ICAO Separation and Airspace Safety Panel

OPERATIONAL USE OF ADS-B
IN
NON RADAR AIRSPACE

GENERIC DESIGN SAFETY CASE

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1.0 Introduction

Use of Data-link in ATM

The successful implementation of new technologies in support of CNS/ATM concepts has resulted in many ground systems providing advanced platforms suitable for the introduction of new Air Traffic Management (ATM) systems based on the used of data-link and satellite technology. The main objective for air navigation service providers by implementing these new systems is to increase safety and efficiency to the aviation industry in a cost-effective manner.

New technology ground systems typically support Air Traffic Control functions in both radar and non radar airspace. However the level of services provided for these airspace types is dependent on the accuracy and quality of the data received for the aircraft operating in that airspace. Typically, in non-radar airspace, aircraft position and other related information are sent to the controller by voice whereby the corresponding flight records are then manually updated by controller inputs. In some systems, data-link applications such as CPDLC may permit automatic update of the ground system data.

In continental non-radar airspace air traffic is currently managed using procedural control or procedural flight information service. Many areas of the world are already experiencing delays due to the large separation standard imposed by procedural control. These delays could be reduced significantly and traffic services improved significantly by the introduction of a low cost surveillance system for these areas. A surveillance system of this type, linked to a new technology ground system, would also increase the safety for aircraft operating in these areas because it provides positive identification and allows safety net functionality such as short and medium term conflict alert, and minimum safe altitude warnings systems to be implemented.

An Automatic Dependent Surveillance Broadcast (ADS-B) based surveillance system is the most cost-effective surveillance system currently being implemented around the world. ADS-B systems are based on a function in the aircraft that periodically broadcasts its state vector and other relevant information. Ground stations are installed to receive and process the information broadcast by the ADS-B transponders. This information can then be sent to an Air Traffic Management system for integration with the existing automation system.

A number of States have already implemented or are in the process of trialling an ADS-B based surveillance system in non-radar airspace. The

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primary objective is to reduce delays and improve traffic services in these areas by adopting separation standards similar to those used for conventional SSR radar.

Initial safety analysis conducted by Eurocontrol [Eurocontrol Automatic Dependent Surveillance, Initial Safety Analysis Report, January 2000, TAG/20229/R02, Issues 1.0 by TA Group Ltd] on use of ADS-B indicates that the use of ADS-B as the sole surveillance system is potentially acceptable for low density / low complexity en-route airspace. Eurocontrol also say that it is more acceptable for those areas, which currently have no surveillance provision.

2.0 Scope

Identify safety requirements for implementation of ADS B in non radar airspace

The aim of this Safety Case is to identify and document generic safety requirements associated with the operational use by air traffic control of a surveillance system based on ADS-B in non-radar airspace.

Dependent surveillance (ADS-C) is already successfully used in a number of regions of the world, and specifically in the South Pacific for FANS 1 aircraft. The significant difference between ADS-C and ADS-B is the airborne equipage and reporting rate.

The ICAO SASP has developed a safety analysis based on a comparative assessment using a reference system methodology, to support the development of 'radar-like' separation minima to be used operationally with ADS-B surveillance. The comparative reference system proposed is a typical monopulse radar system. Such radars are more accurate than conventional Secondary Surveillance Radars (SSR) that have been used for many years to provide a 5 NM radar separation service. It should be noted that the performance characteristics of the conventional SSR were also very modest (e.g. poor accuracy and reliability) when compared to the newer monopulse radars.

The comparative assessment involves identifying the safety and performance requirements applicable to Monopulse SSR and then establishing equivalent or better requirements for the ADS-B based system.

The comparative assessment is included as Appendix 1 to this document.

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3.0 Operational Use and System Description of ADS B

3.1 ADS B in Operational Use

Increased safety in non radar airspace

The operational use of ADS–B in non-radar airspace will provide several significant benefits to air navigation service providers and to the safety of flying operations in such airspace. In many airspaces there may either be no surveillance services provided at all or none below certain flight levels/altitudes given current radar line of sight limitations. Examples are the Burnett Basin area of Queensland, Australia and Alaska, USA. Significant safety benefits will be provided to both pilots and air navigation service providers through the availability of ADS-B. These benefits include:

- Provision of 'radar-like' separation, navigation and advisory services available in areas where it is not provided today.
- More accurate traffic information available to both ATC and aircrew.
- The early visibility of aircraft therefore enhancing the situational awareness of the controller.
- Availability of user preferred tracks and better access to optimum levels as compared to procedural control.
- Reduction in delays for aircraft transitioning from un-controller to controlled airspace.
- Safety improvement brought about by an expansion of the safety net functionalities of radar surveillance airspace (e.g. STCA, MSAW, etc) to airspace where radar is not available.
- Reduced cockpit workload by negating pilot position reporting.

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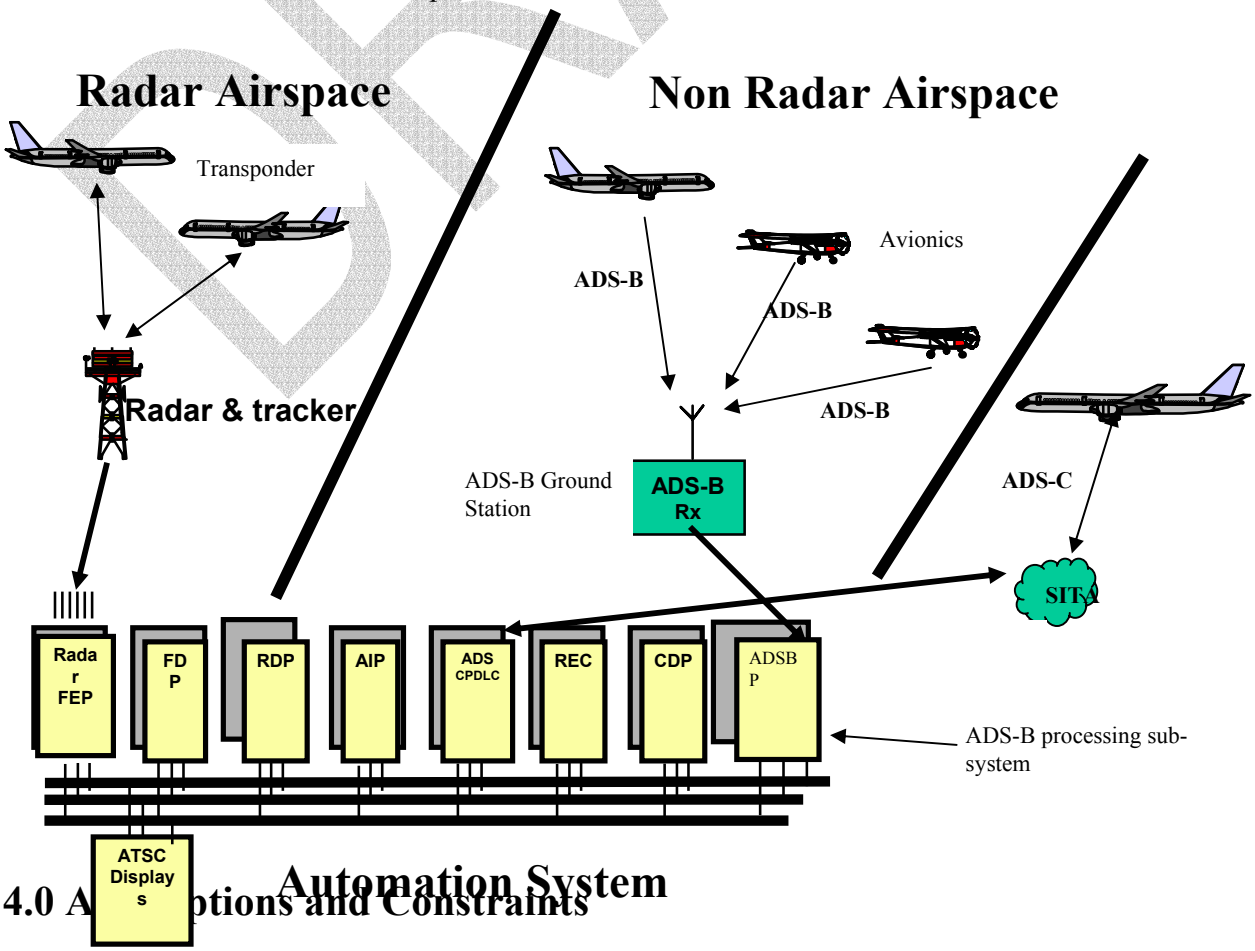
3.2 ADS B System Description

A simple, reliable system

The ADS-B based surveillance system basically comprises of aircraft fitted with an ADS-B transponder broadcasting its state vector and related information at a pre-defined rate (typically once every second). The broadcast message will as a minimum, include:

- aircraft identification
- positional data
- altitude
- velocity vectors
- positional integrity information

A series of ground receivers positioned at appropriate locations, receive this broadcast message and then forward it to the automated ground system for processing and display to controllers. The diagram below provides an overview of typical surveillance systems used in radar and non-radar airspace.



4.0 Assumptions and Constraints

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Use in areas not covered by radar

ADS-B based surveillance system will only be used in airspace not currently covered by radar control. Radar will still be the primary surveillance system and ADS-B data will not be used when radar data is available. Therefore ADS-B will enhance safety by providing surveillance where there is none today.

The proposed separation minimum for use in airspace where ADS-B surveillance is available will be the same as that used in en-route airspace where SSR radar surveillance exists. The separation minimum for en-route SSR radar is 5 NM. This minimum has been used with previous generations of conventional SSR radars (RSR) operated at rotation rates of 5 rpm with ranges of approximately 160 NM. The same minimum continues to be used today with newer technology monopulse radars.

Safety analysis in support of this safety case will be by conducting a comparative assessment on the performance of conventional SSR radars (and/or monopulse radars) against a typical ADS B system.

The 5 NM separation minimum will only be used when the data from ADS B has an accuracy performance of Navigational Uncertainty Categories (NUC) equal of better than 5.

5.0 Systematic Risk Assessment

Comparative analysis against SSR

The risk assessment will be based on:

a) conducting a comparative analysis of the ADS B system performance with current Secondary Surveillance Radar (SSR)
b) conduct of hazard identification process

5.1 Comparative analysis with SSR

Initial comparative analysis with conventional SSR used by one State

The calculated error for the conventional SSR radar (RSR) used by one State, at a distance of 160 NM from the radar head was in the order of + or – 0.77NM. [1] at 3 sigma.

The azimuth resolution performance of the RSR at a distance of 160 NM range was 12.6NM.[1]

The accuracy performance provided by the ADS-B surveillance system for an aircraft with Navigational Uncertainty Categories (NUC) level of 5 is <0.25 (95%) or <0.46 NM [2] at 3 sigma for the horizontal error.

The above clearly shows that the accuracy performance of the ADS-B based surveillance system far exceeds the performance of old technology radars used in the en-route environment. Table 1 provides a comparison of the performance between an ADS-B based and conventional SSR radar based surveillance system.

In addition, the ADS-B based surveillance system, broadcasts at a rate of once every second and does not suffer from the ability to resolve more than one aircraft at the same location.

Many States have replaced older conventional SSR radars (RSR) with modern Monopulse SSR radars. These new Monopulse SSR radars provide improved accuracy and operate at higher rotation rates, typically in the order of 16 rpm. However, the separation minimum of 5NM used in en-route radar airspace remains unchanged.

A common operational availability requirement for Monopulse SSR radar is equal to or better than 0.9995. This figure does not take into account power, air conditioning and other auxiliary systems. The

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figure also does not include the SSR transponder in the aircraft.

In this safety case, an operational availability requirement similar to the Monopulse SSR radar will be specified for the ADS-B based surveillance system. An operational availability of 0.9995 will be required for the ADS-B ground station. A comparative end to end operational availability requirement prediction for the ADS-B system will be conducted as part of the safety analysis.

The UK NATS Risk Model will be used for classifying the likelihood, consequences and risk class associated with the hazards identified.

Conventional SSR (RSR) radar using a 5NM separation standard	**Monopulse SSR radar**	**ADS-B based surveillance system**
Position measurement by radar	Position measurement by radar	Position measurement by avionics
Reporting rate of once every 12 seconds (rotation rate of 5 rpm)	Reporting rate of once every 3.64 seconds (rotation rate of 16.4 rpm) Controller update rate of once per 5 seconds is used	Broadcast rate of every sec with controller update rate of once per 5 seconds
Accuracy performance of + or – 0.77 NM at 3 sigma @ 160NM range	Non manoeuvre accuracy performance of + or – 0.65 NM at 3 sigma at 250 NM range	Accuracy performance equal to or better than 0.46 NM at 3 sigma for NUC level 5 and above. TSO equipment will flag loss of accuracy or integrity
Azimuth resolution performance : 2 aircraft separated by 12.6 NM @ 160 NM range can't be resolved	Azimuth resolution performance : 2 aircraft separated by 4 NM @ 250 NM range can't be resolved	Azimuth resolution problem does not exist. Aircraft at same location can be resolved.
Reliability and Availability performance for radar and transponder based on 1960's technology with mechanical and rotating components.	Reliability and Availability performance for radar and transponder based on 1990's technology with mechanical and rotating components.	Reliability and Availability performance based on modern electronics components with no mechanical and rotating components.

TABLE 1 – Comparison of ADS-B and SSR Radar used by one State

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A detailed comparison is provided in the working paper in Appendix 1. This working paper is subject to change as more information is obtained, catalogued and assessed.

5.2 Hazard Identification

Hazard Identification

The safety requirements associated with the operational use of ADS-B based surveillance system for non-radar airspace were derived from the hazard identification processes undertaken by some States already implementing ADS-B systems. These processes included Functional Hazard Assessment (FHA) based on a structured brain storming exercise by a group of experienced senior operational controllers and system engineers.

The hazards and the associated safety requirements detailed at Appendix 2 are included for ongoing review by SASP as part of their work in developing safety assessments for introduction of ADS-B separation minima. The hazard identification process will continue through the panels development work and is intended to permit the capture of additional hazards identified by SASP.

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6.0 Potential Mitigators and Safety Requirements

Safety requirements derived from hazards identified

The safety requirements derived from the hazard identification process are detailed at Appendix 2. These will be expanded as work continues within SASP in deriving ADS-B safety assessments.

This Safety Case will provide evidence and arguments to demonstrate that the safety requirements can be met by States implementing ADS-B systems.

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APPENDIX 1 – ADS B COMPARISON TO RADAR WORKING PAPER

APPENDIX 2 – HAZARD LOG

APPENDIX 3 – AMENDMENT PROPOSAL FOR PANS-ATM Doc 4444

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APPENDIX 1
ADS B COMPARISON TO RADAR WORKING PAPER

Appendix 1 is subject to change as more information is obtained, catalogued and assessed.

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1. COMPARATIVE ASSESSMENT BETWEEN RADAR AND ADS-B

1.1 **Principle Characteristics.** The key pieces of data provided by an ATC Radar to a Controller and their origin for both Radar and ES-ADS-B is summarised in the table below:

(Shaded areas indicate that ADS-B and Radar are the same)

DATA	RADAR (SSR)	ADS-B
Position	Radar itself measures range and azimuth	Down-linked from aircraft
Altitude	Down-linked from aircraft (Mode C)	Down-linked from aircraft
Identity	Down-linked from aircraft (Mode 3/A and use of Special Purpose Ident)	Down-linked from aircraft (Unique 24-bit address and flight identity)
Velocity Vector	Computed from successive position determinations	Down-linked from aircraft (more responsive)
Emergency Alerting	Down-linked from aircraft (Reserved Mode A codes)	Down-linked from aircraft (Contained in status field)

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COMPARATIVE ELEMENT	RADAR	ADS-B
Position.	Radar measures an aircraft's position in range and bearing. Range is measured by accurate measurement of elapsed time from transmission of an interrogation to the time of reception of the reply from the aircraft. The azimuth (bearing) of the aircraft is determined by the direction the very narrow beam-width antenna is facing. In modern monopulse radar the azimuth within the beam is also determined to further increase bearing measurement accuracy. Radars measure accurately the range but azimuth is measured in angle and hence at long range has lower linear accuracy than range. Air Traffic Controllers assess and utilise the presented radar positional data in the context of the complete traffic management picture. ATC is not based on the presentation of a single positional data report (measurement). Rather, the history of the track together with the most recent data is used to predict where the aircraft will be in the future. Controllers also use other information such as knowledge about aircraft intent and the clearances issued to modify their perception of the data presented. No tool is perfect, and controllers use radar as a significant tool, but take account of its strengths and limitations. Radars measure position in range and azimuth. The range noise errors are 0.125 Nm (1Σ) and the noise errors in azimuth are 0.08 degrees (1 Σ). Since GPS (ADS-B) errors are expressed with respect to a 95% confidence, this paper will use 2.00Σ (95% assuming Gaussian distribution of errors) - namely a 0.16 degree error. In addition to	In an ADS-B system, positional data is determined by the aircraft's navigation system and broadcast to the ground station. Hence the accuracy of the positional data is a property of the aircraft's navigation system which is further explored below. The positional accuracy of ADS-B is determined by the navigation system in the aircraft. For high-end aircraft this is typically FMS/IRS/GPS. These navigation systems have a knowledge of the accuracy of the aircraft position report and this is passed as figure of merit to the ground system which can exclude reports of insufficient accuracy. Similarly GPS based navigation systems can determine figure of merit based on satellite geometry. The accuracy of the ADS-B positional data is not a function of the distance between the aircraft and the ground station. Where the aircraft is very close to a radar site the radar accuracy may exceed the ADS-B accuracy. ATC procedures and separation standards are developed to allow for worst case conditions. Therefore the separation standards allow for the low accuracy of radars at longer ranges. In the case of ATC radar like services using ADS-B, an integrity level of 10^{-7} for a position error of < 0.5 Nm is equivalent or better than existing radar systems which clearly have a possible error of 0.25 Nm @ 95 percentile certainty.

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	these errors one must consider systematic errors of alignment. Radars are typically maintained with an alignment accurate to +-0.044 degrees in azimuth. Azimuth errors are clearly the dominant error, and can be translated into positional errors as follows: Taking into account the random noise errors only: At 50 Nm the 0.16 degree error results in a position error of 0.14Nm At 200 Nm this error has risen to 0.56Nm and to 0.70Nm at 250 Nm Systematic errors of +/- 0.2Nm at 250Nm from the radar also need to be considered. In many monopulse SSR systems, azimuth errors are a function of the received signal strength. Strong signals allow monopulse azimuth determination to work very well whereas at very low signal strength, signal noise causes a significant deterioration. For low signal strength SSR detection (limit of coverage), the positional error could exceed the above values. No "real time" measurement of accuracy over the total coverage area is maintained. Real time monitoring of a single pseudo aircraft (site monitor) gives a degree of comfort that the measurement accuracy is within normal bounds. It is assumed that a commissioned radar continues to deliver accurate positional data within the total coverage area independent of environmental constraints. The reality is that radar is affected by a	

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	large range of phenomena which corrupt the positional data to some extent. These corruptions are typically the result of multipath reflection of radar signals and the "bending" of the beam around obstacles. Transient positional errors are experienced as aircraft fly through regions subject to the phenomena. These errors can result in moderately large position errors up to 0.5 Nm.	
Altitude	A SSR radar does not measure the aircraft's Altitude. Rather the radar interrogates the aircraft's transponder with a request for Flight Level. In response the Transponder replies with the Flight Level as measured by a Barometric Pressure Encoder. For a Mode C reply, the unit of encoding is 100 feet, for a Mode S reply the unit is 25 feet.	In the ADS-B system, the ADS-B transponder spontaneously transmits the exact same information as for a Mode S Transponder. Thus, for Altitude information, there is no distinction between Radar and ADS-B.
Identity	SSR radar does not measure the aircraft's Identity. Rather the radar interrogates the aircraft's transponder with a request for Identity (Mode-A code). In response, the Transponder replies with the Mode-A code entered on the transponder control panel by the pilot. The Controller or the radar display system translates the Mode-A code to a Flight Identity. There is a limited number of Mode-A codes (4096 – some reserved). This may lead to ambiguity in aircraft identification. Special Purpose Ident (SPI) can be activated by the pilot upon controller request to aid in resolving such ambiguity.	In the ADS-B system, the pilot enters the Flight Identity into the control panel. The ADS-B transponder spontaneously transmits the Flight Identity. Provided Flight Identity is allocated uniquely, there can be no ambiguity. Also all Mode S ADS-B messages inherently contain the aircraft's unique 24-bit address. ATC automation systems can check for consistency between the Flight Identity and the airframe registration recorded in the Flight Plan.
Velocity Vector.	SSR radar determines Velocity Vector as a derivative of successive position measurements. Velocity Vector determined in this manner is of limited accuracy. Whenever the aircraft manoeuvres, the vector calculated by the radar lags	In an ADS-B system, velocity vector is determined by the aircraft's navigation system and broadcast to the ground station. Hence the accuracy of the velocity vector is a property of the aircraft's navigation system and typically considerably more

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	the true vector. This leads to a slow detection of an aircraft's commencement of a turn.	accurate and responsive than that calculated by radar.
Emergency alerting	SSR has three reserved Mode A codes to indicate three types of emergency (EMG, RAD, HIJ). SSR has three reserved Mode A codes to indicate three types of emergency (EMG, RAD, HIJ).	In an ADS-B system equivalent data is transmitted in the status field.
Update Rate	SSR update rate is determined by the antenna rotation speed. For Enroute radars this typically is in the range of once per 15 seconds to once per 4 seconds.	In an ADS-B system, positional data is broadcast twice per second. Thus as many as 7 out of 8 broadcast messages can be lost while maintaining the same update rate as high-update rate radar.
Multiple Target Resolution	A limitation of a Mode A &C SSR is encountered when two aircraft are at similar slant range and azimuth but adequately separated by altitude. In this case the transponder replies from the two aircraft overlap in time. When received by the radar, the radar may not be able to distinguish that there are two replies present. Thus only one aircraft is displayed. Radar sensors typically require at least 1.0 degree difference in azimuth to reliably resolve two aircraft. One degree at a range of 250 NM is more than 4 NM apart. Mode S radars, by use of selective interrogation, avoid this limitation.	ADS-B does not have a limited resolution capability. Multiple aircraft at exactly the same position will be fully resolved.
Coverage	SSR coverage is limited by the terrain and buildings around a radar site. The limitations are documented during radar commissioning tests. Controllers use radar with knowledge of its coverage limitations.	ADS-B is also subject to coverage limitations. The limitations will be documented during testing and Controllers will use ADS-B with knowledge of its coverage limitations.
Continuity of Service - Continuity is the	SSR failure causes controllers to transition to	ADS-B failure would also initiate a transition to

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probability of a system continuing to perform its function without unscheduled interruptions during the intended period of operation. Continuity is a function of the system design and the reliability of the various elements forming the system. The elements of the ADS-B system are essentially the same as the receiving portion of a radar system plus the source of positional data on board the aircraft.	procedural control for either a single aircraft (radar transponder failure) or for all aircraft (radar system failure).	procedural control for either a single aircraft (ADS-B transponder failure) or for all aircraft (ADS-B receiving system failure).
Reliability Reliability is a measure of the probability of unexpected loss of the surveillance service. The consequence of the loss may result in reversion to procedural control for either a single aircraft (avionics failure) or for many/all aircraft (sensor system wide failure). Reversion to procedural control for a single aircraft is identical to the treatment of non-ADS-B equipped aircraft. Planned loss of service has no safety impact since procedures are put in place to mitigate any operational impact before the loss of service occurs. An expected and planned for RAIM outage (where RAIM is available as part of the proposed ADS-B system), is treated as a planned loss of service. This can be achieved if controllers are notified in advance through a RAIM prediction notification as per existing GPS RAIM prediction services. Reliability is usually a function of the system design (eg: duplication) and the summation of the various equipment reliabilities. In can also be affected by inappropriate maintenance actions therefore training of staff can have an impact on		

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service reliability. Reliability needs to be considered in conjunction with the backup systems and alternative methods of achieving the operational objectives. In the radar environment, reliability is dependent on - aircraft avionics and supporting systems - ground sensors and supporting systems In the ADS-B environment, reliability is dependent on - reliability of the GPS signals in space (ie: GPS satellite availability) - aircraft avionics and supporting systems - ground sensors and supporting systems Reliability engineering considers the mean time between failure (MTBF) of various system elements to arrive at overall system reliability. The US Department of Defence standards define the procedures and accepted MTBF values for system components (resistors, capacitors etc). Manufacturers usually provide MTBF values for system elements based on the DoD methodology. **These methods do not account for software failures, nor do they account for system events such as human error and for example lightning. In the past two decades, human error and**		

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correlated events such as lightning have tended to become dominant. Protection against correlated events, software error and human error are normally provided through ensuring minimal exposure to single points of failure. However, comparison of systems by examining the reliability (rates of random failure) of each system remain a valid measure of performance between the systems. When comparing radar and ADS-B environments, reliability can be considered as a number of series elements, namely a) Space segment : The availability of GPS signals (in the ADS-B case) b) Avionics segment : The reliability of avionics and aircraft power systems c) The surveillance ground system : The radar ground station or the ADS-B ground station d) The link between the ATC system and the ground sensor e) The ATC display system For the purposes of this assessment, the ground system, links and display system will be calculated together.	✈ **Avionics** Based on a mean time between unit removal	✈ **Avionics** ADS-B Extended Squitter and modern Mode

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	(MTBUR) of transponder – range is 1370 to 3700 hours (as determined by one State) ✈ **Space** No equivalent	S transponders – MTBUR is approximately 3000 hours. ✈ **Space** In the context of ADS-B, a failure is an <u>unexpected</u> loss of positional data. To date, ADS-B ATM systems are exclusively reliant on GNSS systems, specifically GPS, for aircraft positional data. The US Government has published a "Global Positioning System Standard Positioning Service Performance Standard October 2001. The "availability" standard in this document is the only documentation giving a hint of unexpected failure rates. This standard provides a "Service Availability Standards" for an average location on the earth as >=99%. This standard defines the expected time that the GPS service can deliver a 36 metre signal in space solution. It includes both planned and unplanned outages. It also includes the predictable effect of constellation geometry. If the predictable failures are excluded, the service availability can be expected to be significantly higher than 99%. Given the difficulties in providing logistic support in space, exceptionally high satellite reliability is required to achieve this service availability.. The US Government also says : *In support of the service availability standard, 24 operational satellites must be available on orbit with 0.95 probability*

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	✈ **Ground station** MTBF calculated by one State as between 25 and 30 years based on MIL Standards using figures provided by the manufacturers. In practical terms these figures are not achievable. Non random failures such as lighting and human error swamp these figures.	*(averaged over any day). At least 21 satellites in the 24 nominal plane/slot positions must be set healthy and transmitting a navigation signal with 0.98 probability (yearly averaged)* This seems to state that the chance of having 21 satellites radiating is only 98%. This seems grossly underestimated. Field experience in the last 10 years has recorded no event whereby a satellite has unexpectedly failed leaving less than 24 satellites (*refer analysis at para* ***Error! Reference source not found. Error! Reference source not found.*** *which shows an analysis of actual GPS system performance derived from GPS NANU data over the period 1996-2002*). **It is concluded that no announced design system reliability figure is available which can be compared to radar.** ✈ **Ground station + Space** MTBF calculated by one State as approximately 30 years based on MIL Standards using figures provided by the manufacturers. The space component MTBF figure is based on Significant Outage (individual satellite) MTBF of 124 Months [with MTTR of 1 month], and Short term failure (individual satellite) MTBF of 7300 Hours [with MTTR 36 hours]. Also a constellation MTBF of 81 years based on 26 available satellites and 24 required.(J Durand & A Caseau, "GPS Availability, Part II:

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		Evaluation of state probabilities for 21 and 24 satellite constellations," *NAVIGATION: Journal of the ION, Vol 37, No. 3, Fall 1990*") and the "*GRAS Service availability Study Final Report*" prepared by ITT Industries/AES Communication Systems Integration Group).
Integrity. The integrity of data is the probability that the data, when not indicated to be in error, is in fact correct.	**Data-Link Integrity**. Both SSR and ADS-B information is data linked form the aircraft to the ground. Mode S ADS-B is an inherent part of the Mode S SSR system and hence has the same data-link characteristics as Mode S radar. Many of today's radars, which provide satisfactory service, use only Modes A & C. It is useful to compare the integrity of the Modes A&C and Mode S data-links. The Mode A (identity) and Mode C (pressure altitude) data is sent as a frame comprising 12 bits of information. The data is not protected by any parity, cyclic redundancy check (CRC) or any other inherent error detection mechanism. Radars attempt to detect transmission errors by checking for consistency of Replies from multiple interrogations. Error in the received identity (Mode A) could mislead either the controller or the automation system as to the aircraft's identity. Error in the received Mode C code could mislead the controller on aircraft altitude and lead to error in slant range correction and hence the aircraft position is incorrectly displayed. These errors are often seen in an operational environment. The Mode S transmission of data (including ADS-B squitter messages) uses a very robust 24-bit error detection algorithm for integrity check. The integrity check is applied at the radar ground station. If the check fails the data is considered unreliable and is	

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	discarded.	
Radar Positional Data Integrity	SSR end to end performance is continually monitored through the deployment of SSR site monitors. If the radar measured position of the site monitor is in error or the sight monitor is not received, alerts are provided to a controller and the individual radar may be removed from service. Position data errors not detected by this check include multipath corruption of position, SSR reflections, diffraction, "beam bending", Mode C data-link error into Slant Range Correction, incorrect time delay in the transponder and incorrect reply mode from the transponder. When considering Radar Positional data integrity , apart from the site monitor, there is no integrity monitoring of the positional data from other SSR transponders despite the fact that the positional data reported from other transponders being subject to several environmental effects such as multipath corruption of position, SSR reflections, diffraction (which can cause monopulse processing azimuth errors) and "beam bending". Reliance is placed on the results of flight testing to provide confidence that the environmental effects, at the time of test, are acceptable. Radars measure range and azimuth separately. Radar azimuth errors easily lead to positional errors in the order of 0.25 – 0.5 Nm (95 percentile) at ranges in excess of 200Nm – which continues to be used for ATC 5Nm separation standards. Experience also indicates that radar data is not tightly constrained within a defined tolerance of truth. The error distribution tends to have large "tails" due to multipath and other reasons. DO260 indicates an	In an ADS-B system, ADS-B site monitors can also be deployed. The reception of the site monitor broadcast indicates that the ADS-B ground station can 'hear'. If the site monitor ADS-B position data that comes from a GPS receiver, GPS performance can also be verified. The integrity of the positional information from the aircraft navigation system must be sufficiently high. When considering ADS-B data integrity and the use of ADS-B in a manner very similar to ATC radar, it is required that the integrity of the ADS-B data should be equal or better than radar surveillance data. ADS-B integrity is managed in two major ways as follows: a. The ADS-B standards require the transmission of NUCp and/or NIC/NAC/SIL by the avionics to ADS-B receivers. These receivers are then required to determine whether there is adequate integrity and adequate accuracy for the operational requirement. In the case of ATC radar like services using ADS-B, an integrity level of 10^{-7} for a position error of < 0.5 Nm is equivalent or better than existing radar systems which clearly have a possible error of 0.25 Nm @ 95 percentile certainty. Therefore a Navigational Uncertainty Category value of 5 or better is adequate.

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	equivalence of <0.25 Nm(@ 95%) to a <0.5 Nm (@ 10^{-7} level of certainty).	b. The integrity of each and every message is protected by a strong cyclic redundancy check when flags any message corruptions with high certainty.
Altitude data integrity	The integrity of the received mode C altitude data is not assured. The data is passed on the data link without error detection capabilities nor is there any check for aircraft encoder/altimetry error.	
Tracker systems There are large number of different radar tracking and display systems in use around the world. The major challenges in tracking are as follows: a. minimising tracker anomalies such as the mismatching of target reports to the incorrect track b. providing smooth track outputs c. calculating accurate and responsive velocity vectors d. extrapolation of track position to time of display e. detection of manoeuvres The displays for radar and ADS-B can be considered equivalent. Normally the same displays will be used.. The characteristics of the input data provided to any tracker is by far the largest determinant of tracker performance. High quality input data provides high quality result. These characteristics are further examined in this		

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section:		
Input data accuracy		ADS-B data is more accurate than radar hence tracking is smoother and more responsive.
Track swaps	Radar often relies on downlinked 4 digit octal code that is subject to corruption in transmission. Code validation errors are not rare. Performance worse than ADS-B	Downlinks a secure (protected by CRC) airframe unique code which makes the risk of mistracking significantly more remote than radar.
Velocity vectors	Determined by real time computation and smoothing of noise radar position measurement obtained every 3 to 12 seconds (depending on the radar). Performance worse than ADS-B	Determined by airborne avionics able to have precise and temporal measurement of velocity and heading. This data is down-linked inside a CRC protection. New values calculated and down-linked every second
Extrapolation error	System radar tracks are typically updated between 4 seconds and 12 seconds.	Typically new positional data is presented to an ADS-B tracker every second. Therefore in any extrapolation required, for example to the time of display, is less for ADS-B because the extrapolation period is shorter. Extrapolation errors are also less when the velocity vector is more accurate (as it is for ADS-B compared to radar)
Manoeuvre detection	Positional updates between 4 seconds and 12 seconds	With a positional update of every 1 second, the commencement of aircraft manoeuvres can be detected earlier than radars which provide updates every 4 seconds.
Reflections and duplicates	Reception of the radar signal from reflecting objects and multipath can create position errors and “tracker duplicates” because the delay via the object can create position errors. Multipath can cause 2 tracks to appear instead of one.	Positional data is calculated by the aircraft. If the signal arrives at the ground station via different path, it has no impact on positional error nor on determination whether the target is the same as another.
Resolution	Loss of resolution when two aircraft are nearby	The ADS-B tracker does not need to resolve

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	can cause two aircraft to appear as one and cause significant disruption to the positional information from each aircraft. These present significant challenges to any radar tracker.	whether there are 2 aircraft or one because each aircraft is uniquely identified by a 24 bit code
Slant Range Correction.	SSR inherently measures Slant Range of aircraft. In order to determine the True range of the aircraft, an adjusted is made based upon the height of the aircraft. In cases where the aircraft altitude is unknown (no Mode C), a default altitude or other approximation must be used. Significant error in Mode C data (pressure encoder error, data-link error or Mode A reply to Mode C interrogation) leads to an incorrect adjustment. These can lead to significant position errors where the aircraft is close to the radar.	ADS-B does not have an equivalent mechanism and hence is not subject to such errors.
Emergency Navigation Service	Radar may be used to provide emergency navigation to an aircraft when the pilot is unable to navigate by normal means. This service may be required in the event of failure of various items of equipment (navigation sensors or display) or pilot performance limitations (ie VFR pilot in IMC).	Assuming that ADS-B uses positional information from the aircraft's Navigation Sensors, a Controller using ADS-B could provide emergency navigation (vectors) to an aircraft provided at least one navigation sensor was functioning. In the event of total loss of navigation, Separation can be assured using vertical separation, temporarily using half the usual vertical standard if normal vertical standard is not immediately available. Thus the dependence of ADS-B on the aircraft's navigation system should not preclude the deployment of ADS-B. Suitable procedural means exist to provide emergency response to this most infrequent event.

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Emergency Altimeter Service	Radar may be able to provide emergency altitude/Flight Level information to an aircraft when the pilot is unable to determine altitude by the normal means. This service may be required in the event of failure of all altimeters available to the pilot. This service is only available if the Pressure Encoder and Static Pressure Port associated with the Transponder is operating normally	Assuming the pressure encoder and static pressure port associated with the Transponder is operating normally, a Controller using ADS-B, could also provide emergency altitude information to an aircraft.

Discussion on additional issues identified by a comparative assessment

a. Probability and impact of a common mode failure of nav and surveillance. This should be assessed for single aircraft or multiple aircraft scenarios.
See hazard analysis issues/mitigators.

b. Station overlap (mosaic v different ADS-B stations)

c.

Station overlap is not a concern for ADS-B systems. The most recently received data can be used. If two stations receive data from an aircraft at the same time, the data will be identical because it is the aircraft that constructed the data. As a result the ground station display can disregard any second message. Management of such data within ADS-B systems is significantly easier than for radar, as in the latter system the time of detection, the range from the radar (to derive the positional error) etc must be taken into account. Because radars measure SLANT range and azimuth, if two radars measure the position of an aircraft at the same time, they need to rely on altitude data to map them to the same display position.

d. Navigation performance requirement for ADS-B.

The use of a navigational uncertainty category value (NuC) is defined in ICAO XXXXXX. The comparative assessment methodology requires the proposed system to meet or exceed the capability of the reference system. Therefore the navigation performance of aircraft being provided with ADS-B services should comply with this requirement. The table above details the different positional accuracy capabilities for both radar and ADS-B but does not specify a minimum navigation performance requirement. To use the positional data provided by ADS-B for separation services the received positional data must be known to have a low probability of being outside a radius of 0.5 Nm from the real position of the aircraft. In this context the low probability means one occurrence in 10^7 flight hours.

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Note : This requirement is equivalent to the GPS horizontal protection limit of 0.5 Nm. This is equivalent to a 95 percentile of reports within 0.25 Nm (similar to radar).

e. External interference issues

With Mode S based ADS-B external interference is identical to radar because the same frequency is used. However a radar is able to sometimes restrict the interference to a single azimuth for example when the radar is pointing towards the interference source. On the other hand ADS-B receivers only need a single message to break through any interference for valid data to be received, whereas radar requires coherence from interrogation to interrogation and normally from antenna scan to antenna scan. The impact of interference on the application of separation standards is probably more related to a question of system reliability : ie either radar or ADS-B could fail at any time due to interference.

f. Positional data source – nav system or stand alone position

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APPENDIX 2

HAZARD LOG

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Hazards

Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. **1 Failure of ADS-B transponder on the aircraft**

Generic Description
Failure of ADS-B transponder on the aircraft cause a loss of ADS-B message to the ground station

Hazard Cause/Initiating Events
Increase in controller workload due to requirement to revert back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Remote	Remote
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement	Details
ADS-B Transponder Reliability Spec	Ensure ADS-B transponder in the aircraft has reliability requirement equivalent to existing Mode A/C transponder
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. **2 Failure of ADS-B ground station**

Generic Description
Failure of ADS-B ground station

Hazard Cause/Initiating Events
Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Remote	Remote
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

ADS-B Ground System Availability Specification	Allocate an availability requirement of 0.9995 to the ADS-B ground station sub
Monitoring of ADS-B Ground Station	Monitoring of health status of ADS-B ground stations at a remote central position
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. **3 Incorrect data broadcast by the aircraft transponder due to data corruption**

Generic Description

Incorrect data due to data corruption broadcast by the aircraft ADS-B transponder. The GPS unit in the aircraft is still operating correctly.

Hazard Cause/Initiating Events

Significant error in the displayed position of the aircraft therefore could lead to a breakdown in separation without the controller being aware. This only impacts a single aircraft.

Risk

	Initial Risk	Residual
Likelihood	Remote	Improbable
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Controller observation of history trails for forward track jump

Safety Requirement Details

Safety Function for ADS-B tracks	Route Adherence Monitoring processing (or similar) implemented in the automation system for ADS-B tracks.
Comprehensive testing of ADS-B Ground System	Tested and proven ADS-B ground stations with comprehensive checking of integrity data (e.g. use of checksums in ADS B messages) are used for the trial
Training to cover process to request alternate positional data	Training must include the process and procedures for requesting alternate positional information from the pilot when
Checking of ADS-B a/c ident	Procedures shall be developed for cross checking of ADS-B positional data with data provided by other navigational systems (not GPS) in certain circumstances.
Parity check on data transmitted	Ensure parity check is available for all data transmitted
ADS-B avionics systems	Only avionics equipment certified to TSO C129A plus FD&E for GPS navigator and TSO C112 (DO-181C) for Mode S transponder are used for all aircraft participating

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 4 Corruption of data by the ground station

Generic Description

Incorrect data displayed to controller due to data corruption at the ADS-B ground station.

Hazard Cause/Initiating Events

Error in the reported position of the aircraft therefore could lead to a breakdown in separation without the controller being aware. This may affect all data.

Risk

	Initial Risk	Residual
Likelihood	Improbable	Extremely
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Controller observation of history trail for forward track jump

Safety Requirement Details

Procedure to remove corrupted ADS B data	Developed and published procedure to remove corrupted ADS B data from the ground system to ensure that the Flight Data Record is not updated.
Comprehensive testing of ADS-B Ground System	Tested and proven ADS-B ground stations with comprehensive checking of integrity data (e.g. use of checksums in ADS B messages) are used
On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
Safety Function for ADS-B tracks	Route Adherence Monitoring processing (or similar) implemented in the automation system for ADS-B tracks.

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 5 Loss of positional accuracy of reported position

Generic Description

The accuracy performance of the navigational equipment in the aircraft has deteriorated to the level that it is not acceptable to support the specified separation standard.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic. This affects only one aircraft.

Risk

	Initial Risk	Residual
Likelihood	Remote	Improbable
Consequence	Cat 3	Cat 4
Risk	D	D

Existing Mitigation

Safety Requirement Details

On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
Processing based on accuracy performance	Automation system to detect the reduction in accuracy performance and not used that data if it is below the threshold of NUC = VSP (Variable System Parameter- typically 5) and display appropriate visual notification to the controller concerned.

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 6 Incorrect processing of ADS-B data by the automation system

Generic Description

Incorrect processing of ADS-B data by the ground ADS B system leading to error in the reported position of the aircraft concerned.

Hazard Cause/Initiating Events

Possible error in the displayed position of the aircraft therefore could lead to a breakdown in separation.

Risk	Initial Risk	Residual
Likelihood	Remote	Improbable
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Controller observes tracks with respect to reference data (e.g. maps, radar returns, etc)

Safety Requirement Details

Procedure to remove corrupted ADS B data	Developed and published procedure to remove corrupted ADS B data from the ground system to ensure that the Flight Data Record is not updated.
Training to cover process to request alternate positional data	Training must include the process and procedures for requesting alternate positional information from the pilot when
Formal testing of automation system	Formal testing and validation of new functionality to the automation system to support processing and displaying of ADS-B tracks
Ability to enable and disable ADS B tracks	Ensure ground system HMI is provided with the ability to select and deselect ADS B tracks
On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 7 Failure of ADS-B processing subsystem

Generic Description

Failure of the ADS-B processing subsystem in the ground system.

Hazard Cause/Initiating Events

ADS-B tracks will not be displayed on the controller HMI therefore will cause an increase in workload due to the requirement to transition back to procedural control.

Risk

	Initial Risk	Residual
Likelihood	Occasional	Improbable
Consequence	Cat 3	Cat 3
Risk	C	D

Existing Mitigation

Safety Requirement Details

ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
High reliability requirement for ADS-B subsystem	The ADS-B processing sub-system with MTBF requirement of at least 30 years and MDT of equal of less than 2 hours

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Project ICAO SASP Operational Use of ADS-B in Non Radar Airspace

Hazard No. 8 Inadequate ATS Training

Generic Description

Introduction of new ADS-B function is new to ATS and inadequate training will introduce a hazard to the system.

Hazard Cause/Initiating Events

Insufficient training in the areas of HMI, new procedures and transition from ADS-B control to procedural control may increase the probability of breakdown in separation.

Risk

	Initial Risk	Residual
Likelihood	Occasional	Remote
Consequence	Cat 3	Cat 3
Risk	C	D

Existing Mitigation

Training standard manual exist and is required to be followed.

Safety Requirement Details

Integration of ADS-B data with FDP	Ground automation system to process and integrate the ADS-B data with existing FDP function and display the ADS-B tracks with a unique symbol on the controllers display.
ADS-B Training System	Provision of an ADS-B training system capability on the Eurocat simulator.
Ergonomic performance consistent with automation system	Ergonomic performance is consistent and comparable with existing ground system
Use proven and consistent HMI	ADS-B HMI is consistent with current ground HMI with ability to deselect all ADS-B data
Provide ADS-B training capability	Training and lesson plans to support air traffic control of ADS-B equipped aircraft in non radar airspace
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control

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Project ICAO SASP Operational Use of ADS-B in Non Radar Airspace

Hazard No. 9 Flooding of the ADS-B messages

Generic Description

Flooding of the ADS-B broadcast messages caused by multiple transponders transmitting at the same time.

Hazard Cause/Initiating Events

A loss of positional data (update) during the period of flooding. Increase workload for control in reverting to procedural control

Risk

	Initial Risk	Residual
Likelihood	Remote	Improbable
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

Proven ADS-B Ground Stations to handle at least 200 reports	Use tested and proven ADS-B ground stations that can handle at least 200 airborne reports.
ADS-B avionics broadcast rate	ADS-B broadcast rate of 1 sec from the aircraft
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
ADS-B tracks update rate	ADS-B tracks updated rate of every 5 secs

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 10 RF Jamming

Generic Description

RF jamming of ADS-B transmissions due to deliberate or non deliberate actions.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to requirement to transition back to procedural
control

Risk

	Initial Risk	Residual
Likelihood	Improbable	Improbable
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 11 Jamming of GPS transmissions from the satellites

Generic Description

Jamming of GPS transmissions from the satelites due to deliberate or non deliberate actions.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to requirement to transition back to procedural
control

Risk

	Initial Risk	Residual
Likelihood	Remote	Remote
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

Remove ADS-B tracks for poor positional	When downlink positional data is reduced below NUC = VSP (Variable System Parameter - typically 5), ADS-B tracks will be removed within 30 secs
On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
Processing based on accuracy performance	Automation system to detect the reduction in accuracy performance and not used that data if it is below the threshold of NUC = VSP (Variable System Parameter- typically 5) and display appropriate visual notification to the controller concerned.

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 12 Failure of GPS satellite or satellites

Generic Description

Failure of GPS satellite or satellites due to system problem.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Output NUC drops and ADS-B not displayed to controller. Increase in
workload due to requirement to transition back to procedural control

Risk

	Initial Risk	Residual
Likelihood	Remote	Remote
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

Processing based on accuracy performance	Automation system to detect the reduction in accuracy performance and not used that data if it is below the threshold of NUC = VSP (Variable System Parameter- typically 5) and display appropriate visual notification to the controller concerned.
Remove ADS-B tracks for poor positional	When downlink positional data is reduced below NUC = VSP (Variable System Parameter - typically 5), ADS-B tracks will be removed within 30 secs
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 13 Inaccuracy of positional data for aircraft in manoeuvring

Generic Description

Failure to detect aircraft in manoeuvring between display updates.

Hazard Cause/Initiating Events

If the positional error between updates is larger that the separation standard, this could lead to a breakdown in

Risk

	Initial Risk	Residual
Likelihood	Remote	Improbable
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

ADS-B Ground System Availability Specification	Allocate an availability requirement of 0.9995 to the ADS-B ground station sub
ADS-B avionics systems	Only avionics equipment certified to TSO C129A plus FD&E for GPS navigator and TSO C112 (DO-181C) for Mode S transponder are used for all aircraft participating
Comprehensive testing of ADS-B Ground System	Tested and proven ADS-B ground stations with comprehensive checking of integrity data (e.g. use of checksums in ADS B messages) are used for the trial
Accuracy better than conventional SSR radar	Accuracy performance shall be better than of a conventional SSR radar
Azimuth resolution better than to conventional SSR radar	Azimuth resolution performance shall be better than to conventional SSR radar

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 14 Incorrect data sent by aircraft transponder due to fault in GPS unit

Generic Description

The GPS unit reports incorrect positional information but still provide the required FOM

Hazard Cause/Initiating Events

Error in the reported position without the controller awareness therefore could lead to a breakdown in separation. This
only impacts a single aircraft.

Risk	Initial Risk	Residual
Likelihood	Improbable	Improbable
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Controller observes tracks with respect to reference data (e.g. maps, radar returns, etc)

Safety Requirement Details

ADS-B avionics systems	Only avionics equipment certified to TSO C129A plus FD&E for GPS navigator and TSO C112 (DO-181C) for Mode S transponder are used for all aircraft participating
Parity check on data transmitted	Ensure parity check is available for all data transmitted
Checking of ADS-B a/c ident	Procedures shall be developed for cross checking of ADS-B positional data with data provided by other navigational systems (not GPS) in certain circumstances.
Training to cover process to request alternate positional data	Training must include the process and procedures for requesting alternate positional information from the pilot when
Safety Function for ADS-B tracks	Route Adherence Monitoring processing (or similar) implemented in the automation system for ADS-B tracks.
Comprehensive testing of ADS-B Ground System	Tested and proven ADS-B ground stations with comprehensive checking of integrity data (e.g. use of checksums in ADS B messages) are used

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 15 Satellite Failure - Predicted (NANU)

Generic Description

Possible loss of ADS B service due to loss of good NUC from some aircraft.

Hazard Cause/Initiating Events

ADS B tracks will not be displayed on the controller HMI therefore will cause an increase in workload due to the requirement to transition back to procedural control.

Risk

	Initial Risk	Residual
Likelihood	Probable	Probable
Consequence	Cat 4	Cat 4
Risk	D	D

Existing Mitigation

Safety Requirement Details

BARO aiding for navigator	Ensure BARO aiding available if required
On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
Procedure for RAIM predictions and updates	Ensure satellite outages are taken into account in RAIM and ensure procedures (distribution of RAIM predictions and updates) and instructions available (including training)

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 16 Satellite Failure - Unpredicted Detected by FDE 4Nm
Detected by FDE- 4Nm Oceanic FDE
Satellite Failure - Unpredicted -
Detected by FDE- 4Nm Oceanic FDE
Satellite Failure - Unpredicted - Detected by FDE - 4Nm
Satellite Failure - Unpredicted - Detected

Generic Description

Satellite Failure - Unpredicted -
Detected by FDE- 4Nm Oceanic FDE leading to the navigator flag reduced NUC. RAIM loss leading to possible loss of
ADS B

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Improbable	Improbable
Consequence	Cat 3	Cat 4
Risk	D	D

Existing Mitigation

Safety Requirement Details

Procedures for reverting to Flight Plan Track	Ensure procedures as per radar - revert back to Flight Plan Track, is availlable for ADS B
BARO aiding for navigator	Ensure BARO aiding available if required
On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 17 Satellite Failure - Unpredicted - Undetected by FDE Undetected by FDE Satellite Failure - Unpredicted - Undetected by FDE

Generic Description

Satellite Failure - Unpredicted -
Undetected by FDE causing the navigator to flag loss of RAIM and reduced NUC. Possible loss of ADS B data.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Improbable	Improbable
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
BARO aiding for navigator	Ensure BARO aiding available if required
Procedures for reverting to Flight Plan Track	Ensure procedures as per radar - revert back to Flight Plan Track, is available for ADS B

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 18 Satellite Failure - Unpredicted - Undeclared maintenance over regional area

Generic Description

Satellite Failure - Unpredicted - Undeclared maintenance over a regional area will cause the navigator to flag RAIM loss therefore possible loss of ADS B

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Occasional	Occasional
Consequence	Cat 3	Cat 4
Risk	C	D

Existing Mitigation

Safety Requirement Details

Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
Procedures for reverting to Flight Plan Track	Ensure procedures as per radar - revert back to Flight Plan Track, is availlable for ADS B
BARO aiding for Navigator	Ensure BARO aiding available if required

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 19 Loss of Geometry

Generic Description

Loss of geometry from the GPS causing a possible loss of ADS-B due to loss of good NUC from some aircraft

Hazard Cause/Initiating Events

Risk

	Initial Risk	Residual
Likelihood	Probable	Probable
Consequence	Cat 4	Cat 4
Risk	D	D

Existing Mitigation

Safety Requirement Details

On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
Procedure for RAIM predictions and updates	Ensure satellite outages are taken into account in RAIM and ensure procedures (distribution of RAIM predictions and updates) and instructions available (including training)

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Project ICAO SASP Operational Use of ADS-B in Non Radar Airspace

Hazard No. 20 Human error at Mode S transponder - turn off

Generic Description

Human error at Mode S transponder leading to the unit being switched off or in the wrong mode. The impact is possible loss of ADS B data. Identical hazard existed in radar.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Occasional	Occasional
Consequence	Cat 3	Cat 4
Risk	C	D

Existing Mitigation

This only applies to aircraft where pilot has access to the transponder unit. For some installations, the unit is installed in a position where the pilot has no access.

Safety Requirement Details

Pilot training	Ensure pilot handbook, procedures and training minimise the potential for human error
Training to cover process to request alternate positional data	Training must include the process and procedures for requesting alternate positional information from the pilot when required
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 21 Human Error - at Mode S transponder - in wrong mode

Generic Description

Setting the transponder to the wrong mode - on ground - causing no altitude being sent by the squitter.

Hazard Cause/Initiating Events

Incorrect altitude display to the controller.

Risk

	Initial Risk	Residual
Likelihood	Probable	Occasional
Consequence	Cat 4	Cat 4
Risk	D	D

Existing Mitigation

Safety Requirement Details

Pilot training	Ensure pilot handbook, procedures and training minimise the potential for human error
Training to cover process to request alternate positional data	Training must include the process and procedures for requesting alternate positional information from the pilot when

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 22 Fail Altitude encoder

Generic Description

Fail altitude encoder causing a reduced ability to obtain approach RAIM if we don't have a very high Q VFOM

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Occasional	Occasional
Consequence	Cat 3	Cat 4
Risk	C	D

Existing Mitigation

Safety Requirement Details

On-line integrity monitoring using site monitor	A site monitoring system shall provide a degree of on-line integrity monitoring. A warning shall be issued to ATC if the site monitor is not received or indicates a low NuC value
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control

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Hazard No. 23 Corrupt data from altitude encoder

Generic Description

Corrupt data from altitude encoder cause by a stuck bit . This may cause the transponder to provide incorrect alt (same as in radar). The RAIM calculation may be affected in the KLN for cases when there is insufficient satellite causing the NUC to go below 4.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Occasional	Occasional
Consequence	Cat 3	Cat 4
Risk	C	D

Existing Mitigation

Safety Requirement Details

Safety alert function - CLAM	Ensure Cleared Level Adherence Monitoring is available in the ground system displays
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
Training to cover process to request alternate positional data	Training must include the process and procedures for requesting alternate positional information from the pilot when

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Hazard No. 24 Failure of connection between navigation source and Mode S transponder

Generic Description

Loss of connection between the navigation source and transponder leading to no ADS B data output after 2 seconds. This is similar to loss of SSR transponder in radar.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Remote	Remote
Consequence	Cat 3	Cat 4
Risk	D	D

Existing Mitigation

Only licensed installer is allow to install the avionics equipment in the aircraft.

Safety Requirement Details

ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control

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Hazard No. 25 Data Corruption

Generic Description

Data corruption causing erroneous data to the transponder leading to incorrect data transmitted. This is a transitory error and
should be corrected in the next 0.5 sec and could trigger a Automatic Position Report (APR) in the ground system. The data is
protected by CRC checksum.

Hazard Cause/Initiating Events

A momentarily track jump similar to APR reporting for radar track will occur

Risk

	Initial Risk	Residual
Likelihood	Improbable	Extremely
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

Safety Function for ADS-B tracks	Route Adherence Monitoring processing (or similar) implemented in the automation system for ADS-B tracks.
Checking of ADS-B a/c ident	Procedures shall be developed for cross checking of ADS-B positional data with data provided by other navigational systems (not GPS) in certain circumstances.
Parity check on data transmitted	Ensure parity check is available for all data transmitted
Coupling	Ensure REG and 24 bit code are required for coupling. Also, ensure no coupling until the flight plan is coordinated.

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Hazard No. 26 GPS Antenna failure

Generic Description

A GPS antenna failure causing the transponder to stop squitting when data is not refreshed every 2 secs. This has the same
effect as an unpredicted satellite failure except it only affects one aircraft. There will be a loss of ADS B data

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Remote	Improbable
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control

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Hazard No. 27 Incorrect 24 bit code

Generic Description

Incorrect 24 bit code programmed in the aircraft. This will cause a mismatch with the Flight Plan and incorrect TCAS operations. The effect is failure to couple or incorrect coupling. The probability of incorrect coupling is lower than SSR because the code is set by maintenance and not the pilot.

Hazard Cause/Initiating Events

Incorrect coupling

Risk

	Initial Risk	Residual
Likelihood	Occasional	Remote
Consequence	Cat 4	Cat 4
Risk	D	D

Existing Mitigation

Safety Requirement Details

Checking of ADS-B a/c ident	Procedures shall be developed for cross checking of ADS-B positional data with data provided by other navigational systems (not GPS) in certain circumstances.
Checking of 24 bit code at installation	Ensure 24 bit code is adequately checked at installation and the covered in the avionics maintenance procedures
Detecting of incorrect 24 bit code	Ensure the ground test set detects the incorrect 24 bit code during installation check and test.

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Hazard No. 28 Failure of Communications link

Generic Description

Failure of communications link between the ground station and the automated ground system. This will cause a loss of ADS B data.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Occasional	Remote
Consequence	Cat 3	Cat 3
Risk	C	D

Existing Mitigation

Safety Requirement Details

Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
Adequate RMA requirements for comms system	Ensure adequate RMA (reliability, maintainability, availability) requirement is specified for the communications systems (e.g. links, PSN, modems,etc) between the ground station and the ATM centre. Need to provide an alternate path if the third party link service provider cannot meet RMA requirements.
ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Monitoring of Comms equipment	Ensure monitoring is provided for all communications equipment used in ADS B

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Hazard No. 29 Unstable sensitivity of ground sensor

Generic Description

Unstable sensitivity of the ground sensor will cause tracks dropping in and out of coverage in the control area.

Hazard Cause/Initiating Events

Loss of ADS-B positional data to the controller. Increase in workload due to transitioning period back to procedural control and reassess traffic.

Risk

	Initial Risk	Residual
Likelihood	Occasional	Remote
Consequence	Cat 3	Cat 3
Risk	C	D

Existing Mitigation

Safety Requirement Details

ADS-B Fallback procedure	Validated and published instructions for reverting back to procedural control
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
Tuning of receiver sensitivity	Ensure the receiver is properly tuned during setup and testing to provide stable sensitivity.

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Hazard No. 30 Failure of Site Monitor

Generic Description
Site Monitor failure will render the ADS B data not acceptable for separation however could still be used for situation awareness

Hazard Cause/Initiating Events
Indicate the potential loss of ADS B data

Risk

	Initial Risk	Residual
Likelihood	Occasional	Occasional
Consequence	Cat 3	Cat 4
Risk	C	D

Existing Mitigation
Controller observes tracks with respect to reference data (e.g. maps, radar returns, etc)

Safety Requirement Details

Coverage of Site Monitor failure in ATC training	Ensure ATC training and procedures cover the the scenario of Site Monitor failure
Warning for Site Monitor failure	Ensure a warning is sent to ATC when the ADS B site monitor is faulty or unavailable.

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Hazard No. 31 Incorrect 24 bit code in the Flight Plan

Generic Description

Incorrect 24 bit code in the Flight Plan will cause the label to attach to the wrong aircraft. Note that this is less likely when compared to the radar 12 bit code.

Hazard Cause/Initiating Events

Incorrect coupling leading to increase in controller workload

Risk

	Initial Risk	Residual
Likelihood	Remote	Remote
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

Coupling	Ensure REG and 24 bit code are required for coupling. Also, ensure no coupling untill the flight plan is coordinated.
Airline procedures	Ensure airline support the procedure of providing REG and 24 bit code for all flight plans for ADS B aircraft. Remind airline on this requirement for aircraft swap procedure.
Provide ADS-B training capability	Training and lesson plans to support air traffic control of ADS-B equipped aircraft in non radar airspace
Safety Function for ADS-B tracks	Route Adherence Monitoring processing (or similar) implemented in the automation system for ADS-B tracks.

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Hazard No. 32 Coupling and Decoupling parameters

Generic Description

Coupling and decoupling occur differently from radar therefore may confuse controllers

Hazard Cause/Initiating Events

There is different in coupling requirements between ADS B and radar.

Risk

	Initial Risk	Residual
Likelihood	Probable	Probable
Consequence	Cat 4	Cat 4
Risk	D	D

Existing Mitigation

Safety Requirement Details

ADS-B Training System	Provision of an ADS-B training system capability on ground simulator.
Adequate ATC training and	Ensure adequate training and assessment of controller for rating.

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Hazard No. 33 Wrong positional data

Generic Description

Incorrect positional data being reported by an aircraft due to a problem with the avionics (hardware or software) - NUC still better than 4.

Hazard Cause/Initiating Events

A momentary track jump similar to automatic position reporting in radar.

Risk

	Initial Risk	Residual
Likelihood	Remote	Remote
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

Safety Function for ADS-B tracks	Route Adherence Monitoring processing (or similar) implemented in the automation system for ADS-B tracks.
Checking of ADS-B a/c ident	Procedures shall be developed for cross checking of ADS-B positional data with data provided by other navigational systems (not GPS) in certain circumstances.
Parity check on data transmitted	Ensure parity check is available for all data transmitted
Coupling	Ensure REG and 24 bit code are required for coupling. Also, ensure no coupling until the flight plan is coordinated.

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Hazard No. 34 Incorrect position decoded by Ground Station

Generic Description

Position of aircraft may be in the incorrect position when the range exceed 180NM due to decoding process adopted. (local unambiguous)

Hazard Cause/Initiating Events

Incorrect position data leading to increase workload for the controller

Risk

	Initial Risk	Residual
Likelihood	Occasional	Improbable
Consequence	Cat 3	Cat 3
Risk	C	D

Existing Mitigation

Safety Requirement Details

Use Global unambiguous decoding	Ensure ADS B Ground Station use global unambiguous decoding to eliminate problem associated with range greater than 180NM
Comprehensive testing of ADS-B Ground System	Tested and proven ADS-B ground stations with comprehensive checking of integrity data (e.g. use of checksums in ADS B messages) are used for the trial
Checking of ADS-B a/c ident	Procedures shall be developed for cross checking of ADS-B positional data with data provided by other navigational systems (not GPS) in certain circumstances.

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Hazard No. 35 Failure of GPS Time system

Generic Description

Failure of GPS time system input to ADS B track processor will cause loss of time synchronisation and could lead to incorrect aircraft position extrapolation

Hazard Cause/Initiating Events

Potential inaccuracy caused by GPS time failure

Risk

	Initial Risk	Residual
Likelihood	Remote	Remote
Consequence	Cat 3	Cat 3
Risk	D	D

Existing Mitigation

Safety Requirement Details

Procedure to remove corrupted ADS B data	Developed and published procedure to remove corrupted ADS B data from the ground system to ensure that the FDR is not updated.
Time alert message	Ensure an alert message is presented to maintenance supervisor when extrapolation time exceed a defined parameter.
Monitoring of time system	Ensure status of time system is being monitored

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Hazard No. 36 Mixed operating environment - ADS B, Flight Plan and Radar tracks

Generic Description

The system will introduce an additional track (ADS B) to the current environment which will introduce a risk that the controller may inadvertently apply radar or ADS B separation standard to the Flight Plan track.

Hazard Cause/Initiating Events

Potential for incorrect separation standard applied to the Flight Plan track

Risk

	Initial Risk	Residual
Likelihood	Occasional	Remote
Consequence	Cat 3	Cat 3
Risk	C	D

Existing Mitigation

Safety Requirement Details

Provide ADS-B training capability	Training and lesson plans to support air traffic control of ADS-B equipped aircraft in non radar airspace
Adequate ATC training and	Ensure adequate training and assessment of controller for rating.
Coverage awareness during ATC training	Ensure coverage awareness is covered during ATC training for use of ADS B.
Use proven and consistent HMI	ADS-B HMI is consistent with current ground HMI with ability to deselect all ADS-B data
Transition Process for ADS-B Failure	Training and lesson plans to adequately cover the transition process and procedures from ADS-B control to procedural control
Integration of ADS-B data with FDP	Ground automation system to process and integrate the ADS-B data with existing FDP function and display the ADS-B tracks with a unique symbol on the controllers display.
Validate ATC procedures	Validated ATS procedures to support the services provided for ADS-B equipped aircraft

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Project ICAO SASP Operational Use of ADS-B in Non Radar Airspace

Hazard No. 37 Altitude Display

Generic Description

Possibility of controllers confusing Barometric and Geometric levels on display

Hazard Cause/Initiating Events

Geometric level is displayed if the aircraft is at or below the transition altitude AND either Barometric Level is not available or the aircraft is not in a QNH defined area

Risk

	Initial Risk	Residual
Likelihood	Occasional	Occasional
Consequence	Cat 4	Cat 4
Risk	D	D

Existing Mitigation

Geometric Level displayed in a different colour to distinguish it from Barometric Level (displayed in track colour)

Geometric level will only be used for separation if checked within 200 ft of pilot report. This issue will be covered during training.

Safety Requirement Details

Validate ATC procedures	Validated ATS procedures to support the services provided for ADS-B equipped aircraft
Use of Barometric and Geometric levels	Ensure ATC procedures and training adequately cover the use of Barometric and Geometric levels in ADS B

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Hazard No. 38 Altitude incorrect and not checked

Generic Description

If separate pressure encoders are used for the ADS-B and SSR transponders, then there will be a requirement to check
the altitude display with the display in the cockpit whenever the aircraft initially enters either ADS-B or radar airspace

Hazard Cause/Initiating Events

Separate pressure encoders used for ADS-B and SSR transponders, hence aircraft altitude source depends on type of
surveillance being used.

	Initial Risk	Residual Risk
Likelihood		
Consequence		
Risk		

Existing Mitigation

Safety Requirement	Details

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Project **ICAO SASP Operational Use of ADS-B in Non Radar Airspace**

Hazard No. 39 Track couples to wrong Flight Plan

Generic Description

24-bit code and registration in Flight Plan is for another aircraft. The result is that an aircraft's ADS-B track may couple
to the wrong Flight Plan.

Hazard Cause/Initiating Events

24-bit code and registration in Flight Plan is for another aircraft. Could be a result of an aircraft substitution that is not followed by cancellation and re-issue of flight plan.

	Initial Risk	Residual Risk
Likelihood		
Consequence		
Risk		

Existing Mitigation

Safety Requirement	Details

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APPENDIX 3

AMENDMENT PROPOSAL FOR PANS-ATM Doc 4444

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