA - Ground Surveillance Applications
Hz - Hertz
IAS - Indicated Airspeed
ICAO - International Civil Aviation Organization
IFR - Instrument Flight Rules
ILS - Instrument Landing System
INS - Inertial Navigation System
ITU - International Telecommunication Union
JAA - Joint Aviation Authorities
JAR - Joint Aviation Requirements
LSB - Least Significant Bit
MASPS - Minimum Aviation System Performance Standards
MHz - Megahertz
MOPS - Minimum Operational Performance Standards
MTBF - Mean Time Between Failure
NAC P - Navigational Accuracy Category-Position
NAS - U.S. National Airspace System
NAV - Navigation
NAVAID - Navigation Aid
NIC - Navigation Integrity Category
NOTAM - Notice to Airmen
NRA - Non Radar Area
NUCp - Navigation Uncertainty Category - Position
OPA - Operational Performance Assessment
OSA - Operational Safety Assessment
RAIM - Receiver Autonomous Integrity Monitoring
RCP - Required Communication Performance
Rc - Integrity Containment Radius
RF - Radio Frequency
RMP - Required Monitoring Performance
RNP - Required Navigation Performance
RSP - Required System Performance
SARPS - Standards and Recommended Practices
SIL - Surveillance Integrity Level
SPI - Special Position Ident

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SPR - Safety and Performance Requirements
SSR - Secondary Surveillance Radar
TAS - True Airspeed
TIS - Traffic Information Service
TIS-B - Traffic Information Service-Broadcast
TMA - Terminal Manoeuvring Area
TSO - Technical Standards Order
UTC - Coordinated Universal Time
VEPU - Vertical Estimated Position Uncertainty
VHF - Very High Frequency
VPL - Vertical Protection Limit
WGS-84 - World Geodetic System 1984

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I.1.5 REFERENCES

The references cited or used in this INTEROP standard are listed below:

For sections 1 to 3 of this Annex I:

- ICAO Doc 4444, PANS-ATM, 14th edition 2001
- EUROCAE ED78A/RTCA DO264, Guidelines for Approval of the Provision and Use of Air Traffic Services supported by Data Communications;
- EUROCAE ED126/RTCA DOxxx, ADS-B-NRA Safety and Performance Requirements (SPR)

NOTE: *The SPR also contains the Operational Service and Environment Definition (OSED)*

- DO-208, Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)
- DO-229C, Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment
- DO-242, Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)
- DO-242A, Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)
- TSO-C166 (US Department of Transportation)

For Annex J:

- ICAO Annex10,VOL III Amendment 79

NOTE: *there is no change in the definitions in chapter 5 (SSR MODE S AIR-GROUND DATA LINK) against Amendment 77.*

- ICAO Annex10, VOL IV, Amendment 77
- DO - 181C/ED-73B**,** Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment
- DO -260/ED-102**,** Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services (TIS-B)
- DO - 260A**,** Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services (TIS-B)

NOTE: *The Mode S Extended Squitter definitions of Document DO-260/ED-102 are completely covered by the ICAO Annex 10 references given above.*

I.2 DESCRIPTION AND GENERAL REQUIREMENTS FOR ADS-B-NRA

I.2.1 MAIN COMPONENTS

The ADS-B-NRA functional components represent a subset of the components required for the general ASA/GSA system. For the purpose of this standard, an indication of the main functional components used for the ADS-B-NRA system is provided in Figure H-1 adapted from the OPA of the SPR of this application. The domains to be considered for interoperability allocation within the context of this standard are:

- in the aircraft system element, the Transmit Aircraft Domain
- in the ATSP element, the Ground Domain.

The scope of the ADS-B-NRA application is represented by the shadowed shape in the Figure 3

NOTE: *the air-ground link technology is not addressed in this Annex I (Main body).*

Air and ground requirements for a specific technology are given in different Annexes; e.g. Annex J for 1090 MHz extended squitter.

The INTEROP requirements for the ADS-B-NRA application are assigned to the Transmit Aircraft Domain component and/or to the Ground Domain component

In the Transmit Aircraft Domain the following subsystems are taken into consideration for interoperability: the Surveillance Transmit Processing (STP) subsystem and the ADS-B Transmit Function. The STP subsystem takes information from other systems onboard the aircraft, then processes and stores this information for use by the ADS-B Transmit subsystem, that formats and transmits the information following the specifications of the link technology.

In the Ground Domain the following subsystems are taken into consideration for interoperability: the ADS-B Receive Subsystem and the ATC Processing System. The ADS-B Receive Subsystem accepts ADS-B information, assembles it following the ground system requirements, and forwards it to the ATC Processing System. The ATC Processing System associates the ADS-B information with internal flight plan information, when available, and prepares the data for presentation to the ground user.

NOTE: *The indicated subsystems within the domains are not intended to imply a physical architecture. The intent is to describe functional blocks to ease reader understanding of the requirements.*

This standard primarily defines requirements for the output of the Transmit Aircraft Domain and the input to the Ground Domain. Each requirement may levy requirements on the subsystem of the given domain; e.g. integrity requirements for an ADS-B message impose requirements on Data Source components of the Transmit Aircraft Domain.

NOTE: *No specific Aircraft Operator requirements for this application have been identified so far.*

I.2.2 FUNCTIONS OF THE ADS-B-NRA APPLICATION

The functions of the ADS-B-NRA application executed by the Transmit Aircraft Domain and the Ground Domain are to provide enhanced Air Traffic Services in areas where radar surveillance does not exist.

The ADS-B-NRA application is designed to enhance the following ICAO Air Traffic Services.

- Air Traffic Control Service and Flight Information Service principally for the following functions:
- Alerting Service, principally for the following functions:
- Air Traffic Advisory Services

The functions will be enabled by a periodical provision of

- Identification data
- State Vector
- Emergency Data
- Supplementary Data (Quality, Time…)

I.2.3 GENERAL REQUIREMENTS FOR ADS-B-NRA

IR 1 : For the ADS-B-NRA application the following information shall be made available to the ATC Processing System:

- **Identity** (containing at least the aircraft identification and 24-bit address, may also contain mode A code),
- **Position** (containing at least horizontal position, barometric height, quality indicators, and24-bitaddress),
- **Emergency/SPI status** (containing at least the emergency status indicator, SPI, and 24-bit address). (OR 1 :)

I.2.3.1 Messages and Reports

ADS-B information is assembled and transmitted in ADS-B messages from air to ground. Message formats are dependent on the link technology. The link technology specific requirements can be found in the Annex J to this standard.

The ATC Receive Subsystem must receive, assemble and convert the data into a different information format, known as ADS-B reports.

From the definitions given above the following INTEROP requirements are derived:

IR 2 : The Transmit Aircraft Domain shall provide ADS-B messages containing at least the elements which enable the ground system to format the required ADS-B reports for the ADS-B-NRA application.

IR 3 : The Transmit Aircraft Domain shall provide in each ADS-B message a unique identification of the flight and/or aircraft. [79]

NOTE: *The contents and update rates of the ADS-B messages are dependent of the link technology used; definitions for a specific technology are given in the following Annex(es).*

IRec 1 :Recommendation: The ADS Receive Subsystem of the Ground Domain should compose ADS-B reports from the ADS-B messages received using the content of the 24-bit address field for the association of messages to each other.

IRec 2 :Recommendation: The ADS-B Receive Subsystem should only group ADS-B messages into ADS-B reports when the ADS-B messages can be identified as coming from the same aircraft.

IRec 3 :Recommendation: The data format of the ADS-B report should be independent of the particular type of ADS-B technology.

IRec 4 :Recommendation: Operational identification for the end user in ATS system should be achieved by using either the aircraft identification or the mode A code.

NOTE: *Operational identification is the set of characters associated to a traffic target on the traffic situation display of a controller.*

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[79] This needs to be modified (or new one added) to ensure that for flights/aircraft that currently must provide an aircraft id (see mode s program for mandate details) this id shall be given to the transmit function for sending.

NOTE: *The safety and performance requirements are given in sections 3.1.2 and 3.3.4 respectively of the SPR.*

I.2.3.2 Time Reference and Time Stamp

IR 4 : The ADS-B Receive Subsystem shall provide a time stamp in each ADS-B report.

IR 5 : For ADS-B reports containing position information, the time stamp shall represent the time of applicability of the position.

IRec 5 :Recommendation: The time stamp for the report containing the state vector should be either the time of reception in case the received position is forwarded without change or the time of estimated applicability when an estimation process has been applied.

I.3 REQUIREMENTS FOR THE ADS-B-NRA APPLICATION SPECIFIC INFORMATION

I.3.1 IDENTITY

In the ADS-B-NRA application identity within ADS-B reports is given by 24 bit aircraft address and aircraft identification. The report may also contain Mode A code.

Depending on the link technology, ADS-B information may be split into subsets; in this case, the 24 bit address information also permits the association of different ADS-messages.

I.3.1.1 24 bit aircraft address

IR 6 : The Transmit Aircraft Domain shall provide the 24 bit aircraft address within each ADS-B message.

NOTE: *ICAO Doc. 4444, PANS/ATM (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".*

IRec 6 :Recommendation: The ADS-B Receive Subsystem shall use the aircraft address to associate separate ADS-B messages.

IRec 7 :Recommendation: The ATC Receive Subsystem should include the aircraft address in each ADS-B report.

IRec 8 :Recommendation: The ATC Processing System should use the aircraft address to associate ADS-B reports to radar track and, previous reports when the internal flight information includes the aircraft address.

NOTE: *The ATC Processing System may use the aircraft address to associate ADS-B reports to internal flight plan information when the internal flight plan information includes the aircraft address.*

IRec 9 : Recommendation: The ATC Processing System should be able to detect multiple aircraft using the same aircraft address and to provide an alert to the end user.

I.3.1.2 Aircraft Identification and/or Mode A code

IR 7 : The Transmit Aircraft Domain shall provide an ADS-B message containing the aircraft identification and the Mode A code as per sections I.3.1.2.1 and I.3.1.2.2. (OR 1 :, OR 4 :)

IRec 10 : **Recommendation:** The ATC Receive Subsystem should include the aircraft identification and/or Mode A code in an ADS-B report.

NOTE 1: *The ATC Processing System may use the aircraft identification /Mode A code to associate ADS-B reports to internal flight plan information.*

NOTE 2: *The ATC Processing System may use the aircraft identification /Mode A code to associate ADS-B reports to internal flight information (e.g., to a radar track).*

I.3.1.2.1 Aircraft Identification

As per ICAO Doc. 4444, PANS/ATM the following definitions has to be applied by the Transmit Aircraft Domain:

- *(Chapter 1, Definitions) 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',*
- *(Appendix 2, 2.2) one of the following aircraft identifications, not exceeding 7 characters:*

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

  b) 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).

IR 8 : When the aircraft identification capability is available in the airborne system, the Transmit Aircraft Domain shall provide this information in the ADS-B messages. (OR 4 :)

IR 9 : The ADS-B Transmit System shall send the Aircraft Identification as alpha-numeric with no spaces in between. Valid characters are A-Z, 0-9, and trailing spaces.

I.3.1.2.2 Mode A code

NOTE: *The Mode A code is intended to improve the association capabilities for the Ground Domain to ease association, for example in transitions between NRA and RAD areas.*

IRec 11 : **Recommendation:** When the ADS- B message definitions permit and when the information is available in the airborne system, the Transmit Aircraft Domain should transmit an ADS-B message containing the mode A code.

NOTE 1*: In the US airspace the provision of the Mode A code is mandated (TSO-C166).*

I.3.2 POSITION

The position information is represented by

- Horizontal position (Latitude and Longitude),
- Barometric altitude,

- Quality indicators.

IR 10 : The Transmit Aircraft Domain shall transmit position information in a form that can be translated, without loss of accuracy and integrity, to latitude, longitude, and barometric altitude.

I.3.2.1 Horizontal position (Latitude and Longitude)

IR 11 : The Transmit Aircraft Domain and the ADS-B Receive Subsystem shall reference all geometric position elements to the WGS-84 ellipsoid.

NOTE: *The safety and performance requirements are given in sections 3.1.4 and 3.3.6 of the SPR.*

I.3.2.2 Barometric altitude/geometric height

NOTE: *For the ADS-B-NRA application, the barometric altitude is required as essential information for the end user in the separation services.*

IR 12 : The Transmit Aircraft domain shall transmit at least the barometric altitude. (OR 1 :)

NOTE : *Specifications permit that aircraft systems may report*

a) only barometric altitude (also called 'pressure altitude')

or

b)only geometric height which is also called 'GNSS height'

or

c)barometric altitude and the difference between barometric altitude and geometric height

IR 13 : The Transmit Aircraft Domain shall formulate altitude measurements as barometric altitude relative to a standard pressure of 1013.25 hectopascals (29.92in Hg).

IRec 12 : **Recommendation:** The aircraft system should provide a manual deselection of the barometric altitude.

IR 14 : The ADS-B Receive Subsystem shall distinctly mark in the report containing altitude/height whether this information is derived from a barometric or geometric source. This will allow the end user to distinguish between the different parameter indicators.

IR 15 : The ADS-B Receive Subsystem shall interpret barometric altitude as altitude relative to a standard pressure of 1013.25 hectopascals (29.92in Hg).

NOTE 1: *When used, geometric height (HAE) has to be interpreted by aircraft and ground systems as the height above the surface of the (WGS84) ellipsoid.*

NOTE 2: *As per Annex 10,VOL IV (4.3.9.3.1) it is recommend to use a source providing a resolution finer than 7.62 m (25 ft).*

IRec 13 : **Recommendation:** Gilham altitude encoders should not be used by aircraft implementations.

IR 16 : For separation purposes only barometric altitude shall be used by the ATC processing system. (OR 2 :)

NOTE 1: *The safety and performance requirements for barometric altitude are given in sections 3.1.5 and 3.2.4 of the SPR.*

NOTE 2: *No safety and performance analysis for geometric height has been done in the SPR.*

I.3.2.3 Quality Indicators

NOTE 1: *Quality Indicators are used by the ATC Processing System to determine whether the report (and therefore the derived target position) can be used to support the intended functions such as the separation task.*

NOTE 2: *In the following material the term HPL represents an integrity containment parameter on horizontal position derived from a GNSS source or an equivalent containment for horizontal position provided from other sources providing integrity containment monitoring such as RNP qualified FMS.*

NOTE 3: *In the case of other sources than GNSS the probability associated with the containment parameter has to be consistent with the safety requirements.*

IR 17 : The Transmit Aircraft Domain shall provide an indication of quality for the position information. (OR 1 : & OR 8 :)

IRec 14 : **Recommendation**: The ADS-B Transmit function should send accuracy and integrity as independent items (as defined per DO-242A).

IR 18 : The indicators used shall be either NUC as specified in DO-242 or NIC, NAC and SIL as specified in DO-242A.

NOTE 1: *DO-242 and DO-242A also define the relationship between these parameters and the HPL and HFOM indicators when the parameters are derived from a GNSS source.*

NOTE 2: *In the NIC/NAC/SIL environment, when HPL is not available, NIC is set to 0.*

IR 19 : When NUC is used, the aircraft installation and design shall provide HPL to the ADS-B transmit function.

IR 20 : When HPL and HFOM are provided, the ADS-B transmit function shall give priority to HPL.

IR 21 : When receiving NUC, as per analysis provided in Annex G the following thresholds shall be required in the ground domain for the provision of the ATC services: for enroute NUC=4, for TMA NUC=5.

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NOTE: *This translation into NUC values is representing the current state of the ADS-B-NRA SPR requirements*

IR 22 : When receiving NIC and NAC, as per analysis provided in Annex F the following thresholds shall be required in the ground domain for the provision of the ATC services: for enroute NIC=4 and NAC=6, for TMA NIC=6 and NAC=7.

NOTE: These values are representing the current state of the ADS-B-NRA SPR requirements.

IRec 15 : **Recommendation:** The ATC Processing System should be able to monitor degradation of the quality indicators received from each aircraft and to provide an alert to the end user.

NOTE 1: *In cases when the GNSS receiver is unable to generate HPL (e.g.: at GNSS start-up or when there are less than 5 satellites visible to calculate HPL), HFOM may be provided and used to calculate a NUC value.*

As per analysis provided in Annex H the risk of this appearance is not higher than using HPL as basis.

NOTE 2: *When a ground system accepts aircraft installations providing NUC, a safety analysis has to show whether the risk of HPL not being available is acceptable or whether ground means to provide an indication of integrity have to be made available.*

IR 23 : A distinction between NUC and NIC/NAC/SIL airborne implementations shall be provided by the Transmit Aircraft Domain.

IRec 16 : **Recommendation:** The NUC/NIC values should be determined using the HPL value of a DO-208 GNSS receiver or a DO-229C GNSS receiver or equivalent.

IRec 17 : **Recommendation:** The NAC values should be determined using the HFOM value of a DO-208 or a DO-229C GNSS receiver or equivalent.

NOTE 1*: When the ADS-B Transmit Function cannot calculate SIL, SIL is set to value of 2 for GNSS installations with software/hardware assurance level C or else SIL is set to 0.*

NOTE 2: *The safety and performance requirements given above are deriven from the information given in sections 3.1.6 and 3.3.7 of the SPR.*

I.3.3 EMERGENCY/SPI INDICATORS

I.3.3.1 Emergency Indicators

IR 24 : The aircraft system shall provide to the Transmit Aircraft Domain an indication when one or more emergency condition(s) is set (OR 1 :)

IR 25 : The Transmit Aircraft Domain shall provide an indicator when the aircraft system is indicating that it is in an emergency mode. (OR 1 :)

IR 26 : When the aircraft system provides distinct emergency functionality, the appropriate indicator(s) shall be transmitted when the crew selects an emergency code, as defined in the Emergency procedures of ICAO Amendment 77, Annex 10, VOL IV, § 2.1.4.2 and 2.1.4.3 (mode A code 7500, 7600, or 7700). (OR 14 :)

IR 27 : The Transmit Aircraft Domain shall transmit the Emergency indicator(s) for as long as the emergency code is selected.

IRec 18 : **Recommendation:** Avionics providers should implement distinct Emergency indicators.

IR 28 : The Ground Domain shall use the Emergency indicators provided in ADS-B-NRA reports to indicate an emergency state to the end user (controller).(OR 15 :)

IR 29 : When distinct Emergency indicators are provided, the distinct indications shall be provided to the Ground Domain. (OR 15 :)

NOTE: *The safety and performance requirements are given in sections 3.1.7 and 3.3.8 of the SPR.*

I.3.3.2 Special Position Identification (SPI)

NOTE: The SPI is intended to improve the identification capabilities of a given target for the Ground end user (controller).

IR 30 : When the aircraft system provides this functionality, the Transmit Aircraft Domain shall send an indicator when the special position identification (SPI) is set. (OR 1 :)

IR 31 : When provided by the Transmit Aircraft Domain, the Ground Domain shall use the SPI information provided in ADS-B-NRA reports to indicate the state to the end user (controller).(OR 1 :)

I.3.4 GROUND VELOCITY

NOTE: *For the ADS-B-NRA application, the ground velocity is required as essential information for the end user. In current ground implementations, ground velocity is determined by the system from successive radar position updates.*

IRec 19 : **Recommendation:** When the link technology provides aircraft derived ground velocity, the data should be used by the Ground Domain.

NOTE 1: *It has to be recognised that ground velocity received within ADS-B messages will likely become a requirement for other applications.*

NOTE 2: No *safety and performance analysis for this parameter has been done in the ADS-B-NRA SPR.*

I.3.5 OTHER GROUND DOMAIN SPECIFIC REQUIREMENTS FOR THE ADS-B-NRA APPLICATION

IRec 20 : **Recommendation**: The ADS-B-NRA Ground Domain should provide an indication whether the ADS-B-NRA function (i.e. affecting all a/c) is working properly or not.

IRec 21 : **Recommendation:** The functionality indication should take into consideration all subsystems of the ground installation.

IRec 22 : **Recommendation**: The ATC Processing System should contain an ageing function for information derived from the ADS-B-NRA application.

IRec 23 : **Recommendation:** The ATC Processing System should ensure that reports with an age exceeding a defined value are not displayed any longer.

IRec 24 : **Recommendation:** The ATC Processing System should contain a monitoring function to detect mismatches between the ATC clearance and ADS-B reported altitude.

IRec 25 : **Recommendation:** The ATC Processing System should contain a monitoring function to detect and filter inaccurate ADS-B reported altitude.

Note: *This recommendation does not replace the verbal altitude verification procedure described in ICAO Doc. 4444, PANS/ATM.*

Annex J ADS-B-NRA Interoperability Requirements for 1090 MHz Extended Squitter

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J.1 GENERAL INFORMATION ON 1090 MHZ EXTENDED SQUITTER ADS-B

NOTE 1: *For the Mode S Extended Squitter definitions, DO-260/ED-102 is equivalent to ICAO Annex 10, Amendment 79,VOL III and Amendment 77, VOL IV. For the purpose of this document both references are addressed to ease understanding for the reader.*

NOTE 2: *The aircraft transmit function referenced in this document are assumed to be compliant with equipage classes A or B of either D-260/ED-102 or DO-260A.*

NOTE 3: *Specifically it is assumed that the physical layer (e.g. output interfaces such as antenna diversity and power requirements) meets a certain level of capability for the transmission of the ADS-B signal . This applies to extended squitter capable transponders and non-transponder devices. ICAO Annex 10, Volume IV, Chapter 2, section 2.1.5 and 3.1.1.7.11 and DO-260A, Table 2-3 and 3.3.1 refers to the antenna and power capabilities. Other physical layer characteristics should meet sections of ICAO Annex 10, Volume IV or sections 2 and 3 of DO-260A, where applicable.*

J.1.1 BROADCAST MESSAGE CHARACTERISTICS

This section describes data formats and control parameters that shall be used for communications using Mode S specific services on 1090 MHz media.

The format characteristics of ADS-B messages (DF = 17 or DF = 18) shall be as defined in the figure below, extracted from Figure 2-2 in DO-260A,.

NOTE: *Figure 2.2 of DO-260/ED-102, and §3.1.2.8.6 of ICAO Annex 10, Amendment 77, VOL IV are identical.*

BITS	**1 – 5**	**6 – 8**	**9 – 32**	**33 – 88**	**89 – 112**
DF = 17	DF (5 bits)	CA (3 bits)	AA (24 bits)	ME (56 bits)	PI (24 bits)
DF = 18	DF (5 bits)	CF (3 bits)	AA (24 bits)	ME (56 bits)	PI (24 bits)

DF: Downlink format 17 reserved for extended squitter in transponder type equipment and downlink format 18 is reserved for extended squitter in non-transponder type equipment.

CA/CF: Capability field

AA: ICAO 24 bits address

ME: Message extended squitter

PI: Parity/Identity

The content of BDS registers (Comm-B Data Selector) described in this INTEROP document is inserted in the ME field as per DO-260/ED-102 §2.2.3.2.1.6, ICAO Annex 10, Amendment 77 VOL IV §3.1.2.8.6.3 and DO-260A §2.2.3.2.1.6

BDS registers content is defined in DO-260/ED-102 Tables A-1 to A -12, ICAO Annex 10, Amendment 79, VOL III, appendix to chapter 5, tables 2-5 to 2-9 and 2-97 to 2-101. Definitions of BDS content is also defined in DO-260A, tables A-1 to A-12.

Each BDS register is structured as indicated below:

DF = 17/18	DF (5 bits)	CA/CF(3 bits)	AA (24 bits)	ME (56 bits)	PI (24 bits)

Type Code (5 bits)	Data / parameters (51 bits)

The type code indicates the type of message transmitted, and thus the type of data in the "data / parameters" field. The type code is defined in DO-260/ED-102 Table A-2/ICAO Amendment 79, VOL III, §2.3.1 and table A-2 in DO-260A.The table below indicates the correspondence between the type code and the message type.

The type codes in bold form part of the ADS_B-NRA application and are further elaborated in the following sections.

Type Code (5 bits)	Message type
0	No Position Information
1 to 4	**Identification (BDS 0,8)**
5 to 8	Surface position (BDS 0,6)
9 to 18 and 20 to 22	**Airborne position (BDS 0,5)**
19	Airborne velocity (BDS 0,9)
23	Subtype 7: Mode A code
24	Surface System status
25 to 27	Reserved
28	Subtype 1: Extended squitter status (emergency status, BDS 6,1)
29	Subtype 0: Target state and status (BDS 6,2)
30	Reserved
31	Aircraft operational status (BDS 6,5)

Table I. 1: Type code definition

J.1.2 FORMAL DEFINITION

The minimum set of surveillance parameters required for the NRA application as described in the Annex H of this document are:

- **Identity** (containing at least the aircraft identification and/or Mode A code, and 24-bit address),
- **Position** (containing at least horizontal position, barometric height, quality indicators, and 24-bit address),

- **Emergency/SPI status** (containing at least the emergency status indicator, SPI, and 24-bit address).

NOTE: *additional parameters as transmitted and listed below may be used for the ADS-B-NRA application.*

J.1.3 SET OF PARAMETERS

The tables below summarize the parameters for NRA (minimum and additional requirements), and the reference to each document (ICAO Annex 10, Amendment 79 VOL III, DO-260/ED-102, and DO-260/ED-102A).

J.1.3.1 The minimum set of parameters that shall be provided to support the NRA application are:

Parameter		BDS register	DO-242		DO-242A
			ICAO Amendment 79, VOL III, App to chap 5	DO-260/ED-102	DO-260A
Aircraft identification		0.8	§2.3.4	§2.2.3.2.5	§2.2.3.2.5
SPI		0.5	§2.3.2.6	§2.2.3.2.3.2	§2.2.3.2.3.2
Emergency indicator		0.5	§2.3.2.6	§2.2.3.2.3.2	§2.2.3.2.3.2
Barometric altitude/geometric altitude		0.5	§2.3.2.4	§2.2.3.2.3.4	§2.2.3.2.3.4
Quality indicator		0.5	§2.3.1	§2.2.3.2.3.1	§2.2.3.2.3.1
Airborne Position	Latitude	0.5	§2.3.2.3	§2.2.3.2.3.7	§2.2.3.2.3.7
	Longitude	0.5	§2.3.2.3	§2.2.3.2.3.8	§2.2.3.2.3.8

Table I. 2: Minimum requirements for ADS-B-NRA application

J.1.3.2 Recommendation**: The following parameters should be transmitted to support ADS-B-NRA.**

Parameter	BDS register	DO-242		DO-242A
		ICAO Amendment 79, VOL III, app to chap 5	DO-260	DO-260A
Emergency status	6.1	Table 2-97	§2.2.3.2.7.9	§2.2.3.2.7.8
Airborne Ground Velocity	0.9	§2.3.5	§2.2.3.2.6	§2.2.3.2.6
Version Indicator	6.5	No definition	No definition	§A.1.4.10.5
Geometric height diff from baro Alt	0.9	§ 2.3.5.7	§2.2.3.2.6.1.15	§2.2.3.2.6.1.15

Table I. 3: Additional requirements for ADS-B-NRA application

J.1.3.3 **Recommendation:** The following parameter should be transmitted to support ADS-B-NRA in airspace that requires it.

Parameter	BDS register	DO-242		DO-242A
		ICAO Amendment 79, VOL III, app to chap 5	DO-260	DO-260A
Mode A code	Type 23, subtype 1	No definition	No definition	§2.2.3.2.7.3

Table I. 4: Requirement for specific airspace

NOTE: *Any message types defined in ICAO Annex 10, Amendment 79, VOL III, DO-260/ED-102 or DO-260A and given in Table I. 1 may be transmitted.*

J.1.4 AIRCRAFT IDENTIFICATION

J.1.4.1 When the flight identification is available, it shall be transmitted. The aircraft shall encode it in BDS 0.8 as defined in ICAO Annex 10, Amendment 79, VOL III, table 2-8.

J.1.4.2 **Recommendation:** When the flight identification is not available, the aircraft registration should be transmitted. The aircraft shall encode the flight identification in BDS 0.8 as defined in ICAO Annex 10, Amendment 79, VOL III, table 2-8

NOTE: *ADS-B Receive Subsystem must consider that in specific conditions neither flight identification nor aircraft registration may be provided.*

J.1.4.3 Characters used for flight identification or aircraft registration shall be encoded as defined in ICAO Annex 10, Amendment 77, VOL IV, § 3.1.2.9

NOTE: *For the sections above, the definitions in DO-260/ED-102 and DO-260A are identical as given in the reference above.*

J.1.4.4 The transmission rate of the Aircraft identification shall be as defined in DO-260/ED-102 or DO-260A, § 2.2.3.3.2.4

J.1.4.5 The Mode A code shall be encoded in BDS type 23, subtype 7, as defined in DO-260A, § 2.2.3.2.7.3

J.1.4.6 The transmission rate of the mode A code shall be as defined in DO-260A, § 2.2.3.3.1.4.4

J.1.5 SPECIAL POSITION IDENTIFICATION (SPI)

J.1.5.1 A special position identification shall be transmitted when the crew presses the IDENT button on ATC control panel, as defined in SPI procedures of ICAO Annex 10, Amendment 77, VOL IV, § 3.1.1.6.3

J.1.5.2 The activation of the SPI shall change the encoding of the surveillance status field in the airborne position message (BDS 0.5), as defined in ICAO Amendment 79, VOL III, appendix to chapter 5, § 2.3.2.6, and table 2-5.

NOTE: For the sections above, the definitions in DO-260/ED-102 and DO-260A are identical as given in the reference above.

J.1.5.3 The SPI transmission rate shall be as defined in DO-260/ED-102 or DO-260A §2.2.3.3.2.2.

J.1.5.4 The surveillance status field shall indicate the special identification during a period between 15 to 30 seconds, as defined in ICAO Annex 10, Amendment 77, VOL IV, § 3.1.1.7.13

J.1.6 HORIZONTAL (AIRBORNE) POSITION (LATITUDE AND LONGITUDE)

J.1.6.1 Airborne position shall be encoded as per ICAO, Annex 10, Amendment 79 VOL III § 2.3.2

NOTE: *For the section above, the definitions in DO-260/ED-102 and DO-260A are identical as given in the reference above.*

J.1.6.2 Airborne position shall be referenced to WGS-84.

J.1.6.3 The transmission rate of airborne position shall be as defined in DO-260/ED-102 or DO-260A §2.2.3.3.2.2.

J.1.7 QUALITY OF INFORMATION

NOTE: *In the following material the term HPL represents an integrity containment parameter on the horizontal position derived from a GNSS source or an equivalent containment for horizontal position provided from other sources such as FMS.*

J.1.7.1 For implementations following DO-260/ ICAO Annex 10 VOL III, the Quality of information data is called NUC and is encoded in the Type code of the DF17/18 messages (see ICAO Annex 10, Amendment 79, VOL III, §2.3.1)

NOTE: *For the section above, the definition in DO-260/ED-102 is identical as given in the reference above.*

J.1.7.2 When NUC is used, the aircraft installation and design shall provide HPL to the ADS-B transmit function.

J.1.7.3 For implementations following DO-260A, the Quality of information data shall be determined from NIC, NAC & SIL.

J.1.7.4 NIC & SIL shall be encoded as defined in DO260A §2.2.3.2.3.1.1.

J.1.7.5 NAC shall be encoded as defined in DO-260A §2.2.3.2.7.2.7.

J.1.8 EMERGENCY INDICATORS

J.1.8.1 General indicator

J.1.8.1.1 The aircraft shall send an indicator when it is in emergency mode in BDS 0.5

J.1.8.1.2 At least the selection of code 7500, 7600 or 7700 on ATC control panel shall change the encoding of the surveillance status field in airborne position message, as defined in ICAO Amendment 79, VOL III, appendix to chapter 5, § 2.3.2.6, and table 2-5

NOTE: *For the section above, the definitions in DO-260/ED-102 and DO-260A are identical as given in the reference above.*

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J.1.8.2 The transmission rate for emergency indicators shall be as defined in DO-260/ED-102 or DO-260A §2.2.3.3.2.2.

J.1.8.3 Specific emergency indicators

J.1.8.3.1 **Recommendation:** Specific emergency type should be transmitted in BDS 6.1 subtype 1.

J.1.8.3.2 The specific emergency indicator shall be encoded as defined in ICAO Annex 10 Amendment 79 VOL III appendix to chapter 5, § 2.3.8, and table 2-97.

J.1.8.3.3 The transmission rate of BDS 6.1 shall be as defined in DO-260A §2.2.3.3.2.6.3

NOTE: *For the sections above, the definitions in DO-260, DO-260A and Annex 10 Amendment 79, VOL III are identical as given in the reference above.*

J.1.9 BAROMETRIC ALTITUDE/GEOMETRIC HEIGHT

J.1.9.1 Barometric altitude/geometric height shall be encoded as per ICAO Annex 10, Amendment 79, VOL III, § 2.3.2.4

NOTE: *For the section above, the definitions in DO-260/ED-102 and DO-260A are identical as given in the reference above.*

J.1.9.2 The transmission rate for barometric altitude/geometric height shall be as defined in DO-260/ED-102 or DO-260A §2.2.3.3.2.2.

J.1.10 GEOMETRIC HEIGHT DIFFERENCE FROM BAROMETRIC ALTITUDE

NOTE: *Geometric height difference between barometric altitude and geometric height is not a parameter of the minimum subset and it is not mandated for the ADS-B-NRA application.*

J.1.10.1 When provided, the Geometric height difference from barometric altitude shall be encoded as per ICAO Annex 10, Amendment 79, VOL III, § 2.3.5.7

NOTE: *For the section above, the definitions in DO-260 and DO-260A are identical as given in reference*

J.1.10.2 When provided, the transmission rate for geometric height difference from barometric altitude shall be as defined in DO-260 or DO-260A § 2.2.3.3.2.5

J.1.11 GROUND VELOCITY

NOTE: *Ground velocity is not a parameter of the minimum subset and it is not mandated for the ADS-B-NRA application.*

J.1.11.1 Ground velocity shall be encoded as per ICAO, Annex 10, Amendment 79, VOL III, § 2.3.5, subtype 1 and 2

NOTE: *For the section above, the definitions in DO-260/ED-102 and DO-260A are identical as given in the reference above.*

J.1.11.2 The transmission rate for ground velocity shall be as defined in DO-260/ED-102 or DO-260A §2.2.3.3.2.5.

NOTE: *The quality indicator for velocity (NACv) is out of the scope of this document.*

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J.1.12 VERSION INDICATOR (DISTINCTION BETWEEN ICAO ANNEX 10, AMENDMENT 79,

J.1.13 VOL III AND DO-260A AVIONICS IMPLEMENTATIONS)

J.1.13.1 The indication that the installation is compliant with DO-260A shall be provided in the field "version number" in BDS 6.5, as defined in DO-260A §A.1.4.10.5.

J.1.13.2 The transmission rate for BDS 6.5 shall be as defined in DO-260A §A.1.4.10.1.

J.1.13.3 The ADS-B Receive Subsystem shall use the value of version number field in BDS 6.5 to distinguish a DO-260/Annex 10 Amendment 79 VOL III from a DO-260A compliant installation.

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Appendix A Acronyms

ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance - Broadcast
AIW	Area Infringement Warning
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Service
CNS/ATM	Communication, Navigation, and Surveillance/ Air Traffic Management
CWP	Controller Working Position
ER	En Route
FDPS	Flight Data Processing System
FIR	Flight Information Region
GNSS	Global Navigational Satellite System
GPS	Global Positioning System
HF	High Frequency
ICAO	International Civil Aviation Organisation
MSAW	Minimum Safe Altitude Warning
NEAN	North European ADS-B Network
NRA	Non Radar Airspace
NUP	NEAN Update Programme
OPA	Operational Performance Assessment
OSA	Operational Safety Assessment
OSED	Operational Services and Environment Description
PANS	Procedures for Air Navigation Services
PSR	Primary Surveillance Radar
SAR	Search And Rescue
SDPD	Surveillance Data Processing and Distribution system
SID	Standard Instrument Departure
SPI	Special Pulse Identification
SPR	Safety & Performance Requirements
SSR	Secondary Surveillance Radar
STCA	Short Term Conflict Alert
TMA	Terminal Area
VHF	Very High Frequency

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Appendix B Guidance material on ATC processing system for new implementation

Text to be further developed.

Gnd-Pro corrupts an ADS-B track during operations (erroneous ID)	1,00E-04 pH	SR 29 :	The likelihood that ground system corrupts ID for all aircraft received via ADS-B shall be no greater than 1E-04 per hour.
Gnd-Pro corrupts an ADS-B track during operations (erroneous position)	1,00E-04 pH	SR 30 :	The likelihood that ground system corrupts the position of an aircraft received via ADS-B shall be no greater than 1E-04 per hour.
Gnd-Pro corrupts all ADS-B tracks (erroneous position)	1,00E-04 pH	SR 31 :	The likelihood that ground system corrupts position for all aircraft received via ADS-B shall be no greater than 1E-04 per hour.
Gnd-Pro corrupts an ADS-B track at initiation (QI lower than real level)	1,00E-04 pH	SR 32 :	The likelihood that ground system corrupts quality indicator for an ADS-B track (QI lower than real level) shall be no greater than 1E-05 per hour.
Gnd-Pro corrupts an ADS-B track during operations (QI lower than real level)	1,00E-05 pH	SR 34 :	The likelihood that ground system corrupts quality indicator for all ADS-B track (QI lower than real level) shall be no greater than 1E-04 per hour.
		SR 33 :	QI has to correctly be determined by ground system for each track based on ADS-B messages received from aircraft.
Gnd-Pro corrupts an ADS-B track during operations (QI higher than real level)	1,00E-04 pH	SR 35 :	The likelihood that ground system corrupts quality indicator for all ADS-B track (QI higher than real level) shall be no greater than 1E-04 per hour.
Gnd-Pro corrupts all the ADS-B tracks (QI higher than real one)	1,00E-04 pH	SR 36 :	The likelihood that ground system corrupts quality indicator for all ADS-B track (QI higher than real level) shall be no greater than 1E-04 per hour.
Gnd-Pro corrupts an ADS-B track during operations (erroneous altitude)	1,00E-05 pH	SR 37 :	The likelihood that ground system corrupts altitude for an ADS-B track shall be no greater than 1E-05 per hour.
Gnd-Pro partially process an ADS-B track during operations (no altitude)	1,00E-04 pH	SR 38 :	The likelihood that ground system does not provide altitude for an ADS-B Track shall be no greater than 1E-04 per hour.
No ground processing of one ADS-B track at initiation	1,00E-04 pH	SR 39 :	The likelihood that ground system does not process and provide data for an ADS-B

No ground processing of one ADS-B track	1,00E-04 pH		Track shall be no greater than 1E-04 per hour.
		SR 40 :	ADS-B coverage shall be assured/known in the controlled airspace
No ground processing of all ADS-B track	1,00E-04 pH	SR 41 :	The likelihood that ground system does not process and provide information for all ADS-B tracks shall be no greater than 1E-04 per hour.

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