NATS

Performance
through Innovation

General Aviation: ADS-B / GPS Trial Results

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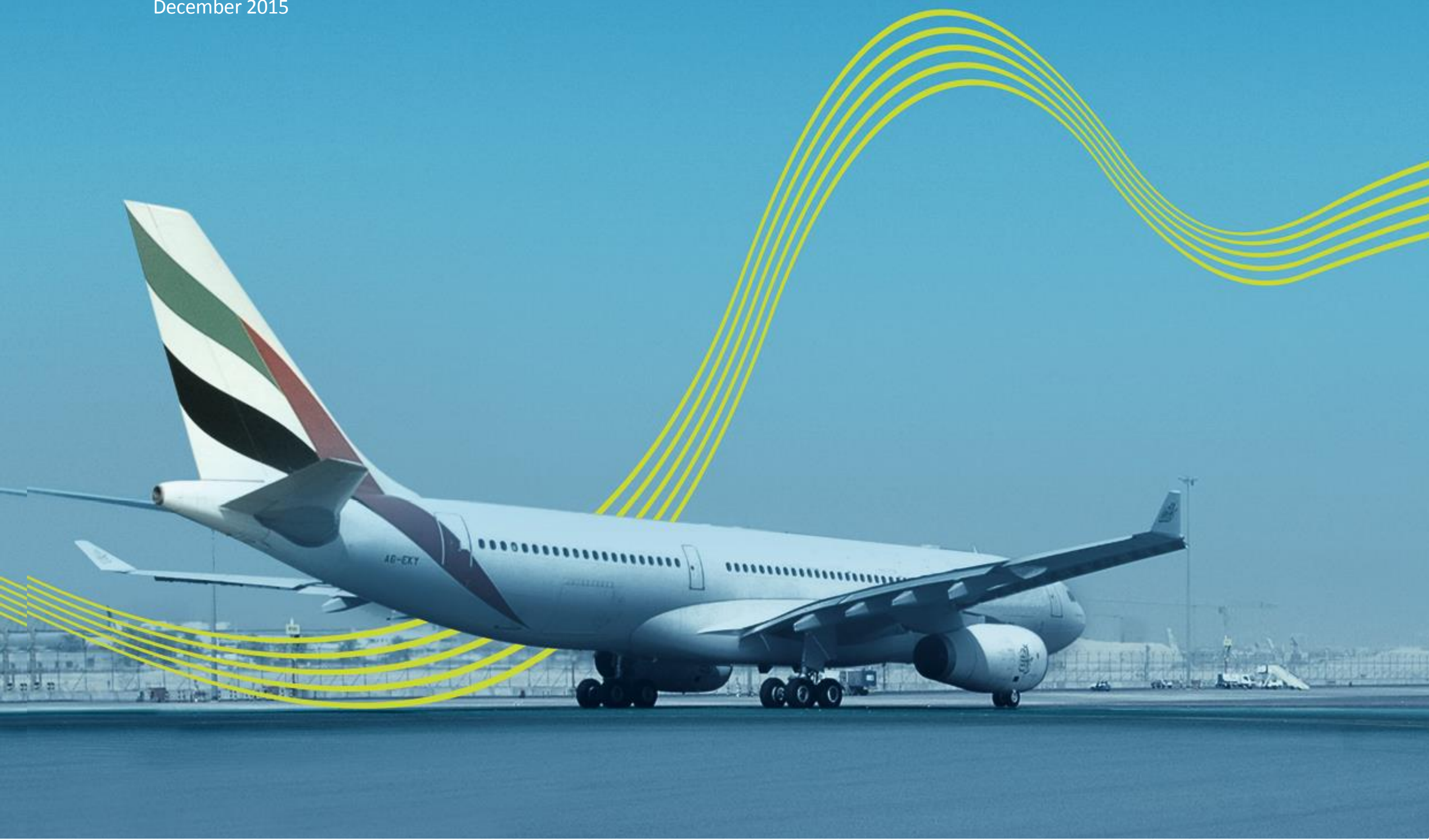

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Referenced documents

List of documents referenced in this document:

(1) EUROCONTROL Specification for ATM Surveillance System Performance, Vol 1, Eurocontrol-SPEC-0147, EUROCONTROL, March 2012
(2) EUROCONTROL Specification for ATM Surveillance System Performance, Vol 2, Eurocontrol-SPEC-0147, EUROCONTROL, March 2012
(3) Trial Participation email 2015
(4) ARTAS V8A Tracker Parameter Classification(TRK-PARAM), V1.00, 17.05.2010
(5) Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B), ED-102A, January 2012 (*ED-102A/DO-260B is a joint publication of EUROCAE and RTCA*)
(6) Trig TN70 price: http://www.gps.co.uk/trig-tn70-ads-b-out-solution/p-0-1711/
(7) Minimum Aviation System Performance Standards For Automatic Dependent Surveillance Broadcast (ADS-B) DO-242a, June 2002
(8) STANDARD CHANGES AND STANDARD REPAIRS, CS-STAN, July 2015
(9) LPAT High Level Safety Performance and Certification Assessment, NATS (Helios), April 2013
(10) MINIMUM OPERATIONAL PERFORMANCE STANDARDS (MOPS) FOR AIRCRAFT SURVEILLANCE APPLICATIONS (ASA) SYSTEM, ED-194A, June 2014

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Executive Summary

This report details the results and findings of the recent CAA backed study to assess the quality of Automatic Dependent Surveillance – Broadcast (ADS-B) data. Specifically, ADS-B generated by general aviation (GA) airframes equipped with Mode S transponders capable of extended squitter (ES) and where the broadcast position information is taken from a non-certified Global Positioning System (GPS) source.

The comparative assessment was conducted against key ESASSP ATC surveillance requirements using NATS NODE-L multi-radar data as the truth track for conformance. The quality of the ADS-B horizontal position updates derived from the non-certified GPS sources was also compared to a baseline of aircraft equipped with certified GPS sources (DO-260B/ED-102A compliant airframes); albeit with different flight profiles.

The assessment necessitated the use of several assumptions, namely that the GPS satellites were in a fault free condition and that the accuracy of the multi-radar track data was sufficiently high to apportion any position errors to the ADS-B reports.

The accuracy of the non-certified GPS position reports was found to be very similar to that of the certified aircraft; however the trial did record several extremely large horizontal position errors. Investigation of these errors determined they were broadcast by one particular airframe and were caused when the reported longitude position swapped from negative to positive for an update. It is not expected that a single large error would lead to significant issues to ATC as a single report would be considered as an outlier by a surveillance tracker and not lead to credible corruption.

When assessed against the ESASSP requirements, the mean horizontal position error (HPE) was measured to be 43.94m well within the required 300m and recommended 210m, Overall 99.84% of ADS-B HPE's recorded by the non-certified fleet were below 300m, which was a higher percentage than that of the certified comparison fleet which recorded 99.7% and a mean HPE of 40.35m.

In terms of acceptability for the airborne situational awareness application in uncontrolled airspace, the GA fleet mean HPE of 43.94m is also well within 103m which equates to an error of +/- 12.5 degrees at 3NM range, which is the cited acceptable error limit.

The Navigational Accuracy Code for Position (NACp) quality indicator that reports the expected accuracy of the position reported, was on the whole found to be very conservative in the non-certified fleet; however this is better than over-estimating the accuracy capability.

With regards to consecutive errors that could cause credible corruption, the distribution generated by the non-certified GPS fleet was similar in proportion to that of the certified comparator fleet, however the number generated does highlight the potential need for an independent means of validating ADS-B reported position on a continual/concurrent basis.

The trial has identified that the probability of update of the reported ADS-B positions was very low for both the GA and comparator fleet. Although it is not possible to determine the reasons for the low probability of update (given the absence of data), it is likely that the low-level coverage of the available ADS-B receiver network is poorer than that of the NATS secondary radar network.

Based on the results of this trial, it can be seen that the quality of non-certified GPS is sufficient for use in enhancing visual acquisition / electronic conspicuity of general aviation. There was no identified impact on the current or planned UK ATC use of 1090MHz / regulated uses of surveillance on 1090MHz, although it makes sense to ensure some form of periodic monitoring of installations to ensure transmission remain of suitable quality.

Therefore, General Aviation should be encouraged forthwith to enable ADS-B from capable transponders to start creating an ADS-B based EC environment to support the introduction of dedicated EC devices, such as NATS LPAT.

Acronyms and Terminology

Acronym	Description
ACID	Aircraft Identity
ADS-B	Automatic Dependent Surveillance – Broadcast
AIRB	Basic Airborne Situation Awareness
ARTAS	ATM suRveillance Tracker And Server
ASA	Airborne Surveillance Applications
ASTERIX	All Purpose STructured Eurocontrol suRveillance Information Exchange
ATC	Air Traffic Control
ATM	Air Traffic Management
BGA	British Gliding Association
BMAA	British Microlight Aircraft Association
CAT	Commercial Air Traffic
CDTI	Cockpit Display of Traffic Information
CPR	Compact Position Reporting
CPS	Central Processing System
CONOPS	Concept of operations
ES	Extended Squitter
ESASSP	EUROCONTROL Specification for ATM Surveillance System Performance
FL	Flight Level
GA	General Aviation
GPS	Global Positioning System
GVA	Geometric Vertical Accuracy
HPE	Horizontal Position Error
IFR	Instrument Flight Rules
Km	Kilometres
LPAT	Low Powered ADS-B Transceiver
LTMA	London Terminal Manoeuvring Area
MHz	Mega-Hertz
MOPS	Minimum Operational Performance Specification
MURATREC	MUlti RAdar Track REconstruction System
NACp	Navigation Accuracy Code for Position
NIC	Navigational Integrity Category
NICbaro	Barometric Altitude Integrity Code
NM	Nautical Miles

Acronym	Description
NMEA	National Marine Electronics Association (*GPS data transmission format*)
NODE-L	NATS Operational Display Equipment-London
NUCp	Navigation Uncertainty Category for Position
Pd	Probability of Detection
R&D	Research & Development
RF	Radio Frequency
RMS	Root Mean Square
RRRS	Radar Recording and Replay System
SASS-C	Surveillance Analysis Support System – Centre
SBAS	Satellite Based Augmentation System (*GPS augmentation*)
SDA	System Design Assurance
SIL	Source Integrity Level
TSAA	Traffic Situation Awareness with Alerts
VFR	Visual Flight Rules
WAAS	Wide Area Augmentation System (*GPS augmentation*)

1 Introduction

1.1 Purpose

This report details the results and findings of the recent CAA backed study to assess the quality of Automatic Dependent Surveillance – Broadcast (ADS-B) data. Specifically; ADS-B generated by general aviation (GA) airframes equipped with Mode S transponders capable of extended squitter (ES) and where the broadcast position information is taken from a non-certified Global Positioning System (GPS) source.

1.2 Trial background

Controlled airspace infringements by non-transponding aircraft, in ATC surveillance terms referred to as 'primary' only contacts, pose a significant risk to NATS operations, particularly at low level within the London Terminal Manoeuvring Area (LTMA).

The risk posed by these infringing aircraft could be more readily managed if they were clearly identifiable from clutter and other artefacts inherent with primary only returns. Cooperative surveillance, facilitated by transponder equipage, is currently the only option available to reduce this risk. However the uptake of Mode S transponders within the lower end of the GA market, viz. those aircraft which do not require access to airspace requiring transponder equipage is low. This is seen to be on grounds of transponder cost, weight, availability of electrical power, airframe constraints and a perceived lack of user benefit.

However, any improvement in electronic situational awareness will not be fully realised until other GA aircraft already equipped with transponders also provide ADS-B data. Although LPAT can provide non-directional proximity warnings against nearby Mode A/C/S transponders based on signal strength.

Therefore, NATS R&D and Swanwick Safety are exploring the provision of ADS-B by GA users already equipped with extended squitter capable Mode S transponders, but lacking the connection to a GPS source. Currently within the GA domain, equipping with an aeronautical certified GPS receiver is often economically prohibitive due to the units cost typically starting from around £2,500 ref (6), installation and aircraft downtime costs. The unit costs are in part driven by the certification costs and increased part costs. Certified GPS units enable the provision of ADS-B quality indicators for integrity and development assurance to support the provision of separation services.

GPS receivers not certified for aeronautical navigation have a significantly lower cost, but due to historical guidance by the CAA have not been permitted to be connected to Mode S transponders capable of broadcasting ADS-B. This is because they typically lack certain features and capabilities required by the applicable GNSS and ADS-B MOPS and MASPS applicable to certified units, most notably GPS integrity and interference protection mechanisms for the 1090MHz band.

This trial, in agreement with the CAA, will explore the quality of ADS-B position information provided by GA airframes equipped with non-certified GPS receivers connected to Mode S transponders capable of broadcasting extended squitter messages.

1.3 Trial Aim

The overarching aim of the trials is to assess the intrinsic quality of ADS-B horizontal positions and associated quality indicators derived from non-certified GPS receivers.

1.3.1 Trial Objectives

The trial objectives are:

- Gather and collate empirical evidence as to the quality of ADS-B data items transmitted by participant GA airframes equipped with non-certified GPS receivers connected to ES capable Mode S Transponders
- To specifically assess;
    - Accuracy (e.g. position error referenced to secondary radar, altitude and identification) of the reported ADS-B data content,
    - Track continuity (e.g. large deltas between consecutive reports…),
    - Correct setting of parameters (e.g. Quality indicators should be set to zero for non-certified GPS sources),
    - Reporting of false data (e.g. population of Selected Flight Level (SFL))
    - Frequently reported information.
- Identify nominal quality data,
- Identify frequency of trial 'worst case' data and assess and/or identify its potential impact on NATS systems,
- Investigate any significant failings in data quality to determine the root causes (e.g. GPS receiver, transponder model or version, or receiver and Transponder combination),
- To assess the interest of GA users in 'situational awareness' applications that augment the pilots ability to visually acquire nearby traffic,
- Assess the reliability of the data over time (e.g. does the data degrade?)

1.4 Scope

The initially envisaged scope of the trial was to undertake the connection of existing Mode S ES transponder installations to a non-certified GPS source within any powered or non-powered airframes.

Following discussions with a number of transponder manufacturers this aspiration was limited to a subset of manufacturers' transponder equipment, so as to ensure that the certification and warranties of certain existing Mode S ES transponders were not invalidated. This unfortunately led to a number of applicants being excluded.

GA Aircraft fitted with certified GPS units were also excluded as they would misrepresent the quality provided by non-certified GPS sources. However, a dataset of airframes with certified GPS sources was used as a baseline for comparison of the non-certified units. These airframes were identified from a DO-260B/ED-102A (5) 'whitelist' of Mode S addresses supplied by EUROCONTROL.

The trial was open to both EASA regulated and nationally regulated airframes. The trial did not seek to demonstrate that the use of non-certified GPS is safe for use in any type of aviation or ATC safety relevant service or application.

1.4.1 Trial Temporal and Geographical Limits

The trial was anticipated to run for the period from 1st January 2015 to 31st August 2015.

The data analysed within this report covers 2nd May 2015 to 3rd October 2015. Any GA aircraft equipped with a Mode S ES capable transponder flying in southern and eastern England was invited to participate. The NATS' ADS-B coverage map was included with the invitation to demonstrate the preferred area for the trial[1].

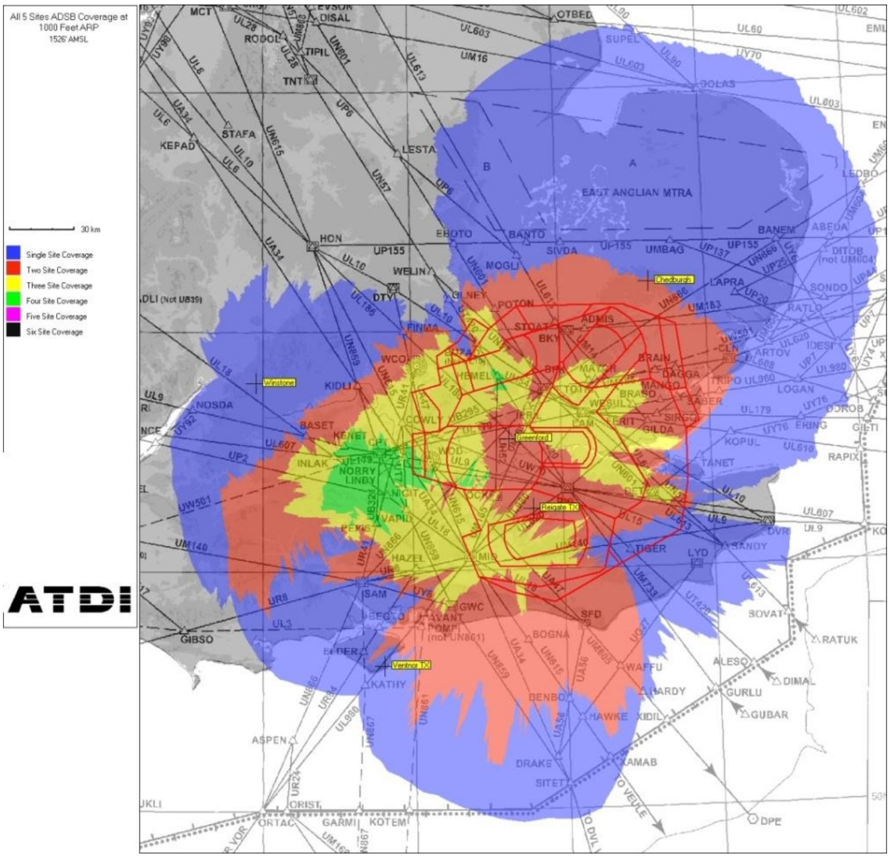

Figure 1: Theoretical coverage of NATS' ADS-B sensor network at 1000' ARP[2] (where RF line of sight influences range more than transponder power, 125W used).

2 Approval process for the Mode S GPS trial

2.1 CAA support for the trial

Permission to run a trial that encouraged GA aircraft owners to connect a non-certified GPS unit to a Mode S Extended Squitter transponder began in June 2014. This took place alongside discussions secure permissions to conduct flight test trials with the three LPAT prototypes. Approval to commence the Mode S GPS trial was received in November 2014 with the CAA further

[1] A less detailed earlier version of the theoretical coverage map was sent to trial participants, however the coverage indicated on that version is similar to that in Figure 1.

[2] Note that this coverage does not include the receiver at Daventry which was installed during the trial period.

demonstrating their support for this trial by agreeing to waive their minor modification fees for the trial participants. This gesture was a key element for the success of the trial.

2.2 Transponder manufacturers' support for the trial

Trig Avionics and Funke Avionics responded positively to the technical support request and provided extensive information for connecting and configuring their respective transponders. Some avionics manufacturers questioned the impact on the certification of the transponder in the trial and were therefore reluctant to support the trial or allow users with their devices to participate in the trial.

2.3 Invitation to participate in the trial

The trial initially started by contacting flying clubs. The contact list was constructed from the "Flyer" distribution list provided by Ian Seager. The Flyer distribution list was in a non-standard database format and the contact points were a mixture of email, postal and web page types. It was a very 'mandraulic' exercise to construct a usable list and to contact 163 flying clubs through the variety of contact points.

The response from the invitation to the flying clubs was very low with only three clubs responding and none of them had aircraft with compatible transponders.

A decision was taken to broaden the scope of the trial to include all GA pilots[3]. A great majority of the responses came from owners of Annex II aircraft so NATS, the CAA, the LAA, the BMAA and the BGA held joint discussions to propose a process for submitting and approving a minor modification, which allowed an aircraft owner to connect a non-certified GPS source to a Mode S ES transponder.

An overview of the process flow for LAA participants can be found in Appendix A2. The process flow for BGA and BMAA participants was essentially identical to the LAA process except the owner had to consult their respective association.

3 Methodology

3.1 Data collection

The comparative assessment of the reported ADS-B messages necessitated that the trial was limited to southern and eastern England where the NATS R&D ADS-B receiver network could provide overlapping coverage with NATS secondary surveillance radar.

This report compares the ADS-B and NATS NODE-L[4] track data for the airframes of interest (approved GA Trial aircraft and certified DO-260B/ED-102A (5) compliant aircraft) from the 2nd of May 2015 to 3rd of October 2015 (156 days).

Nine GA airframes were used in the comparative assessment of ADS-B based on un-certified GPS Analysis

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[3] Due to the manner in which the trial was publicised and coordinated, there were delays in replying to applicants who had applied via different routes.

[4] NODE-L is the current multi-radar track surveillance source for NATS provision of 3 NM separation services in the LTMA.

The ADS-B messages were recorded from six receiver ground stations located in the South of England into a single stream of ASTERIX CAT021 v2.1 data (see Figure 1 in section 1.4.1).

It should be noted that raw ADS-B position reports are different to those reported in the ASTERIX CAT021 data. In the raw ADS-B broadcast the WGS84 latitude and longitude is encoded using 'compact position reporting' (CPR) in consecutive 'odd and even' ADS-B position message reports to reduce the bandwidth required to continually broadcast what is essentially small changes in position from the aircraft. Different data collections are broadcast in different messages. The ASTERIX records assessed within this report concatenate several ADS-B reports into a single line of data.

The Multi-radar tracker output of NODE-L recorded in ASTERIX CAT062 format was used as the comparator 'truth track'.

In formal radar assessments undertaken by the NATS Radar Analysis Team; the MURATREC tool within the SASS-C analysis suite is used to provide the 'truth track', as given the benefit of hindsight of contributing radar sources, the accuracy of the reconstructed trajectory is better than that of the multi-radar tracker. Typically 99.9% of horizontal position errors for NODE-L are less than 200m (99% are less than 100m) which only slightly larger than for MURATREC accuracy, when certain effects in turns are excluded.

However, as SASS-C analysis is resource intensive and given the large number of data samples to be analysed and as this is an R&D study to look at the feasibility of non-certified ADS-B, a simplified comparison[5] between the NODE-L track data was deemed tolerable. If feasible, further validation work would be required to ensure the system was fit for purpose.

Several data processing scripts, spread sheets and statistical and geographical software packages were used to convert the ASTERIX CAT021 and CAT062 binary data in to text readable format, process, calculate and compare the metrics listed in section 3.3.

To put the results from the non-certified GPS into context, ADS-B data from DO-260B/ED-102A (5) compliant airframes with certified GPS receivers were used as a comparison baseline. The 'whitelist' of the airframes was produced by EUROCONTROL and compiled in September 2015.

This list contained 1,935 Mode S addresses, of which 878 were detected within a spatially filtered coverage assessment volume. A spatial filter was necessary due to the large proportion of aircraft in the baseline comparator fleet undertaking high-level typically straight and level en-route flights over the UK, which is in contrast to the low level often manoeuvring GA flights in the trial. The spatial filter rejects all data plots above FL100 and outside of a rectangle bounded by WGS84 coordinates 002E, 003W, 53N and 50.5N.

A number of the charts used within the assessment display the metrics in terms of 'fraction of total ADS-B plots' to allow direct population comparison between the non-certified GA and certified baseline fleets.

[5] The simplified comparison did not exclude turns from the analysis as the typical flight of GA aircraft involves many turns.

3.2 Surveillance requirements

The appropriate European requirements for ATC TMA separation surveillance performance is given by ESASSP (see ref(1) and (2)).

Although the ADS-B derived position data will not be used for separation provision, the measurements recorded in the trial will be assessed to the following applicable ESASSP requirements below, for compliance to highlight limitations of the data.

Requirement	Description	Evaluation criteria	Assessment Justification
3N_C-R1	Measurement interval for probability of update assessments (R2, R7 and R14)	Less than or equal to 5 seconds	Assessment uses 4 seconds (however ADS-B broadcasts position approximately twice a second; odd/even broadcasts)
3N_C-R2	Probability of update of horizontal position	Greater than or equal to 97% for 100% of the flights, any flight below 97% shall be investigated as defined in R22	Assessed
3N_C-R3	Ratio of missed 3D position involved in long gaps (larger than 16.5 s = 3 x 5 s + 10%)	Less than or equal to 0.5 %	Assessed
3N_C-R4	Horizontal position RMS error	Less than or equal to 300 metres global and less than 330 metres for 100% of the flights, any flight below 550 m shall be investigated as defined in R22	Assessed
3N_C-R5	Ratio of target reports involved in sets of 3 consecutive correlated horizontal position errors larger than 555 m - 0.3 NM	Less than or equal to 0.03 %	Assessed
3N_C-R6	Relative time of applicability of horizontal position for aircraft in close proximity (less than 11110 m - 6 NM)	Less than or equal to 0.3 seconds RMS	N/A: Out of scope of assessment.
3N_C-R7	Probability of update of pressure altitude with correct value	Greater than or equal to 96 % global	N/A: Out of scope of assessment.
3N_C-R8	Forwarded pressure altitude average data age (see Note 7 in § 3.4.5)	Less than or equal to 2.5 seconds	N/A

3N_C-R9	Forwarded pressure altitude maximum data age	Any forwarded pressure altitude data item with an age greater than or equal to 16 s shall be considered as not available when assessing R3, R7, R8 and R10	N/A: Out of scope of assessment.
3N_C-R10	Ratio of incorrect forwarded pressure altitude (see Note 7 in § 3.4.5)	Less than or equal to 0.1 %	N/A: Out of scope of assessment.
3N_C-R11	Pressure altitude unsigned error (see Note 7 in § 3.4.5)	Less than or equal to 200/300 ft in 99.9% of the cases for stable flights and less than or equal to 300 ft in 98.5% of the cases for climbing/descending flights	Assessed.
3N_C-R12	Delay of change in emergency indicator/SPI report	Less than or equal to 7.5 s for 100% of the cases, case above 7.5 s shall be investigated as defined in R22	N/A: Instances of SPI in sample will be investigated.
3N_C-R13	Delay of change in aircraft identity	Less than or equal to 15 s for 100% of the cases, case above 15 s shall be investigated as defined in R22	N/A: Assessment of aircraft identity matches will be undertaken.
3N_C-R14	Probability of update of aircraft identity with correct value (see Note 8 in § 3.4.5)	Greater than or equal to 98 % global	Assessed.
3N_C-R15	Ratio of incorrect aircraft identity	Less than or equal to 0.1 %	Not assessed.
3N_C-R16	Rate of climb/descent RMS error	Less than or equal to 250 ft/mn for stable flights and less than or equal to 500 ft/mn for climbing/descending flights	N/A: Out of scope
3N_C-R17	Track velocity RMS error	Less than or equal to 4 m/s for straight line and less than or equal to 8 m/s for turn	N/A: Out of scope
3N_C-R18	Track velocity angle RMS error	Less than or equal to 10° for straight line and less than or equal to 25° for turn	N/A: Out of scope

3N_C-R19	Density of uncorrelated false target reports	Less than or equal to 2 false target reports per area of 100 NM2 and over a duration of 720 applicable measurement intervals	N/A: Out of scope
3N_C-R20	Number per hour of falsely confirmed track close to true tracks	Less than or equal to 1 falsely confirmed track per hour that are closer than 16700 m - 9 NM from true tracks	N/A: Out of scope
3N_C-R21	Continuity (probability of critical failure)	Less than or equal to 2.5 10-5 per hour of operation	N/A: Out of scope
3N_C-R22	Investigations	Flights/cases for which requirements R2, R4, R12 or R13 are not achieved shall be investigated and an impact assessment conducted and appropriate risk mitigation/reduction measures introduced if necessary.	N/A: Out of scope

Table 1: ESASSP requirements

Note: A number of the requirements are out of scope as it is anticipated that ADS-B data for ATC separation services would be fed into a tracker prior to display on an ATCO's terminal. As such the requirements would be made at the tracker level rather than the on the raw data.

3.2.1 Airborne surveillance applications

In addition to assessment against the ESASSP requirements, the assessment will also consider the requirements established for the airborne surveillance applications of EvAcq/AIRB (Enhanced visual Acquisition / Basic Airborne Situation Awareness) and TSAA (Traffic Situational Awareness with Alerts) as specified in ED-194A (10).

3.3 Metrics

This section provides an overview of the metrics collected in the trial to support the assessment of the requirements listed in section 3.2.

3.3.1 Horizontal position error

ADS-B data item compared: ASTERIX I021/130 (Position in WGS-84 co-ordinates).

Assessed against ESSASP 3N_C-R4.

The horizontal position error, along track and across track errors[6] were computed against a 'pseudo radar plot' taken along the interpolation between two consecutive radar plots for the same ADS-B position receive time. The horizontal position error is the absolute distance between the ADS-B reported position and the pseudo radar plot. An example of this process is given in Figure 2 below.

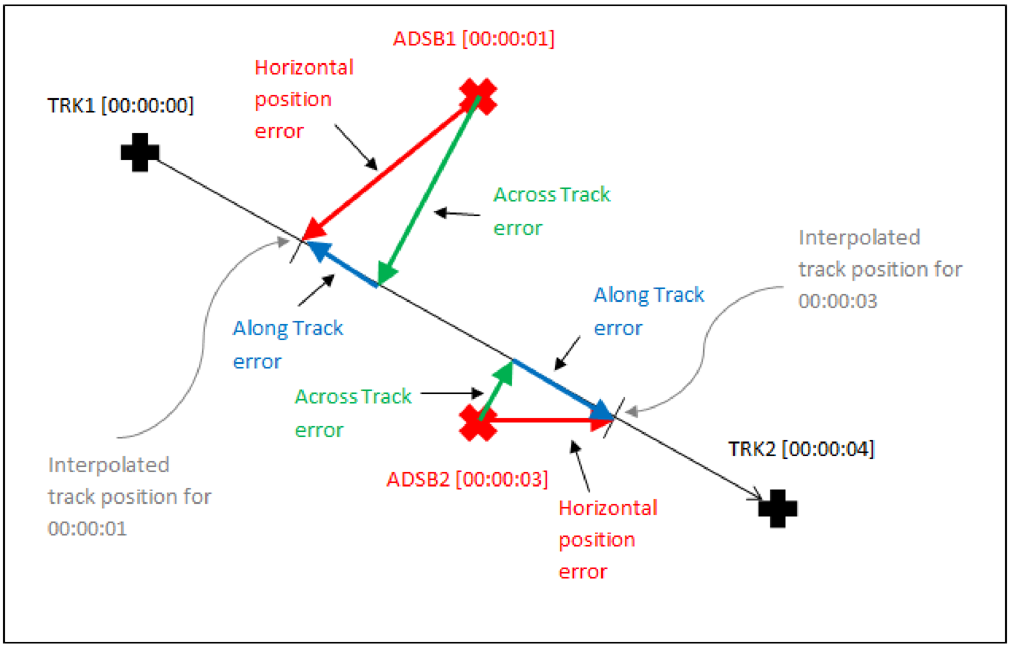

Figure 2: Overview of horizontal position error (HPE) assessment

3.3.1.1 Along track error

The along track error is the component of the horizontal position error of a direct, straight line course between the two consecutive radar plots. See Figure 2 above. *It is expected that due to delays between the transponder broadcasting the position in the ADS-B message, the distribution of the along track error will be shifted negatively from the track position.*

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[6] This document uses the term 'error' to describe the distances measured between the ADS-B reported position and the NODE-L tracked position; however for some consecutive error instances it is not possible to determine whether it is the ADS-B positions or track positions that are in error.

3.3.1.2 Across track error

The across track error is the component of the horizontal position error that is tangential to the interpolation between the two consecutive radar plots. See Figure 2 above. *It is expected that the across track distribution will follow a Gaussian distribution centred on the interpolation of the track data.*

3.3.2 Consecutive errors

Assessed against ESASSP 3N_C-R5.

Consecutive errors are a concern as infrequent single large plot deviations can often be considered as outliers by a tracking algorithm or visually discarded by controllers. Consecutive errors, can cause credible corruption of the tracker output, and therefore present a significant concern.

3.3.3 Probability of Update

Assessed against ESASSP 3N_C-R2 and 3N_C-R3.

The 'probability of update' metric is used to demonstrate that the position is consistently reported to, and received by the ATC surveillance tracking systems. Infrequent and/or sporadic updates could generate an erroneous or confusing display picture to air traffic controllers. It should be noted that the probability of update can be affected by the detection coverage of the ground systems and/or the reporting capabilities of the airframes assessed.

3.3.4 Mode C

ADS-B data item compared: ASTERIX I021/145.

Assessed against ESASSP 3N_C-R11.

The 'Mode C' metric measures the difference between the Mode C (FL) reported by the interrogation of the transponder (Mode S) and the flight level broadcast via ADS-B. It is not anticipated that this will be different given the same source of the data.

3.3.5 Ground speed

ADS-B data item compared: ASTERIX I021/160 Airborne Ground Vector.

The ADS-B ground speed measurement is derived from the GPS of the airframe, while the radar groundspeed measurement is based on the tracking of successive radar plots. This metric records the difference between the two measurements.

3.3.6 Altitude reporting capability

ADS-B data item examined ASTERIX I021/040 Target Report Descriptor

The altitude reporting capability details whether the aircraft is providing 25ft or 100ft reporting capability via ADS-B.

3.3.7 Mode A

ADS-B data item compared: ASTERIX I021/070 Mode 3/A Code.

Assessed against ESASSP 3N_C-R14.

This metric records whether the four digit octal identification code provided via ADS-B matches the code derived via interrogation of the transponder (Mode S). It is not anticipated that this will be different given the same source of the data.

3.3.8 Aircraft identification

ADS-B data item compared: ASTERIX I021/170 Target Identification.

Assessed against ESASSP 3N_C-R14.

This metric records whether the eight character aircraft identification (ACID) provided via ADS-B matches the ACID derived via interrogation of the Mode S transponder.

3.3.9 MOPS version

ADS-B data item examined: ASTERIX I021/210.

Minimum Operational Performance Specification version (MOPS) 'Version 0' is given to aircraft compliant with DO-260, 'version 1' with DO-260A and 'version 2' Do-260B / ED-102A (5). *All participant aircraft are either 'version 1' 'version 2'; it should be noted however that if the message type field that reports the MOPS capability has not been received for a while the ADS-B CPS will assume the MOPS capability is 'version 0'.*

3.3.10 Navigational Integrity Category

ADS-B data item examined: ASTERIX I021/090.

Navigational Integrity Category (NIC) is quality indicator provided by ADS-B installations compliant with MOPS 'version 1' and 'version 2'. The indicator provides the containment radius of the reported position (similar to RNP containment radius). The NIC is reported in conjunction with the SIL (see section 3.3.12).

For the purposes of the trial the airframes were permitted to participate if either the NIC and / or the SIL were set to zero to indicate 'no integrity' of the reported ADS-B position.

NIC (Notes 1, 2)	Horizontal and Vertical Containment Bounds	Comment	Notes
0	$R_C \geq$ 37.04 km (20 NM)	Unknown Integrity	
1	$R_C <$ 37.04 km (20 NM)	RNP-10 containment radius	6
2	$R_C <$ 14.816 km (8 NM)	RNP-4 containment radius	3, 6
3	$R_C <$ 7.408 km (4 NM)	RNP-2 containment radius	6
4	$R_C <$ 3.704 km (2 NM)	RNP-1 containment radius	6
5	$R_C <$ 1852 m (1 NM)	RNP-0.5 containment radius	6
6	$R_C <$ 1111.2 m (0.6 NM)	RNP-0.3 containment radius	6
7	$R_C <$ 370.4 m (0.2 NM)	RNP-0.1 containment radius	6
8	$R_C <$ 185.2 m (0.1 NM)	RNP-0.05 containment radius	6
9	$R_C <$ 75 m and VPL < 112 m	e.g., WAAS HPL, VPL	4, 5
10	$R_C <$ 25 m and VPL < 37.5 m	e.g., WAAS HPL, VPL	4, 5
11	$R_C <$ 7.5 m and VPL < 11 m	e.g., LAAS HPL, VPL	4, 5

Table 2: NIC quality indicator values (ref(7))

3.3.11 Navigation Accuracy Code for position

ADS-B data item examined: ASTERIX I021/090.

Navigation Accuracy Code for position (NACp) provides the expected accuracy of the reported geometric position.

Table 3 below details the breakdown of NACp possible values.

NAC_P	95% Horizontal and Vertical Accuracy Bounds (EPU and VEPU)	Comment	Notes
0	EPU ≥ 18.52 km (10 NM)	Unknown accuracy	
1	EPU < 18.52 km (10 NM)	RNP-10 accuracy	1
2	EPU < 7.408 km (4 NM)	RNP-4 accuracy	1
3	EPU < 3.704 km (2 NM)	RNP-2 accuracy	1
4	EPU < 1852 m (1NM)	RNP-1 accuracy	1
5	EPU < 926 m (0.5 NM)	RNP-0.5 accuracy	1
6	EPU < 555.6 m (0.3 NM)	RNP-0.3 accuracy	1
7	EPU < 185.2 m (0.1 NM)	RNP-0.1 accuracy	1
8	EPU < 92.6 m (0.05 NM)	e.g., GPS (with SA)	1
9	EPU < 30 m and VEPU < 45 m	e.g., GPS (SA off)	2
10	EPU < 10 m and VEPU < 15 m	e.g., WAAS	2
11	EPU < 3 m and VEPU < 4 m	e.g., LAAS	2

Table 3: NACp quality indicator values (ref (7))

3.3.12 Source Integrity Level

ADS-B data item examined: ASTERIX I021/090

Source Integrity Level (SIL) is an ADS-B quality indicator that is complementary to the NIC. The SIL specifies the probability of the actual position lying outside of the containment radius specified by the NIC without alerting the flight crew.

3.3.13 Priority status

ADS-B data item examined: ASTERIX I021/200 (Target Status)

Priority status (PS) bits are set to indicate an emergency on the airframe.

As an emergency within the trial is an unlikely event, any indication of the PS bits would be investigated for authenticity.

4 Results

4.1 Overview

Nine general aviation aircraft were accepted into the GPS Trial on a rolling basis from April 2015.

This comparative assessment examines 156 days of data collected between 1st of May 2015 to 3rd of October 2015.

Spatial filtering was used to reduce aircraft performance variation between the datasets as a result of effects observed in a previous assessment. This variation was due to the large proportion of aircraft in the baseline comparator fleet undertaking high-level typically straight and level en-route flights over the UK, which is in contrast to the low level often turning GA flights in the trial. The spatial filter rejects all data plots above FL100 and outside of a rectangle bounded by WGS84 coordinates 002E, 003W, 53N and 50.5N.

For the GPS Trial, 341,128 spatially filtered ADS-B messages were assessed against to the NODE-L track data and are shown in Figure 3 below. A further 40,691 messages where the aircraft reported the same latitude and longitude at the same time in succession were removed to reduce biases caused by double counting. It is conjectured that these 'double counts' arise from the reception of an ADS-B message by two ground stations at essentially the same time, but not removed by the tracking aspect of the ADS-B Central Processing System (CPS).

The 341,128 ADS-B messages were compared to 111,976 NODE-L multi-radar track updates; corresponding to 124.4 flight-hours (assuming an average tracker update period of 4 seconds.)

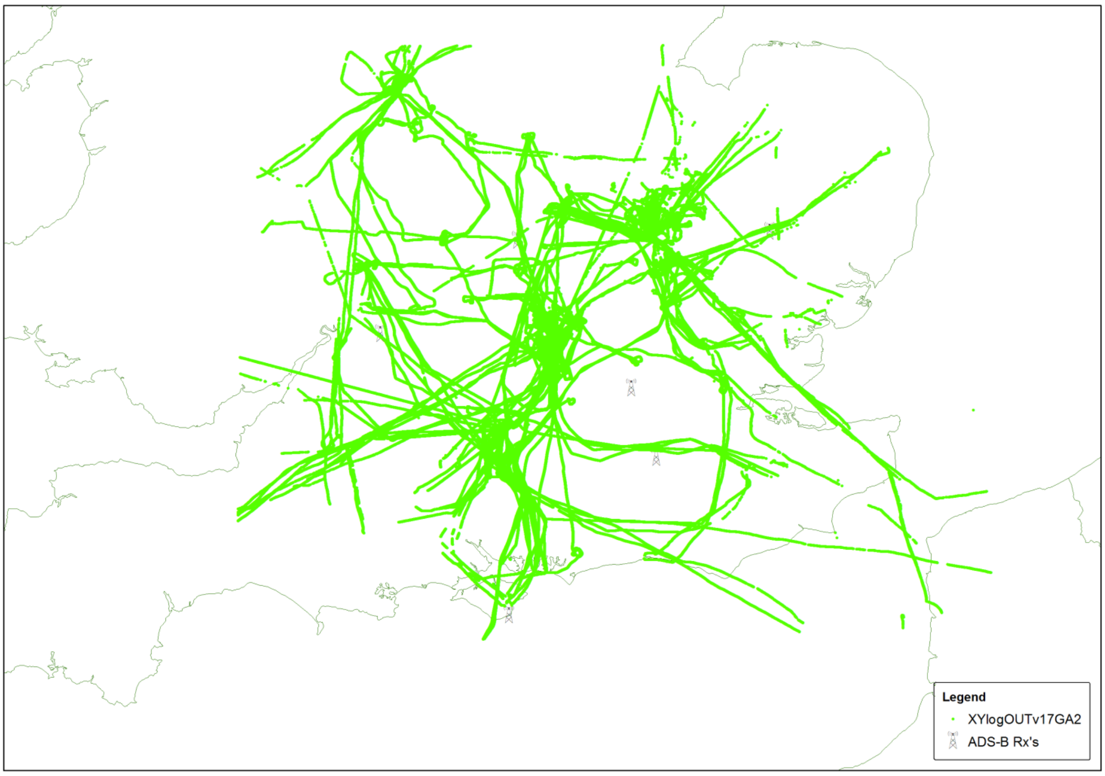

Figure 3: All GA trial ADS-B position reports

The spatially filtered comparison fleet dataset comprised of 8,435,800 ADS-B position updates that were assessed against 2,488,227 track updates which are shown in Figure 4 below. The number of track updates corresponds to approximately 2,765 flight hours of recordings.

Despite the spatial filtering, the flight profiles of the datasets are still markedly different; however both datasets now exhibit large numbers of turns. As commercial aircraft are typically faster, the speed of the airframes and therefore spacing between position updates is also expected to differ, potentially altering the along track error component.

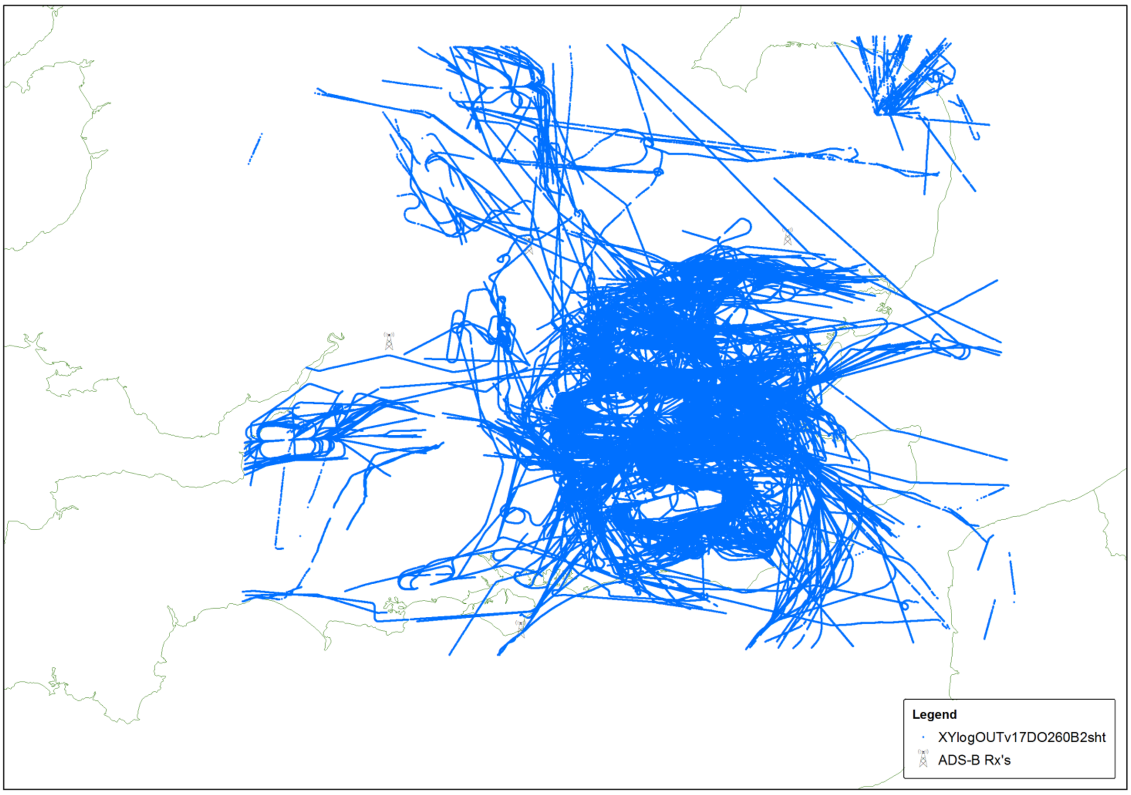

Figure 4: All DO-260B/ED-102A (ref (5)) compliant comparison ADS-B position reports used in the assessment

4.2 Horizontal position error

The summary statistics of the horizontal position error (HPE) provided by the trial airframes indicate a median value of 34.04m, a mean of 43.94m and a standard deviation of 600.5m. The standard deviation is large due to four extremely large outliers emerging from one airframe. Removing the four outliers reduces the standard deviation to 46.6m and mean to 42.02m.

The maximum HPE error recorded in the data sample was 268,956m (145.2NM) and 8,297m (4.48NM) with the four outliers removed. Further investigation into the large HPE deviations within this dataset is provided in section 4.15.1

In terms of compliance to ESASSP 3N_C-R4; the average HPE of 43.94m is well within the 300m required value, and 210m recommended value. Furthermore 340,594 (99.84%) of the horizontal position errors were less than 300 m. However, ESASSP 3N_C-R4 also required that no individual flight should have an average HPE of greater than 330m; although this assessment did not record metrics on individual flights, it did record metrics on each airframe where all airframes recorded average HPE's well within 300m (32.53m – 83.63m)[7]..

When compared to the DO-260B/ED-102A (5) compliant comparison fleet; 8,412,563 (99.7%) of the 8,435,800 ADS-B messages had a horizontal position error of less than 300m, providing a mean HPE of 40.35m. It should be noted that the 'whitelist' used to define the comparison fleet contained 1,935 aircraft, of which 878 flew within the spatially filtered coverage assessment volume and were therefore eligible for assessment. As was the case with the GA trial fleet, there were several large outliers (max HPE was 216,000m) that increased the entire sample standard deviation to 702.7m.

The location of the GA trial horizontal position errors greater than 300m, are highlighted in pink in Figure 5 below. No statistical analysis has been conducted on the geographical location of the HPE to ascertain any possible correlation

It was noticed that one particular airframe was contributing to the very large outliers observed. Section 4.15.2 investigates the effect this airframe had on the horizontal position assessment.

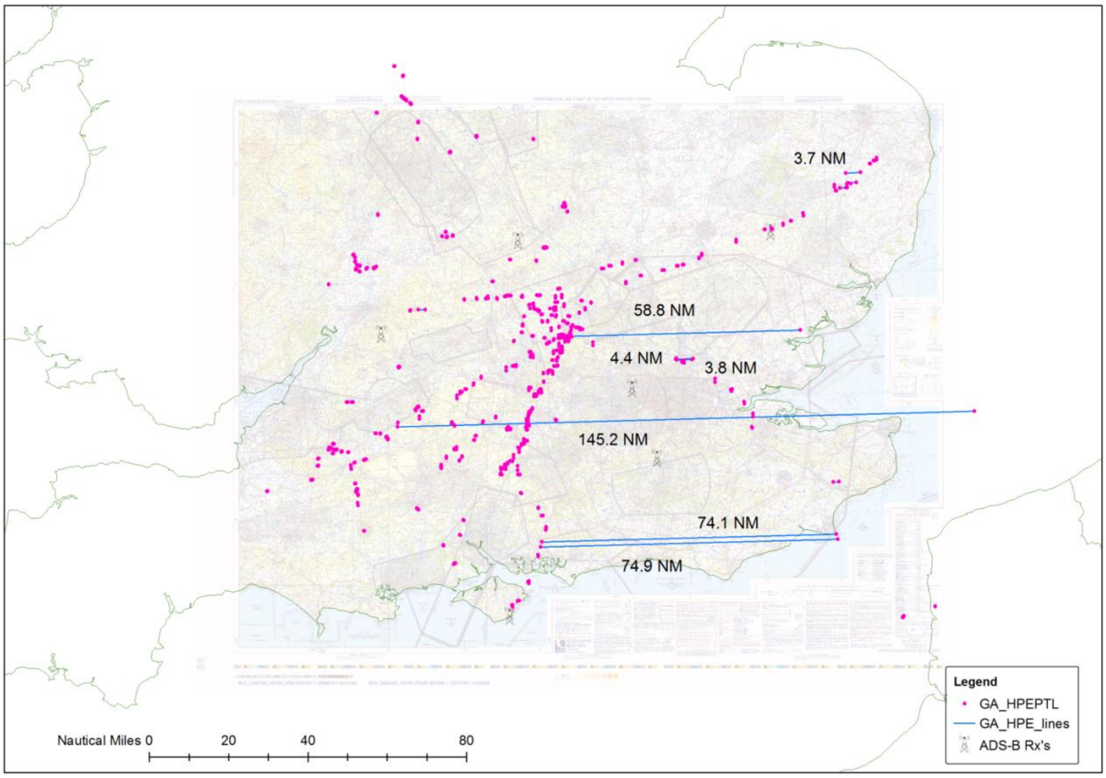

Figure 5: GA Trial Horizontal Position Errors > 300m

The location of the HPE's > 300m in the comparator dataset are displayed in Figure 6 below. The figure indicates that two distinct collections of very large horizontal position errors. See section 4.15.2 for further investigation of these errors.

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[7] The requirement for ESASSP 3N_C-R4 is clearer in ESASSP volume 2 (2)

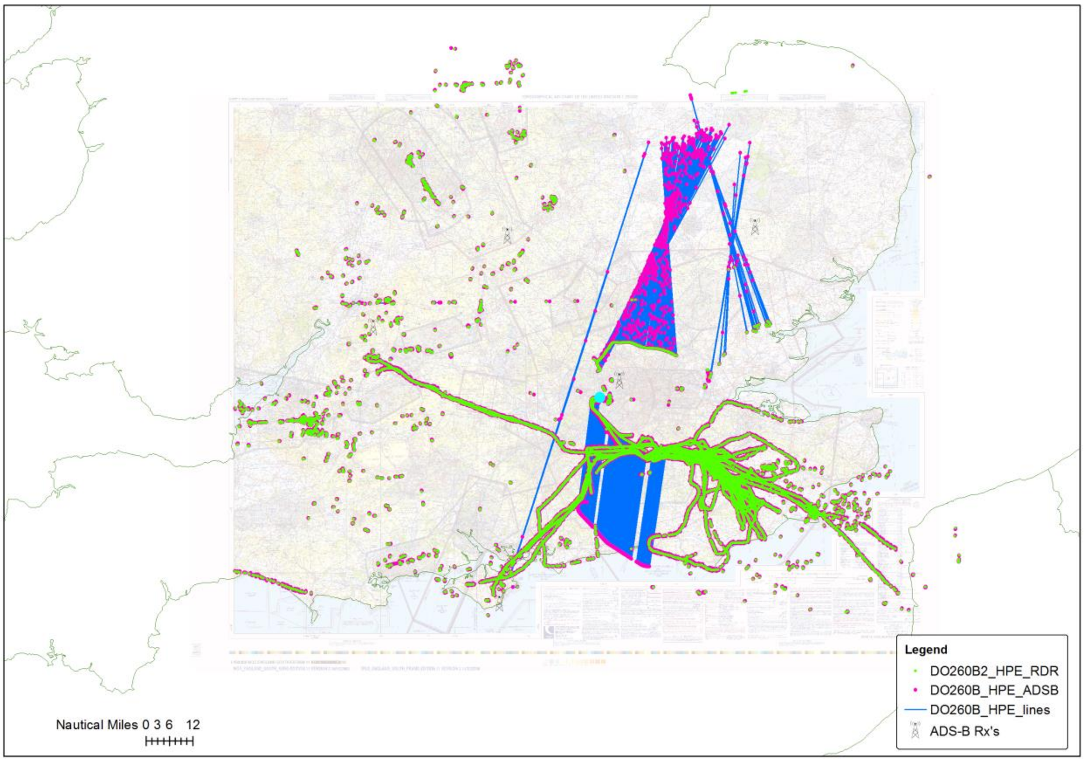


Figure 6: Comparator Horizontal Position Errors > 300 m

The summary statistics for the HPE recorded by the comparison fleet indicated a median value of 28.09m, a mean of 40.35m and a maximum value of 215,600m which contributed to giving a standard deviation of 702.7.

A '1 – Cumulative Distribution Function' of the horizontal position errors in each sample recorded in the trial is displayed in Figure 7 below. *Note the log scale on the y axis.*

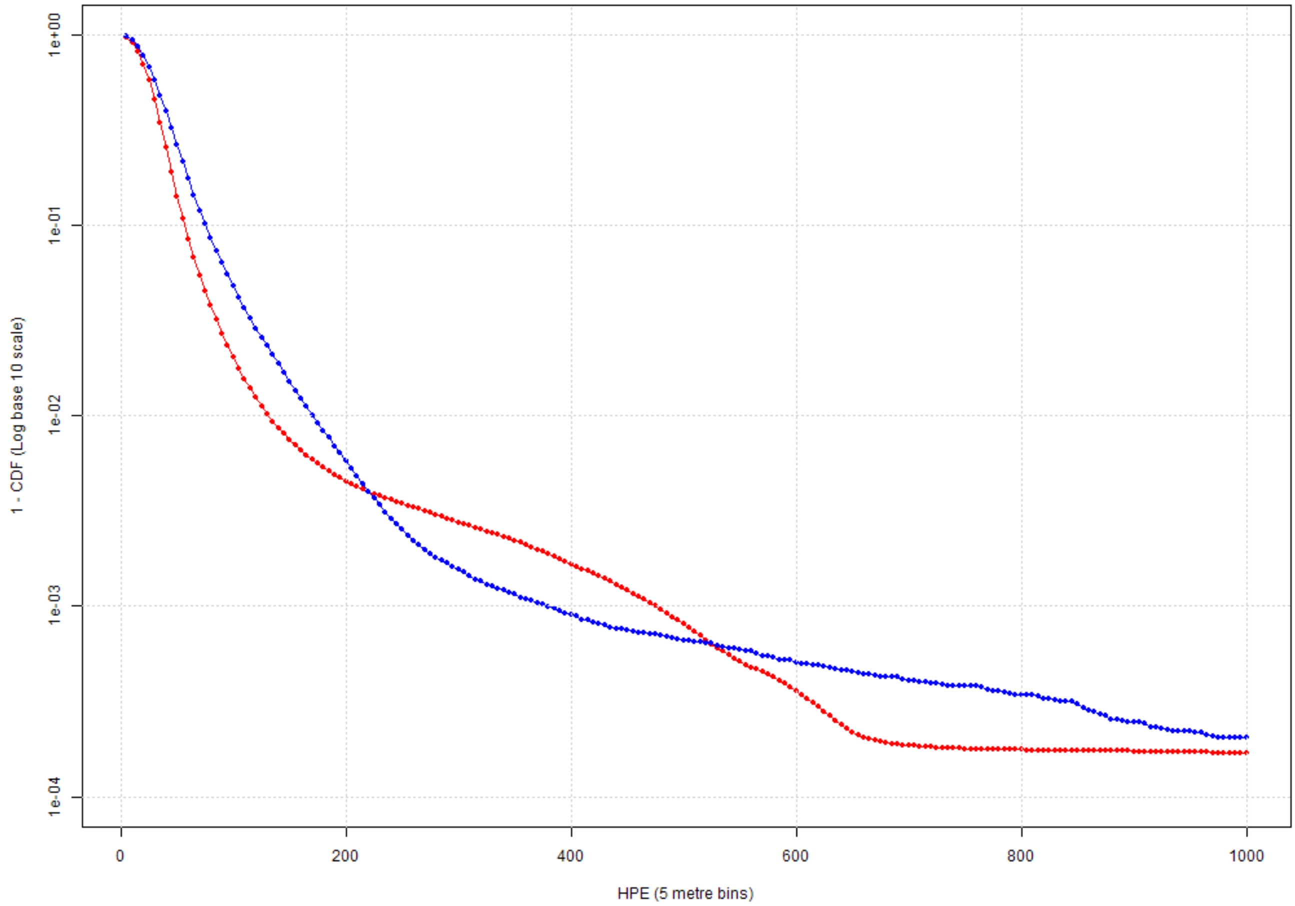


Figure 7: HPE distributions as '1 – Cumulative Distribution Function' of total plots in each dataset (log 10 scale), *GA fleet in blue, Comparator fleet in red*

In Figure 7 above, it can be seen that initially for low HPE values (less than 50m) the distributions are quite similar. However, for HPE values between 50 and 300m, the comparator fleet is observed to be more accurate than the GA trial fleet. Beyond 450m, the number of total plots available in each sample to generate the fractions dominates, limiting the confidence in the comparison. Both samples have long tail residuals.

Overall, the flatter distribution of the GA trial fleet indicates that the GA fleet has larger errors and is therefore less accurate than the certified GPS comparator fleet. This is to be expected, as these effects may be due to functions or installed nature of certified installations.

It should be noted that the analysis of the horizontal position error is conservative, as the 'truth track' in this assessment is provided by the multi-radar tracker and is therefore subject to track delay when aircraft begin to manoeuvre laterally, particularly in tight turns, such as those often undertaken by the trial participants.[8] Figure 8 below illustrates an example of this tracking delay contributing to a large HPE. In this figure, the green triangles are the ADS-B position updates, the pink circles are the ADS-B position updates identified with a HPE > 300m and the blue circles are the pseudo radar points plotted along the interpolation between consecutive tracked radar plots. The aircraft in this instance is undertaking a relatively tight left turn into its destination

[8] Tracker derived turn direction information was not available for the GA trial aircraft so it was not possible to assess the accuracy of turns or exclude turns from the analysis.

airfield and the tracker takes approximately four plots (actual track plots not displayed) to match the ADS-B position updates on the turn.

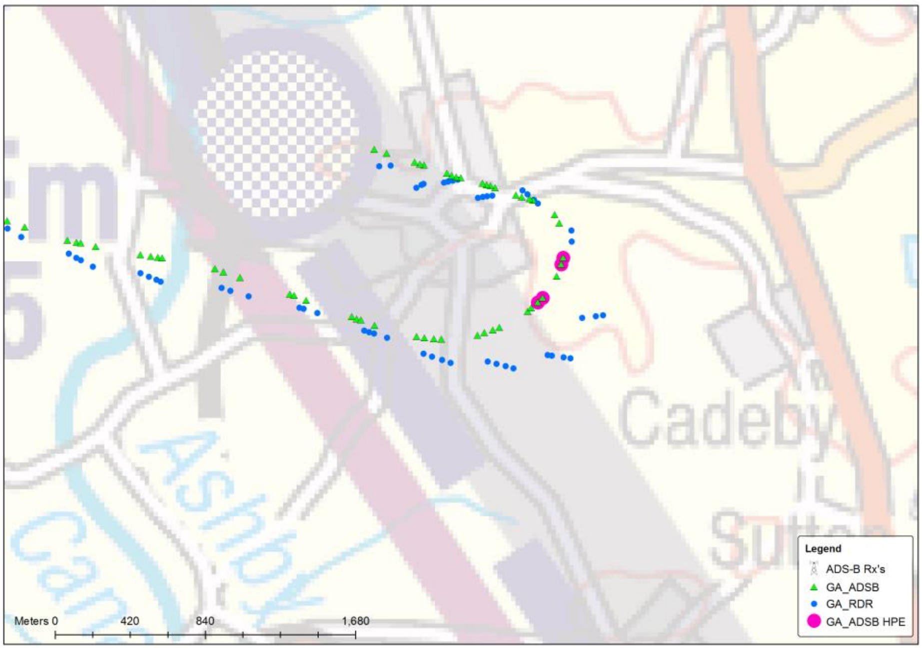


Figure 8: Example of tracking delay identified as a HPE

Figure 8 also illustrates a ‘pulsing’ effect of spurts of ADS-B position updates in quick succession. This effect should be investigated in an ADS-B compatible tracker for assessment e.g. ARTAS V8B3.

Overall, the horizontal position error from the GA trial is slightly worse than the comparison fleet, but still within the ESASSP requirements. However, this is overshadowed by several very large single errors that are investigated further in section 4.15.1.

4.2.1 Along track error

The central peak of the along track error distributions of the GA trial fleet and comparison fleets are of the same magnitude, indicating similar performance amongst the two fleets. The distributions are asymmetric around zero and the difference between the two distributions is greater on the negative side of the distribution. The reason for this disparity is unknown, but it is reasoned that this is likely due to the electronics involved on the airframe delaying the measured position.

The summary statistics of the along track error produced by the GA trial airframes indicated a mean of -22.47m; however the largest negative value was -253,594m, the largest positive value was 56,027m, which contributed to a standard deviation of 492m (removing the airframe that caused the particularly large deviations reduced the standard deviation to 32m). The large outliers are the same outliers identified in sections 4.2 and investigated further in section 4.15.1.

Although the comparison fleet along track error also had some outliers, the mean was found to be -19.5m with the standard deviation 653m driven by the large outliers previously identified, the minimum -215,585.95 being and the maximum 131,760.17. As with the GA fleet, further investigation revealed that a particular airframe was causing the large deviations, removing this airframe reduced the standard deviation to 175m. This investigation is detailed in section 4.15.2

A chart comparing the along track error of each fleet is provided in Figure 9 below.

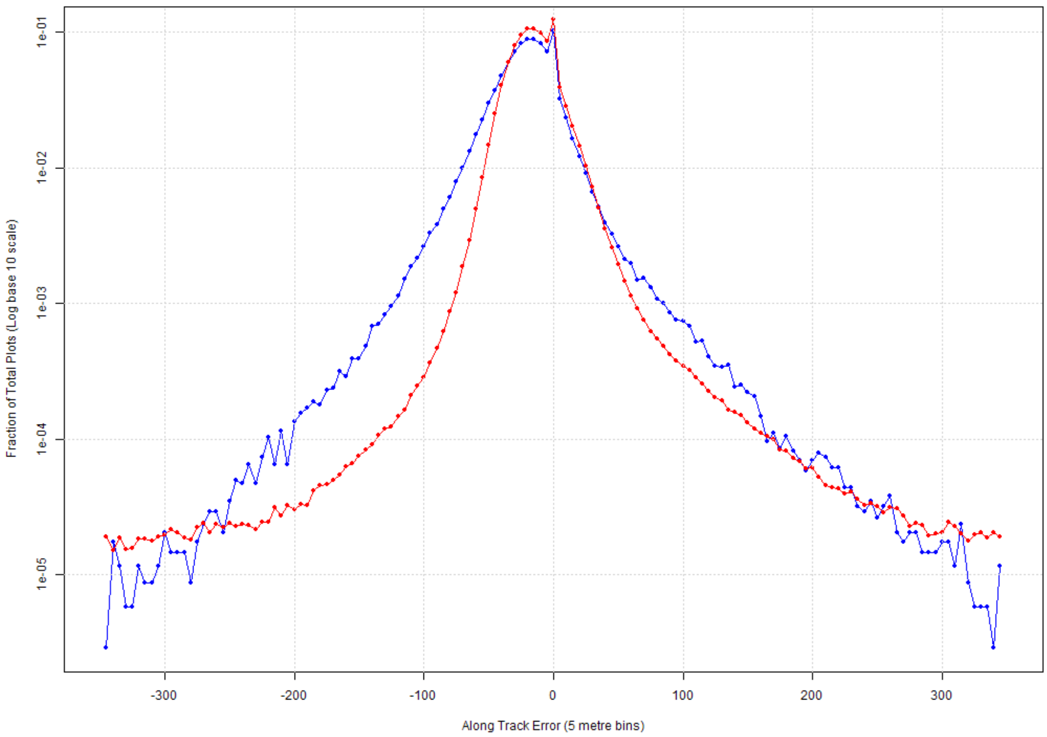


Figure 9: Along track error distributions as fraction of total plots in each sample (y axis log 10 scale), *GA fleet in blue, Comparator fleet in red*

4.2.2 Across track error

The across track error distribution generated by all the trial airframes is shown below Figure 10.

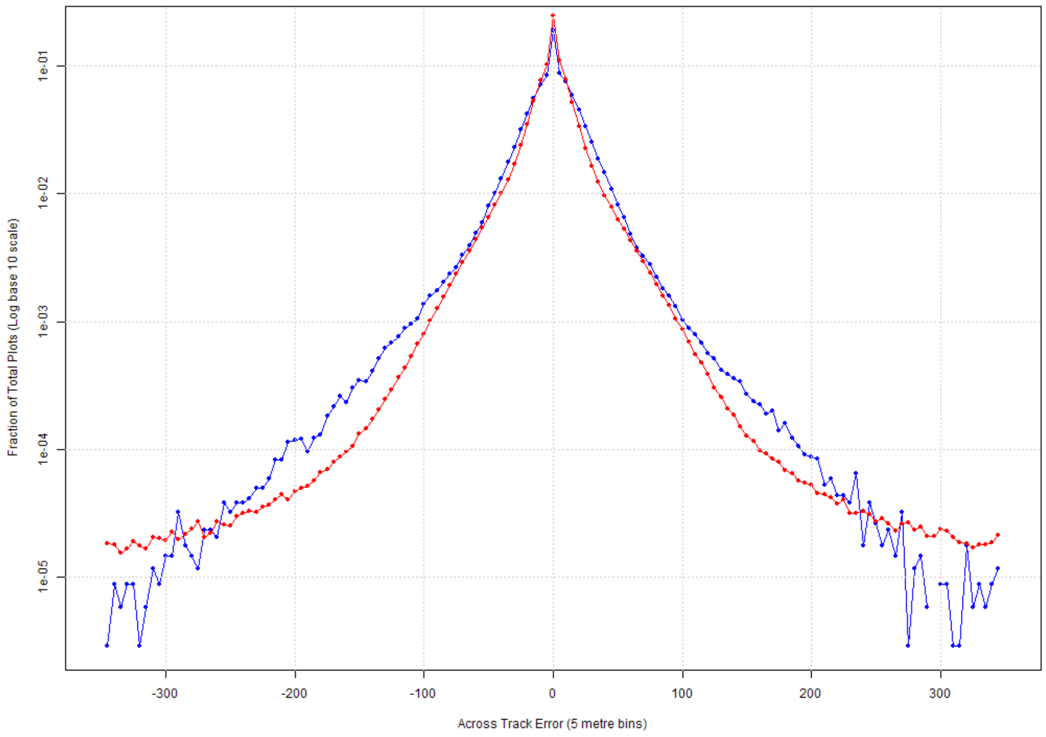


Figure 10: Across track error distributions as fraction of total plots in each sample (y axis log 10 scale), *GA fleet in blue, Comparator fleet in red*

Overall a visual comparison of the core distributions between plus and minus 100m is near identical although, as with the along track error, the flatter error distribution of the GA fleet is also present in the across track error.

The mean of the trial airframes across track error was found to be -0.27m, with a standard deviation of 346m, which was driven by the extreme outlier values of -127,527m and + 89,595m. As investigated in section 4.15.1, removing one airframe from the analysis altered the maximum across track error to 507m and the standard deviation to 33m.

The across track error of the comparison fleet was similar to of the trial participants, with a mean value of -1.02m, and a standard deviation of 261m. The maximum outlier values was -51,893m.

4.3 Consecutive errors

In the trial data sample, there were 534 (0.156%) Horizontal position errors greater than 300m. Of these, 228 (0.067%) instances were recorded where there were two or more consecutive horizontal position errors of greater than 300m. This compares to 23,236 (0.275%) HPE's greater than 300m and 8,535 (0.101%) instances where there were two or more consecutive HPE's of greater than 300m in the comparison fleet, with the longest lasting for 316 position reports.

The consecutive errors (and single HPE's) as plotted in terms of fraction of total reports are shown in Figure 11 below for both fleets.

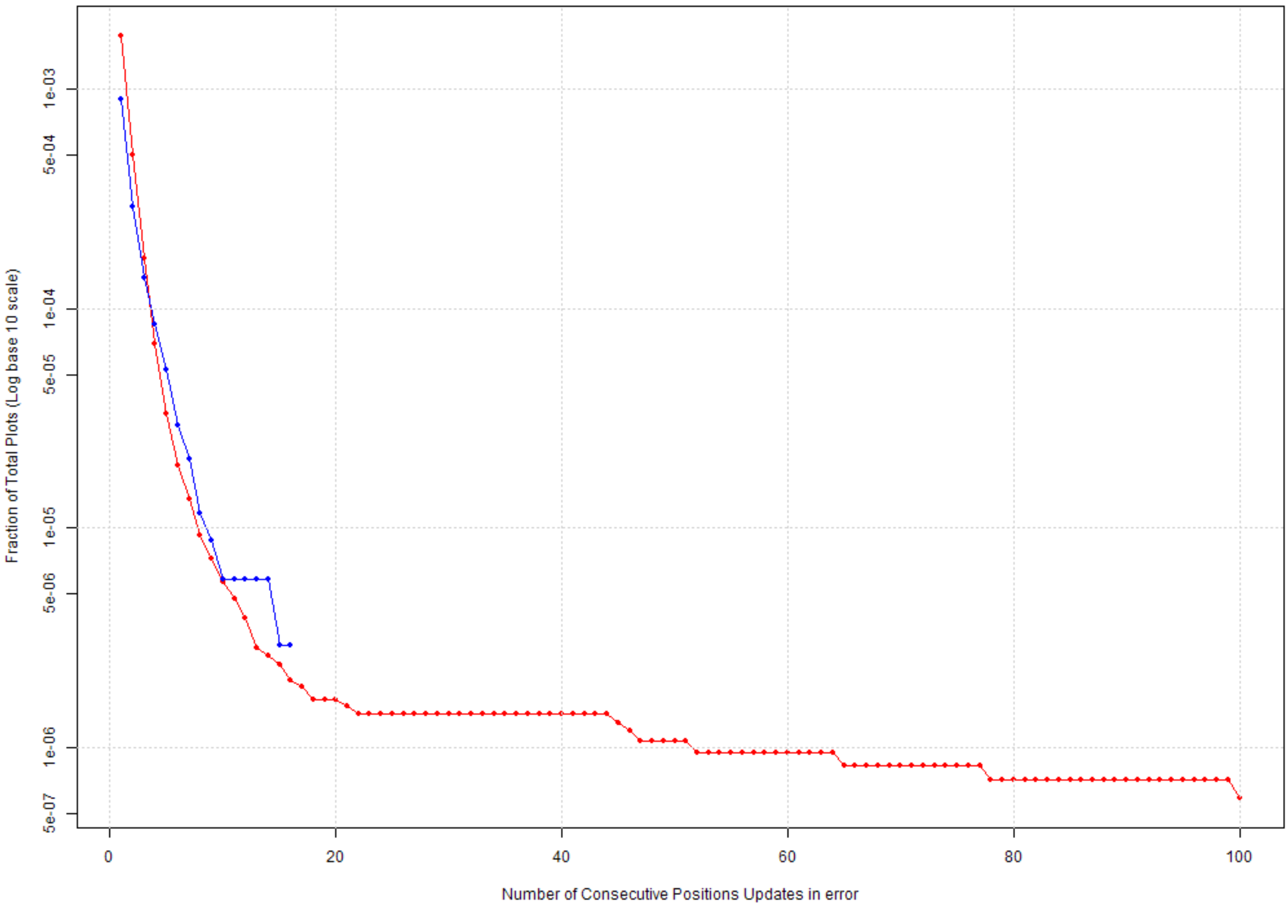


Figure 11: Consecutive errors where HPE > 300m as the fraction of total plots (y axis log 10 scale), *GA fleet in blue, Comparator fleet in red*

Figure 11 which is a log plot of the fraction of instances of consecutive errors against the number of plots involved in each instance, indicates that the occurrence of <15 plot consecutive errors in near identical in both fleets, however data is too limited to draw conclusions in the distribution tails. The fact the distribution where available is similar for both fleets, indicates that the GA fleet is not generating proportionally more consecutive errors than the certified fleet.

To assess compliance against ESASSP 3N_C-R5, albeit with errors > 300m rather than 550m, the number of consecutive errors in the GA fleet with three or more updates was 130 (0.0004%) for the trial and 4,294 (0.0005%) for the comparison fleet.

This indicates that even when using a stricter error threshold of 300m rather than 550m, the GA participant airframes would still be compliant with this requirement, and both fleets are less than one tenth of the requirement's 0.03% criteria.

This result suggests that there is a very low chance that large errors in GA ADS-B horizontal position could cause credible corruption under fault-free GPS conditions. However the magnitude of the large horizontal position errors in both fleets suggests that a means of continual or recurrent independent verification of the positions should be considered if the position reports were to be used for separation provision, and strict mitigation or acceptability of impact studies undertaken for simulated GPS fault conditions.

For reference the locations of consecutive errors recorded within the GA trial fleet and comparator fleet are provided in Figure 12 and Figure 13 below:

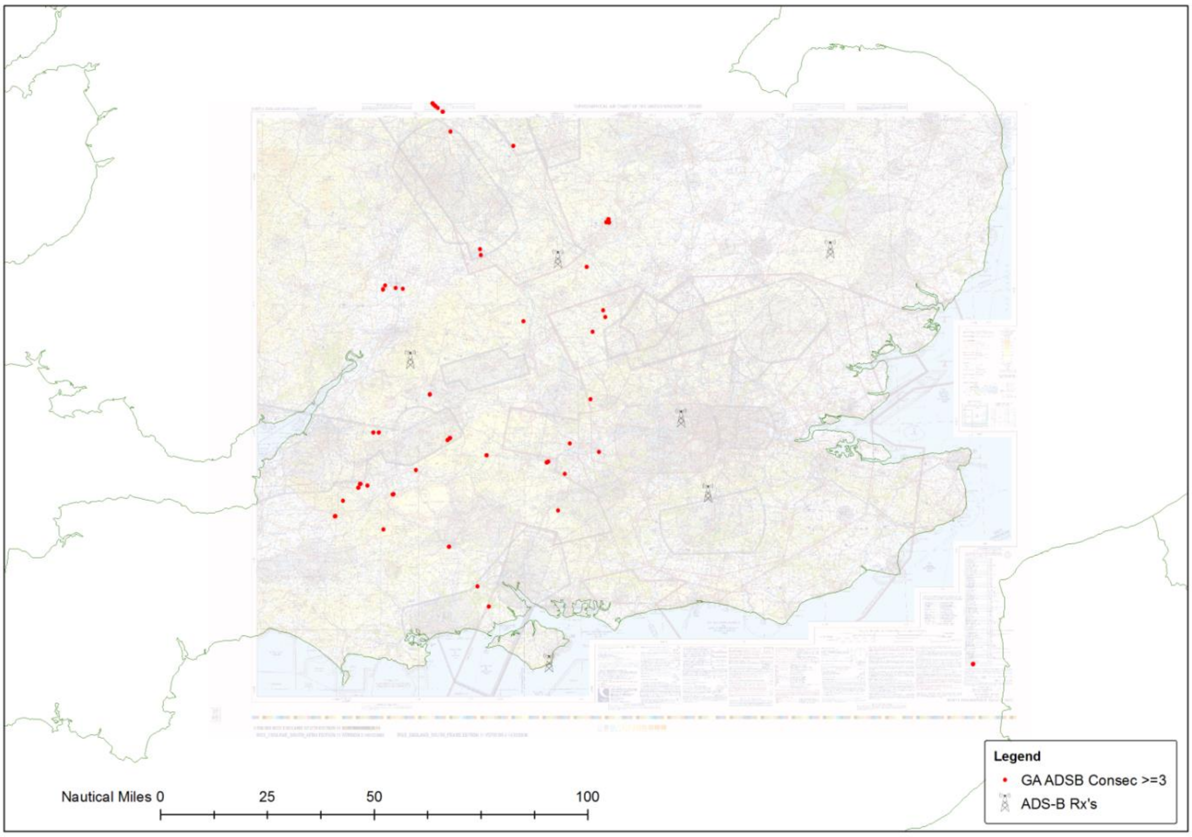


Figure 12: GA trial consecutive error locations

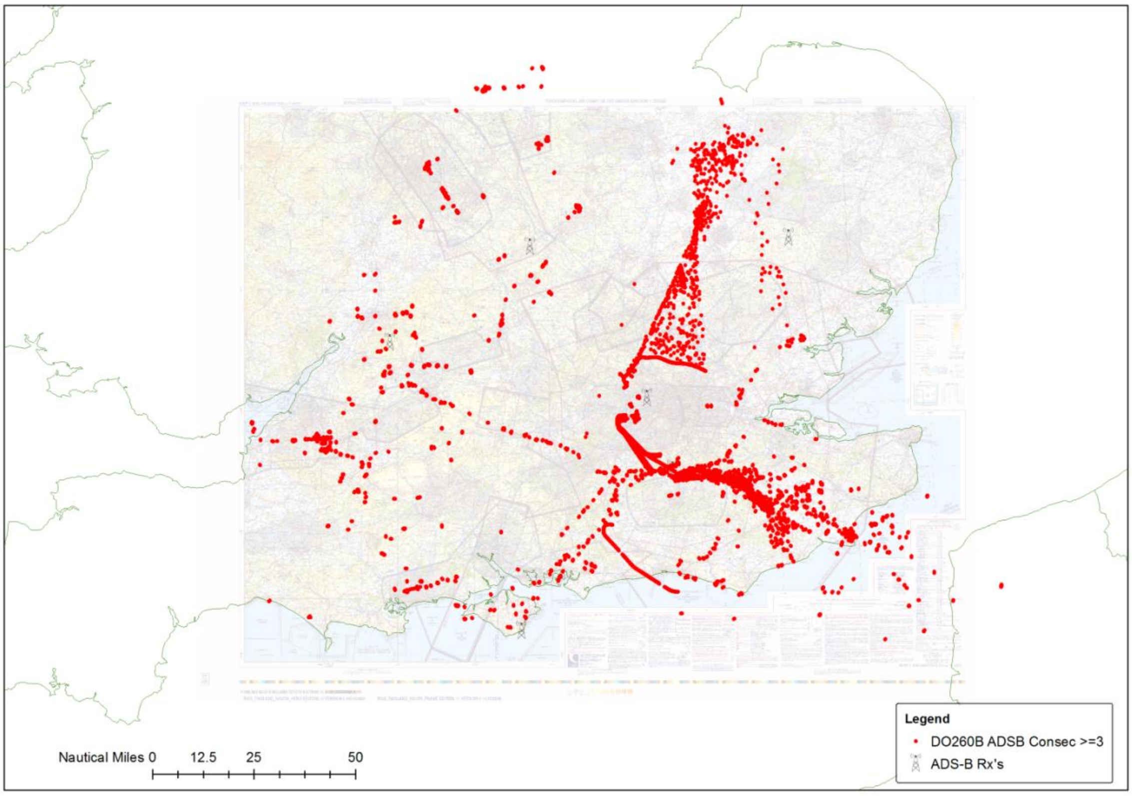


Figure 13: Comparator fleet consecutive error locations

It is also worth noting that only four of the 69 HPE's greater than 1000m were involved in three or more plots of consecutive error..

4.4 Probability of update

The probability of update assessment looked at several aspects of the position updates, namely a record of when position updates were not present between radar updates, long gaps where 16 seconds of missed ADS-B plots were received in succession and the time between ADS-B reports. It should be noted that coverage differences between the ADS-B network and multi-radar track truth data can influence the probability of update measurement.

For the GA fleet, of the 142,339 radar track plots that were used to assess the probability of update metric, 111,965 had ADS-B position updates on or between the next radar track update equating to 78.6% of all radar plots. Instead ESASSP 3N_C-R2 requires that 97% of all flights have a probability of update within the measurement interval for probability assessments, which in this document is taken as 16s (4 x the assessment interval set by ESASSP 3N_C-R1). Therefore, the GA fleet assessment is non-compliant with this requirement.

'Long gaps' which equate to gaps of 16 or more seconds, based on 4 times the assessment interval, accounted for 15.5% of all the radar track plots used in the assessment. Requirement ESASSP 3N_C-R3 stipulates that long gaps should equate to no more than 0.5%. Therefore, on initial inspection the GA ADS-B data is non-compliant with this requirement.

In contrast, the comparator fleet utilised 2,906,043 radar track updates, of which 2,488,023 (85.6%) had ADS-B plots associated with them. With respect to long gaps, (12.2%) of the radar track updates with no associated ADS-B position updates. As with the GA fleet, the comparison fleet would also seem to fail the ESASSP 3N_C-R2 and 3N_C-R3 requirements.

However, Figure 14 below shows the location of the radar plots associated with the ADS-B long gaps in the GA trial. The chart is colour coded to Altitude, with red indicating 0ft and low level, while green indicates 4000 - 5500ft. The spatial distribution of the plots indicates that for many the lack of ADS-B could be due to lack of reception of the signals when the aircraft are at low level. Investigation into the higher altitude long gaps, particularly near the ADS-B ground stations indicates the reception of the reports ended abruptly.

It is not possible to stipulate what is causing the long gaps in the trial although low-level coverage would appear to be a contributing factor in at least some of the instances (despite the theoretical coverage) given the limited number of long gaps occurring in the centre of the receiver network. Furthermore, a fault was subsequently identified with the Chedburgh receiver which would limit low level coverage in the North East of the assessment area.

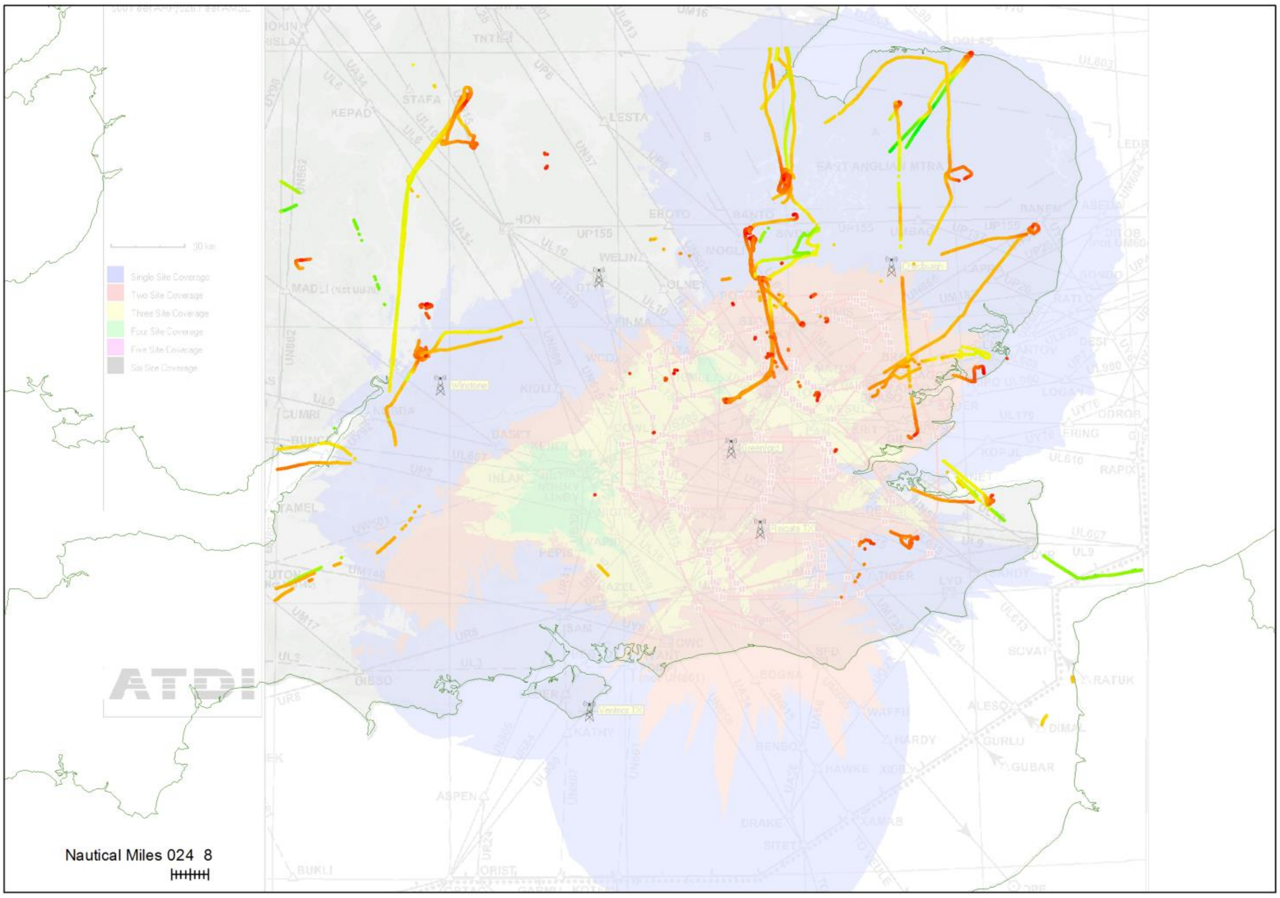


Figure 14: Radar plots of ADS-B 'long gaps' for the GA trial (colour coded by altitude, overlaid on 500ft ARP theoretical ADS-B coverage)

Plotting the long gaps from the comparator fleet in Figure 15 indicates two distinct locations where the aircraft may have been below ADS-B coverage, but also that a number of tracks are completely missing. The plot indicates that the majority of the tracks are headed into and away from Farnborough, Northolt and Biggin Hill and Luton airports that are known hubs for business aviation. A visual inspection of a sample of the aircraft ID's of the aircraft involved in the long gaps indicates that the majority are not for standard commercial flights, instead most likely business aviation; which agrees with the destination and origin airports noted above, although does not answer why this particular group of users would not provide ADS-B when expected to.

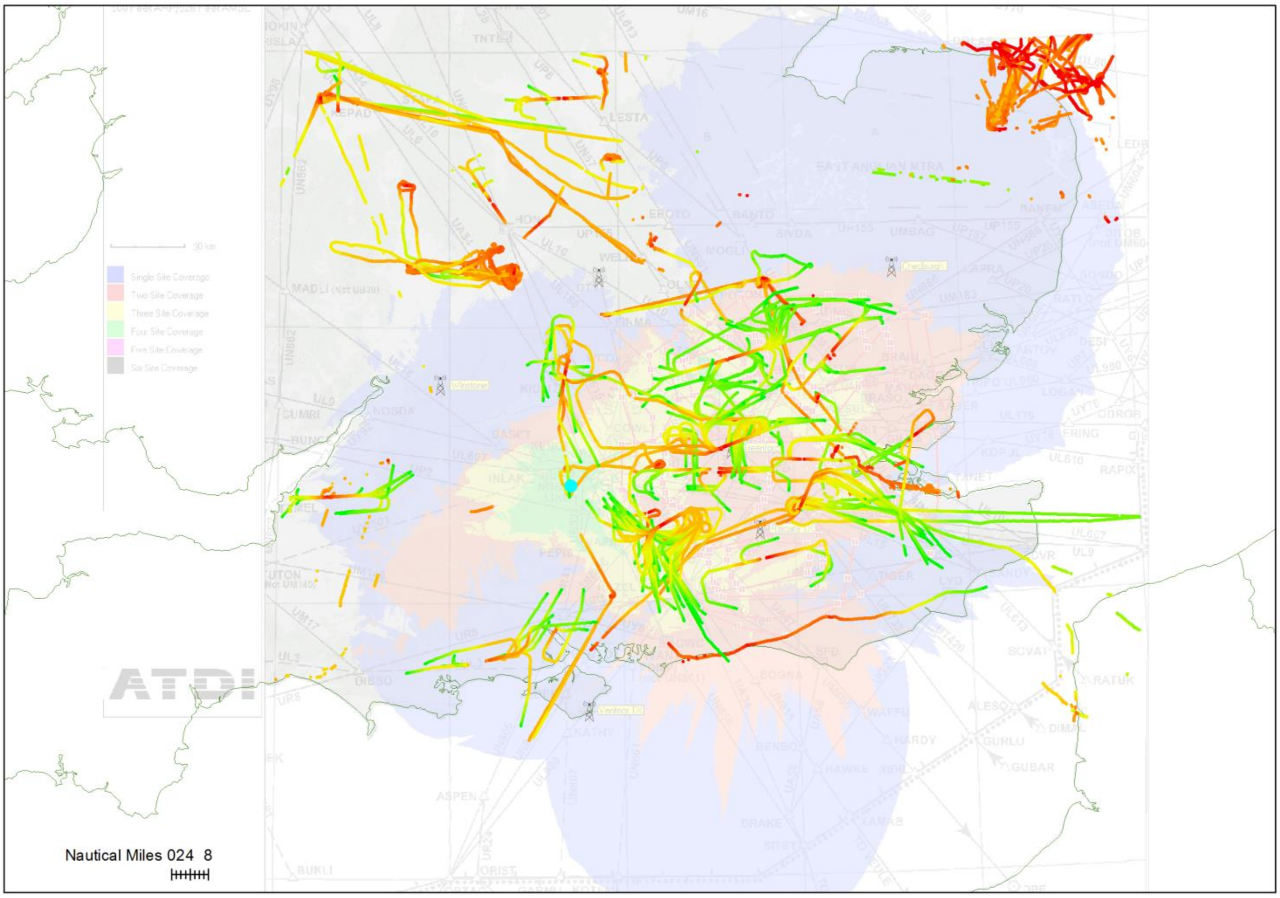


Figure 15: Radar plots of ADS-B 'long gaps' for the comparator fleet (colour coded by altitude, overlaid on 500ft ARP theoretical ADS-B coverage)

When ADS-B reports are received, they generally have a higher update rate than traditional radar. Figure 16 below shows the cumulative probability of an update via ADS-B for both fleets against time. On average, the time between ADS-B position updates from the GA fleet was 1.34 seconds compared to 1.17 seconds in the comparator fleet.

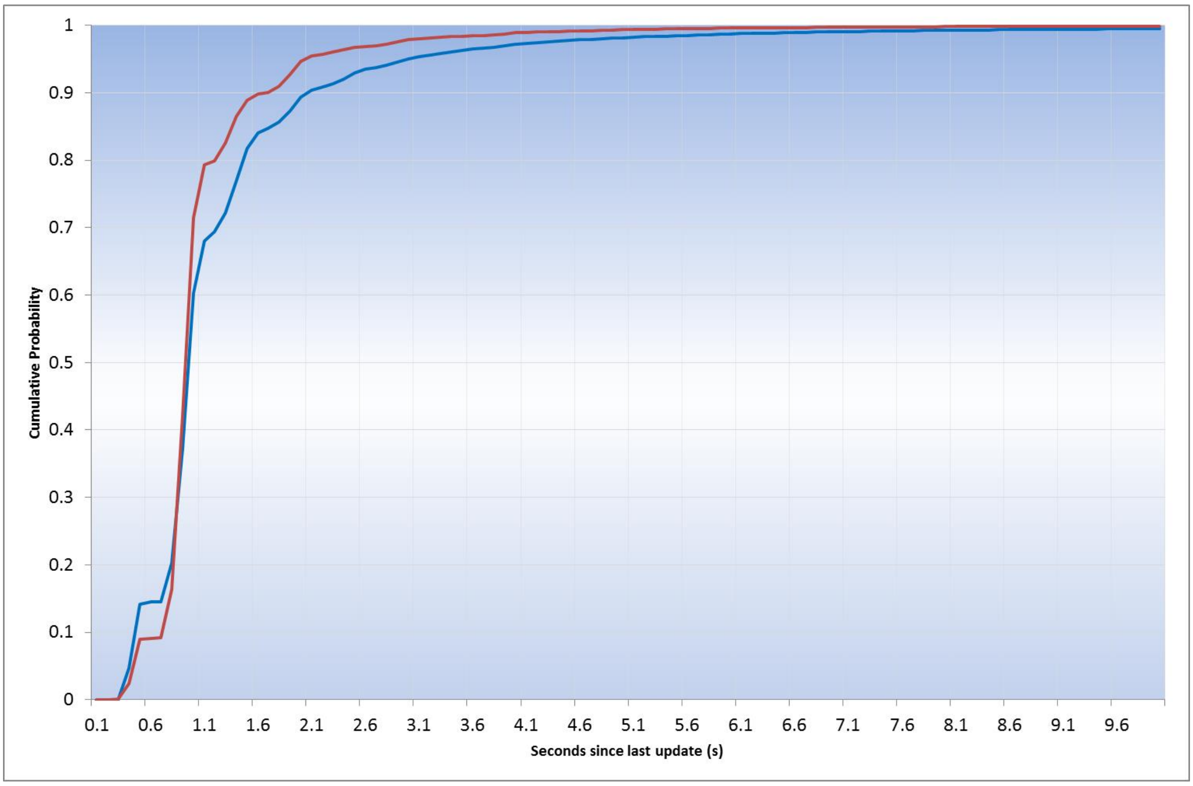


Figure 16: Cumulative probability of time between position updates (*GA is blue, Comparator fleet is red*)

4.5 Mode C & Altitude Reporting Capability

4.5.1 Mode C

The comparison of the reported Mode C (Flight level) was undertaken on the 341,125 (99.999%) of messages where the Mode C value was recorded in the ADS-B data. The frequency distribution of the Mode C error is shown in Figure 17 below.

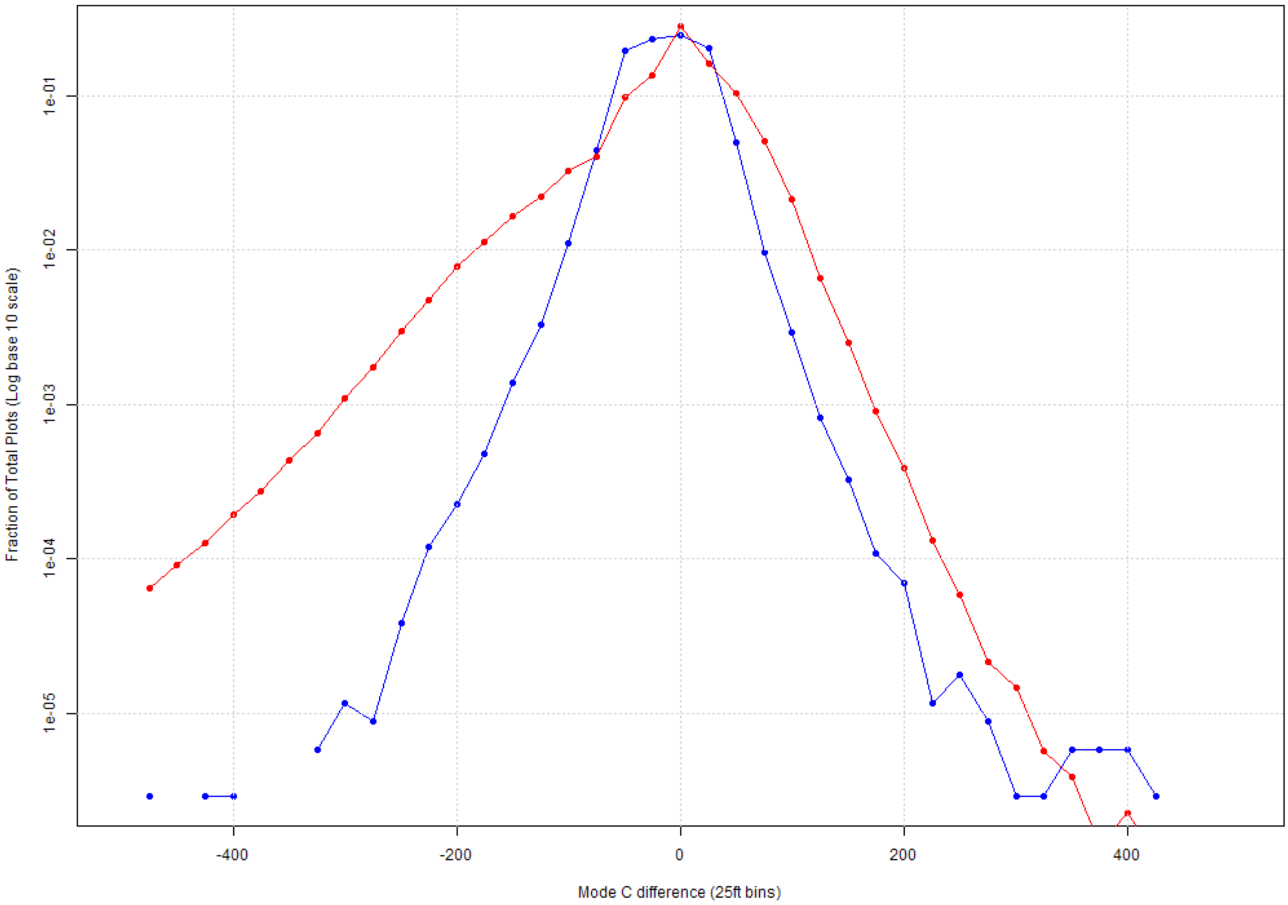


Figure 17: Trial Mode C error distribution (y axis log 10 scale), *GA fleet in blue, Comparator fleet in red*

The mean of the distribution was -12.04ft, while the standard deviation was 36.6ft. The largest negative error recorded was -600ft, while the largest positive error was +750ft.

To assess compliance against ESASSP 3N_C-R11 (which required 99.9%); of the 341,125 messages where a Mode C value was provided by ADS-B; 341,107 (99.99%) were within 300ft of the track value, meeting the requirement.

For reference, the comparison fleet also provided Mode C data via the ADS-B message for 99.999% of the 8,435,800 messages. The error distribution (shown against the trial fleet in Figure 17 above) was greater than that of the GA trial airframes, with a mean of -10.06ft, a standard deviation of 64.75ft, a largest negative error of -1075ft and largest positive error of 1750ft.

The figure shows that the distribution of the comparison fleet is flatter compared to the GA trial fleet, which reflects the greater error in the Mode C value where 99.79% of the reports were within 300ft. The kinematic characteristics of the two fleets could explain the asymmetric difference observed, with higher climb and descent rates expected to be undertaken by the comparator airframes compared to the GA airframes.

4.5.2 Altitude reporting capability (ARC)

All 341,128 ADS-B messages provided the ARC, of which 338,268 (99.16%) indicated an altitude reporting capability of 25ft.

8,312,453 of the 8,435,800 (98.54%) the comparison airframes provided an altitude reporting capability of 25ft, with the reaming 123,347 reporting ing 100ft capability.

4.6 Ground speed

The ground speed was provided in 293,966 (86.17%) of the recorded GA ADS-B messages. It was found that airframe #05 provided no groundspeed reports contributing to 43,693 of the 47,162 reports lacking ground speed.

The mean groundspeed error was calculated to be -0.39kts while the standard deviation of the distribution was 5.41kts. The largest negative error was -97kts, while the largest positive error was +198kts. Figure 18 below shows the groundspeed error distribution of both fleets.

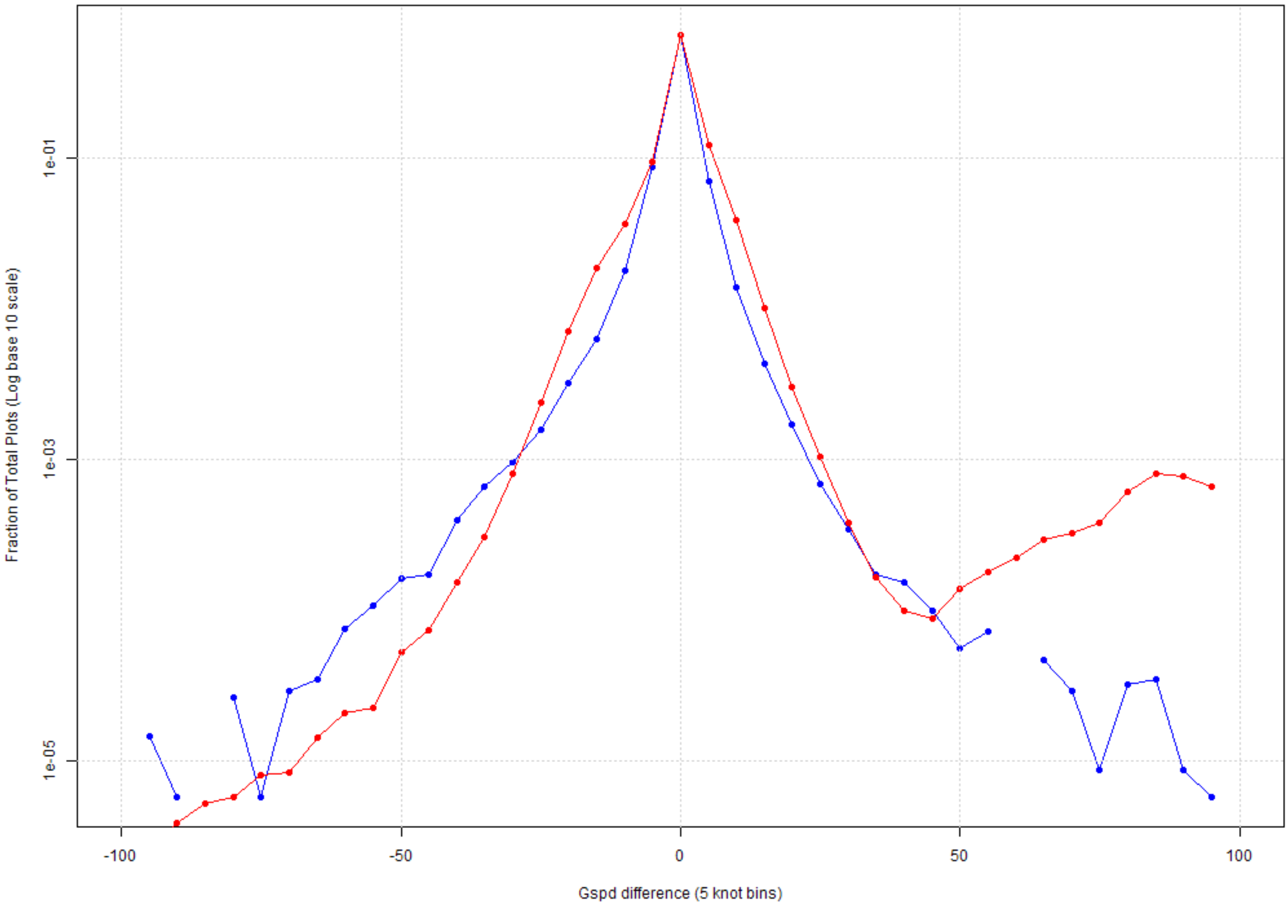


Figure 18: Trial ground speed error distribution (y axis log 10 scale), *GA fleet in blue, Comparator fleet in red*

For reference the comparison fleet provided ground speed for 99.64% of all received reports. The summary statistics indicated a mean error of -9.834kts, a standard deviation of 200kts, while the largest negative error recorded was -4,060kts and the largest positive error was +367kts.

Although the core error distribution of the GA fleet is less than that of the comparison fleet, the tails show variation, with the tail error is larger for negative values, while the comparator fleet has higher errors for positive values outside of the core distribution.

The lower percentage of groundspeed reports from the GA fleet could be an issue for a tracker.

4.7 Mode A

Although the Mode A code was provided in 341,101 (99.99%) ADS-B reports, the Mode A code was not available in all of the corresponding radar track updates. As such only 237,818 (69.72%) ADS-B messages could be compared; of these 237,043 matched the Mode A code provided by the tracker equating to 99.7% compliance.

For comparison the Mode A code could be assessed in 8,243,254 (97.72%) of all reports; of these 8,238,488 (99.94%) of the Mode A codes matched that of the tracker.

For the trial ADS-B reports where the assessment against the track data could be made, the 99.7% code match which is within the requirement of 98% specified in ESASSP 3N_C-R14.

4.8 Aircraft identification

Aircraft identification was provided in 340,106 ADS-B messages where (99.7%) of the ACID's provided match that of the track data, the remaining 1,022 reports did not provide an aircraft ID for correlation. It should be noted that ADS-B does not broadcast the aircraft ID every message.

The figure of 99.7% demonstrates that the GA airframes could provide data compliant with ESASSP 3N_C-R14 which only required 98% to match.

4.9 MOPS version

The Minimum Operational Performance Specification 'version 0' indicator is assigned to aircraft compliant with DO-260, 'version 1' with DO-260A and 'version 2' DO-260B / ED-102A (5).

The majority of the messages were received from trial aircraft reporting 'version 2' (DO-260B/ED-102A); with a total of 193,581 (56.74%) messages, followed by 'version 1' with 143,012 (41.92%), with a further 4,535 (1.33%) messages indicating 'version 0'.

As all participant aircraft were approved on the basis they either comply to 'version 1' or 'version 2'; it should be noted however that if the Type Code 31 message type field that reports the MOPS capability has not been received for a several message updates the ADS-B ground system will assume the MOPS capability is 'version 0' for backward compatibility and translate the NIC and NACp values into NUCp; it is assumed that this is the cause behind the small proportion of 'version 0' messages recorded in the trial.

4.10 Navigational Integrity Category

The quality indicator Navigational Integrity Category is broadcast as part of the message subtype header information of the ADS-B position messages; as such 100% of the 341,128 messages provided this information. The majority of the messages assessed (56.7%), reported a NIC of '3' (radius of containment of 4NM; see Table 2) while 29.2% reported a NIC of 7 (radius of containment of 0.2NM).

The full break down of the reported NIC's is given in Figure 19 below; however as the trial aircraft were using non-certified GPS sources to provide the broadcast position information, any corresponding SIL value accompanying any broadcast NIC value should have been set to '0' to indicate the radius of containment was not applicable (this was not the case for one airframe as discussed in section 4.12).

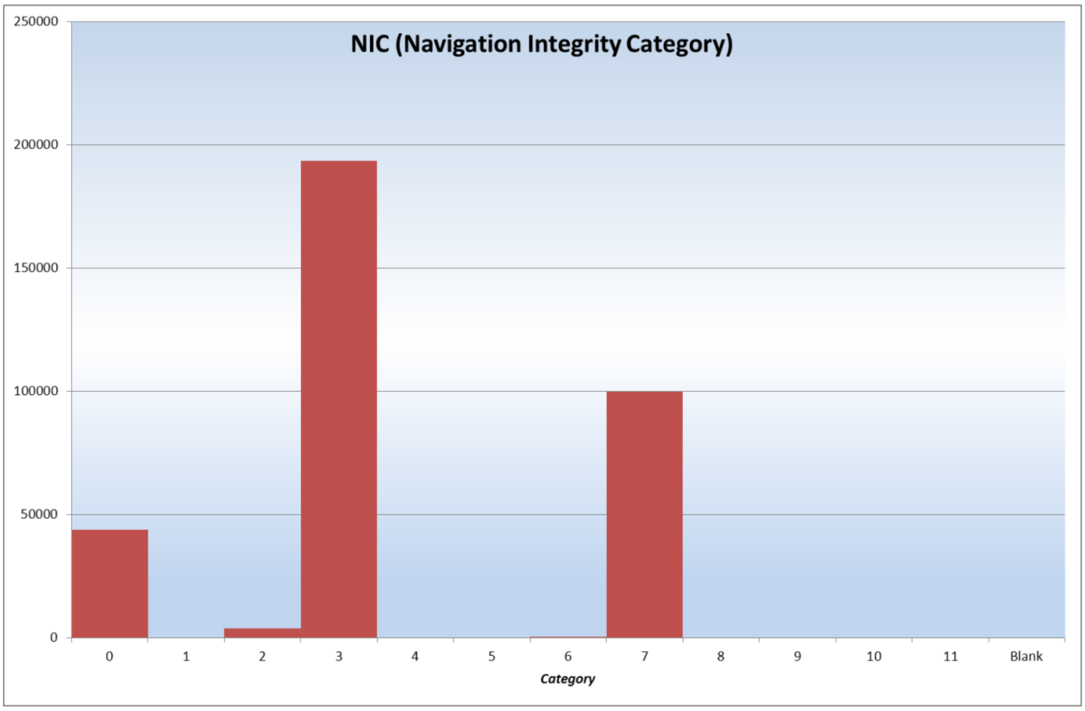


Figure 19: GA Trial reported Navigation Integrity Category values

4.11 Navigation Accuracy Code for position

Navigation Accuracy Code for position was assigned with 297,435 (87.19%) of the ADS-B reports.

Of these, the most frequent accuracy provided was NACp=3 equating to a reported horizontal positional accuracy of 2NM which was reported in 193,462 reports or 56.7% of all messages. It should be noted that 77,473 (22.71%) of reports received indicated NACp=10 corresponding to an accuracy bound of less than 15m. A summary bar chart of these values is provided in Figure 20 below.

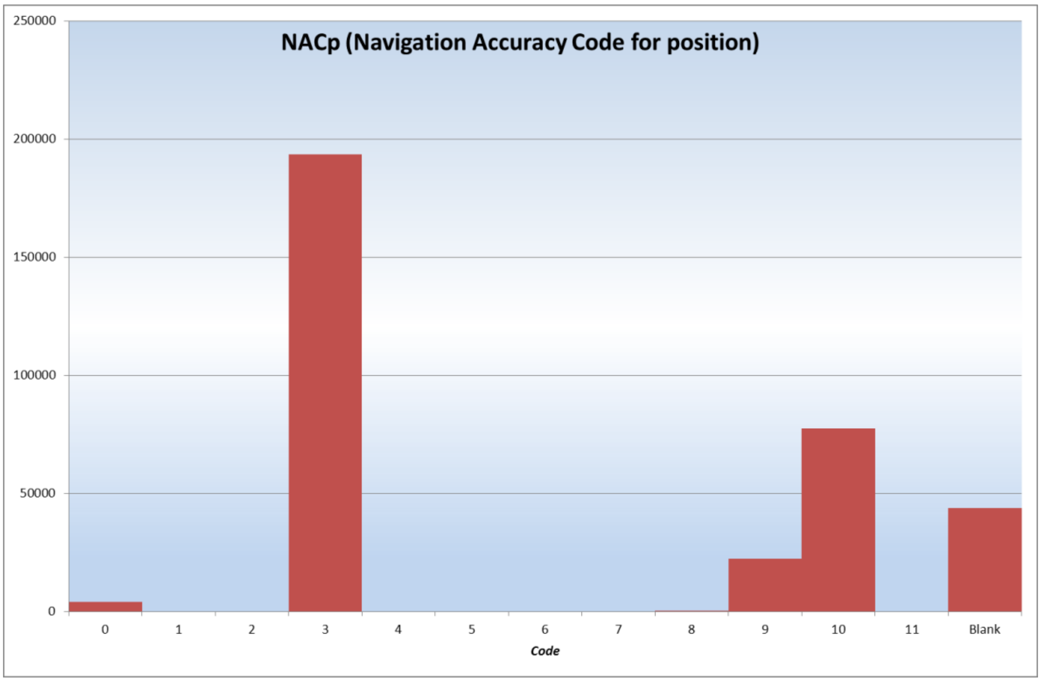


Figure 20: GA Trial reported Navigation Accuracy Code for position values

The quality indicator NACp=10 indicates that the position broadcast by the airframe should be within 15m of the aircrafts actual position. As this assessment uses radar track data as the baseline 'truth track' it is not possible to definitively assess to the reported accuracy to 15m (a DGPS fitted to the airframes would be required for this task), however a plot of the HPE of all airframes reporting NACp=10 would be anticipated all be within the 300m tolerance; given the expected accuracy of the radar track. Figure 21 below shows the cumulative plot of HPE's for all GA airframes reporting NACp=10 (red) and NACp=3 (green).

It can be seen that 99% of airframes reporting NACp=10 are within a HPE of 150m. However, the largest reported HPE for the NACp=10 sample was 1,126m. The mean HPE for NACP=10 reports was 34.43m, with a standard deviation of 28.94m.

For the airframes reporting NACp=3, which indicates that the aircraft are reporting a position within 2NM of their actual position (see Table 3), the mean HPE was 38.54m with a standard deviation of 29.4m and a maximum HPE of 1,080.76m

The results and Figure 21 below illustrates that although the error bound NACp=10 is much less than for NACp=3, the overall the magnitude of the HPE's are very similar suggesting that the for the majority of the time, NACp=3 airframes are extremely conservative at reporting the accuracy capability of the GPS source under fault free conditions.

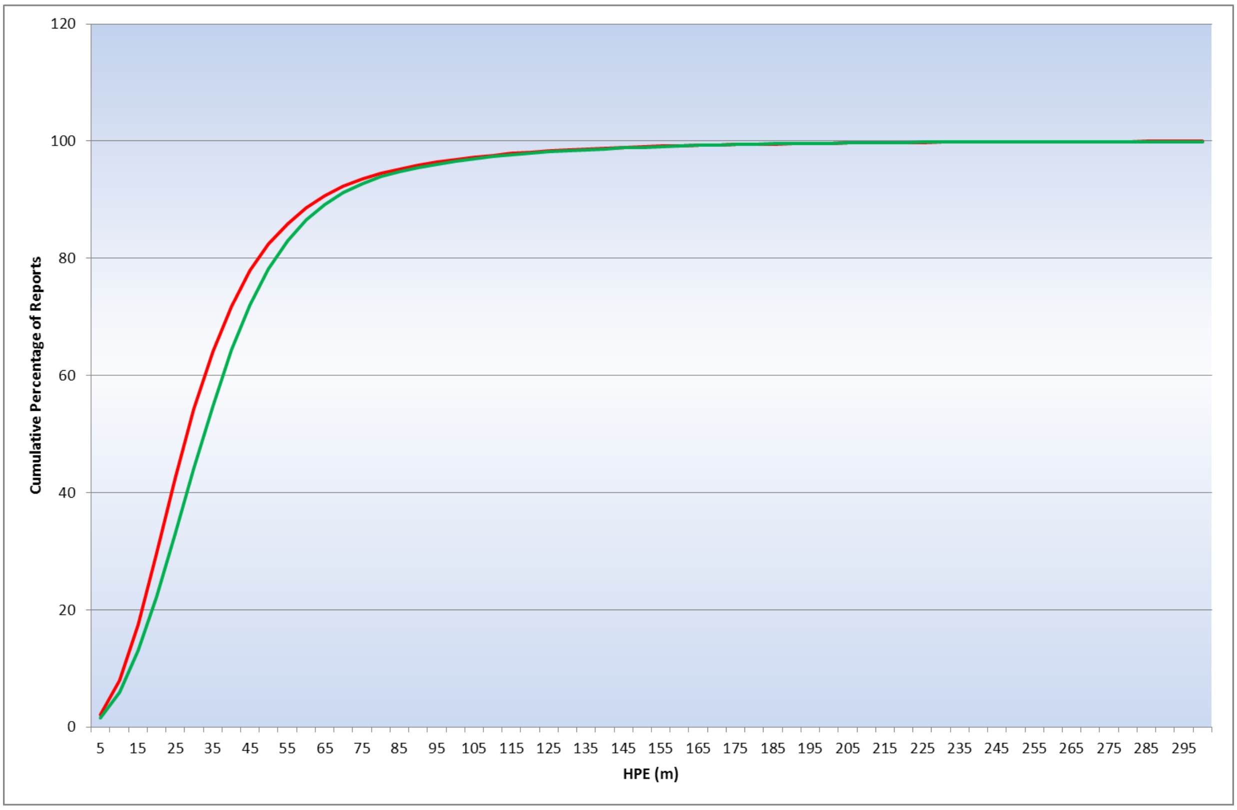


Figure 21: Cumulative plot of HPE for GA airframes reporting NACp=10 (red) and NACp=3 (green)

4.12 Surveillance Integrity Level

The quality indicator 'Surveillance Integrity Level' was assigned with 297,435 of the GA ADS-B messages (87.19%) where 294,011 (86.19% of total messages) reported SIL=0 and the remaining 3,424 (1.00% of total messages) reported SIL=1.

Further investigation into the SIL=1 flights concluded that they were all produced by airframe #09 which generated 3,489 plots in total. When the remaining 65 plots generated by airframe #09 where for SIL=0, the NIC value changed to 2 from 3 and the NACp value changed from 3 to 0. This was due to the aircraft being temporarily recognised as MOPS 'version 0' by the ground station ADS-B tracking and modifying the quality indicators of the ASTERIX message to reflect NUCp rather than NIC, NACp and SIL.

An operational use of ADS-B should be cognisant of the effect that a sporadic reversion to the assumed MOPS 'version 0' rather than an actual 'version 1' can have on the quality indicators reported within ASTERIX CAT021.

4.13 Priority status

As expected all 341,128 messages assessed reported the 'priority status' as zero, indicating no emergency condition during the trial.

4.14 Airborne surveillance applications compatibility

The airborne surveillance applications (ASA) system provides the avionics for the surveillance processing and display of aircraft-to-aircraft applications (10). The two most basic ASA applications are EvAcq (Enhanced visual Acquisition) and AIRB (Basic airborne situation awareness) which are both intended to provide ADS-B enhanced traffic situation awareness to a CDTI (Cockpit Display of Traffic Information). The TSAA (Traffic Situation Awareness with Alerts), provides additional alerting functionality against the ADS-B traffic.

The compatibility of the non-certified GPS position data broadcast from the GA fleet in this assessment takes two forms; firstly whether the typical accuracy measured meets the requirements for EvAcq/AIRB and TSAA functionality and secondly whether the quality indicators broadcast would provide interoperability with certified installations of EvAcq/AIRB and TSAA.

The 3D state vector quality requirements for EvAcq/AIRB and TSAA are taken from Table 2-4 of ED-194A (10) reproduced in Table 4.

According to Table 4, to be eligible for processing and subsequent display, airborne traffic needs to have an accuracy of <0.5NM denoted by the provision of NACp≥5 for aircraft broadcasting Version 2 ADS-B data.

Section 4.11 illustrates that 56.7% of the ADS-B position messages reported an accuracy of NACp=3 which equates to an accuracy that is within 2NM (see Table 3). However, section 4.11 also indicates that the reported NACp is highly conservative with Figure 21 indicating that 95% of both NACp=3 and NACp=10 reports were measured within this assessment to have an HPE of approximately 85m or less.

As the NACp metric is taken to be '95% Horizontal accuracy bound' (for NACp=0 to 8, but also including the vertical accuracy bound for NACp=9 to 11), the assessment would suggest that the measured typical accuracy although not the reported accuracy (NACp) would be sufficient to support the traffic situation awareness.

This aligns with the 'LPAT High Level Safety Performance and Certification Assessment' (9) which concluded that for an airborne situational awareness application in uncontrolled airspace, a directional position error of ± 12.5 degrees was sufficient to support See-and-Avoid. The mean HPE of 43.93m measured, is well within the 103m of error that 12.5 degrees of directional error equates to at a range of 0.25nm. It can also be noted that only two of the GA airframes generated a HPE greater than 1232m, which is equivalent to a ±12.5 degree error at a range of 3NM.

In terms of interoperability, the remit of the trial required that either of the quality indicators of NIC and SIL had to be set to zero, indicating unknown quality. As such, the broadcast positions from the GA fleet in this trial would not be processed by the airborne surveillance applications.

Requirement Category	Requirement	Applicable Subsystem Interfaces (See FIGURE 1-1)	EVAcq/AIRB/TSAA (9) Traffic On ground When Ownship is On ground	EVAcq/AIRB/TSAA (9) All Other Traffic
State Data	Horizontal Position Uncertainty (95%)	A1→B1	< 0.1 NM ($NAC_P \geq 7$)	< 0.5 NM ($NAC_P \geq 5$)
	Horizontal Velocity Uncertainty (95%) (1)	A1→B1	< 10 m/s ($NAC_V \geq 1$)	
	Vertical Position Uncertainty (95%)	A1→B1	On Ground or Valid Pressure or Valid Geo (3 & 10)	
	Vertical Velocity Uncertainty (95%)	A1→B1	N/A	
State Data Integrity	Source Integrity Level	A1→B1	N/A	
	Navigation Integrity Category	A1→B1	N/A	
	System Design Assurance (2)	A1→D	1E-3	
	Validation of Traffic Position with TCAS Data	A1→B1	N/A	
State Data And Status Timing	Maximum Total Latency (6, 8)	A1→G	5.5 s	
		A1→B1	0.9 s	
		B1→D	1.1 s	
		D→E	0.5 s	
		E→F	2.5 s	
		F→G	0.5 s	
	Maximum Position Data Age until Dropped	at E	11 s (moving) 25 s (static)	25 s
Traffic ID	Maximum Latency (5 & 6)	A1→G	29 s	
		A1→B1	1.0 s	
		B1→D	9.0 s	
		D→E	0.5 s	
		E→F	18 s	
		F→G	0.5 s	
	Maximum Data Age Until Drooped	at E	Until track termination	

Table 4: ED-194A TRAFFIC APPLICATION SPECIFIC REQUIREMENTS SUMMARY

4.15 Observations and investigations

4.15.1 Maximum Horizontal position error

Figure 22 below shows in magenta the very large horizontal position errors recorded during the GA trial. The largest seven have been labelled with the magnitude of error in nautical miles.

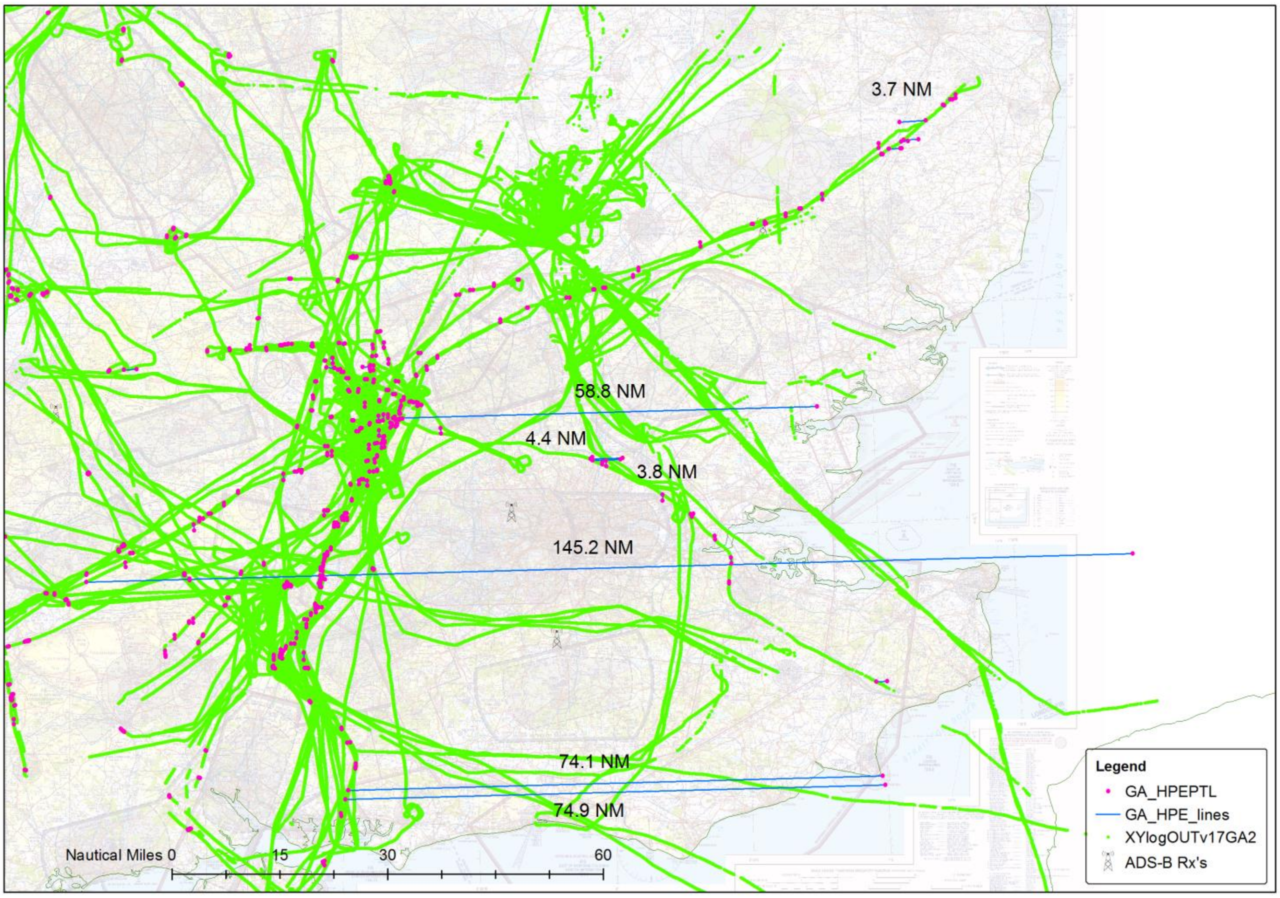


Figure 22: GA trial large HPE's

Table 5 below details the top 10 largest HPE's observed in the assessment. All but the tenth largest HPE were generated by airframe #05, while the tenth was by airframe #03 (which had a different avionics fit to airframe #05).

The top six large errors can be attributed to the omission of the longitude sign indicating West; which has caused the reported position to jump to the East of Greenwich meridian. All six of these errors originated from trial participant airframe #05.

The other four errors also appear to be East-West errors but are not due to a 'sign swap'.

Date	Time	Partipant	MOPS	ADSB Long	ADSB lat	Rdr long	Rdr lat	RMS (m)	NACP	NIC	SIL
20150816	'12:46:02	5	0	1.9379	51.4006	-1.9368	51.4010	268,957	-1	0	-1
20150621	'08:54:46	5	0	0.9890	50.8913	-0.9899	50.8910	138,792	-1	0	-1
20150621	'08:55:46	5	0	0.9798	50.9128	-0.9804	50.9122	137,408	-1	0	-1
20150603	'13:56:18	5	0	0.7913	51.7743	-0.7908	51.7743	108,960	-1	0	-1
20150722	'09:27:39	5	1	0.0604	51.6694	-0.0623	51.6700	8,297	-1	0	-1
20150722	'09:27:54	5	1	0.0514	51.6665	-0.0528	51.6667	7,042	-1	0	-1
20150511	'14:59:42	5	1	1.1449	52.4251	1.2434	52.4247	6,809	-1	0	-1
20150511	'14:57:27	5	1	1.2141	52.3829	1.1570	52.3837	3,866	-1	0	-1
20150511	'14:56:06	5	1	1.1493	52.3633	1.0973	52.3628	3,386	-1	0	-1
20150811	'15:04:14	3	2	-1.7496	51.8934	-1.7991	51.8921	3298	9	7	0

Table 5: Top 10 largest HPE's in GA dataset

It should be noted that of the 534 HPE's greater than 300m, 284 (53.1%) were generated by airframe #05 (as can be seen below in Table 6). Airframe #05 also had the highest percentage of HPE's per ADS-B report with 0.65% of all ADS-B positions classified as a HPE.

Participant Airframe	ADS-B Reports	Count of HPE's > 300 m	Percentage of All HPE's > 300 m (%)	Percentage of a/c reports with HPE > 300m (%)	Maximum HPE (m)
01	19,358	3	0.56	0.0155	333
02	48,706	55	10.30	0.1129	1,081
03	29,253	64	11.99	0.2188	3,298
04	23,880	41	7.68	0.1717	651
05	43,693	284	53.18	0.6500	268,956
06	98,841	61	11.42	0.0617	621
07	71,049	21	3.93	0.0296	1,126
08	2,860	0	0.00	0.0000	251
09	3,488	5	0.94	0.1433	826

Table 6: Horizontal Position Error summary by trial participant airframes

Of the 534 HPE's, 85 (15.9%) reported a Navigational Integrity Code (NIC) of 7. The largest of these errors was broadcast by airframe #03 reporting NIC=7 was 3,298m; however as noted previously the corresponding Source Integrity Level (SIL) was set to zero – effectively invalidating the integrity reported by the NIC as per DO-260B / ED-102A specifications (5).

Note: From a potential ground use perspective, ATM suRveillance Tracker And Server (ARTAS) Version 8A (4) does not include parameters to define minimum level of SIL which is acceptable for track processing, instead it only includes parameters for NUC, NACp and NIC. Therefore, a high NIC=7 with a SIL=2 or 3 would not be distinguishable from a NIC=7 with SIL=0 in ARTAS V8A which may be undesired when trying to filter on lower quality ADS-B messages.

Removing a/c #05 from the analysis provides the following high level metrics and associated location chart of HPE's:

Metric	Including Address #05	Omitting Address #05
Mean HPE (m)	43.94	38.109
HPE Standard Deviation (m)	600.5	31.22883
Max HPE (m)	268,956	3,297.67
Total HPE's > 300 m	1,169	250
Percentage of HPE's > 300m(%)	0.342687	0.084
Mean Across Track Error (m)	-0.27	0.07
Max Across Track Error (m)	89,595.88	506.98
Across Track Error Standard Deviation (m)	346.55	33.07
Mean Along Track Error (m)	-22.47	-17.05
Max Along Track Error (m)	56,027.72	3,178.36
Along Track Error Standard Deviation (m)	491.95	32.30

Table 7: GA Fleet Metrics with address of A/C #05 omitted

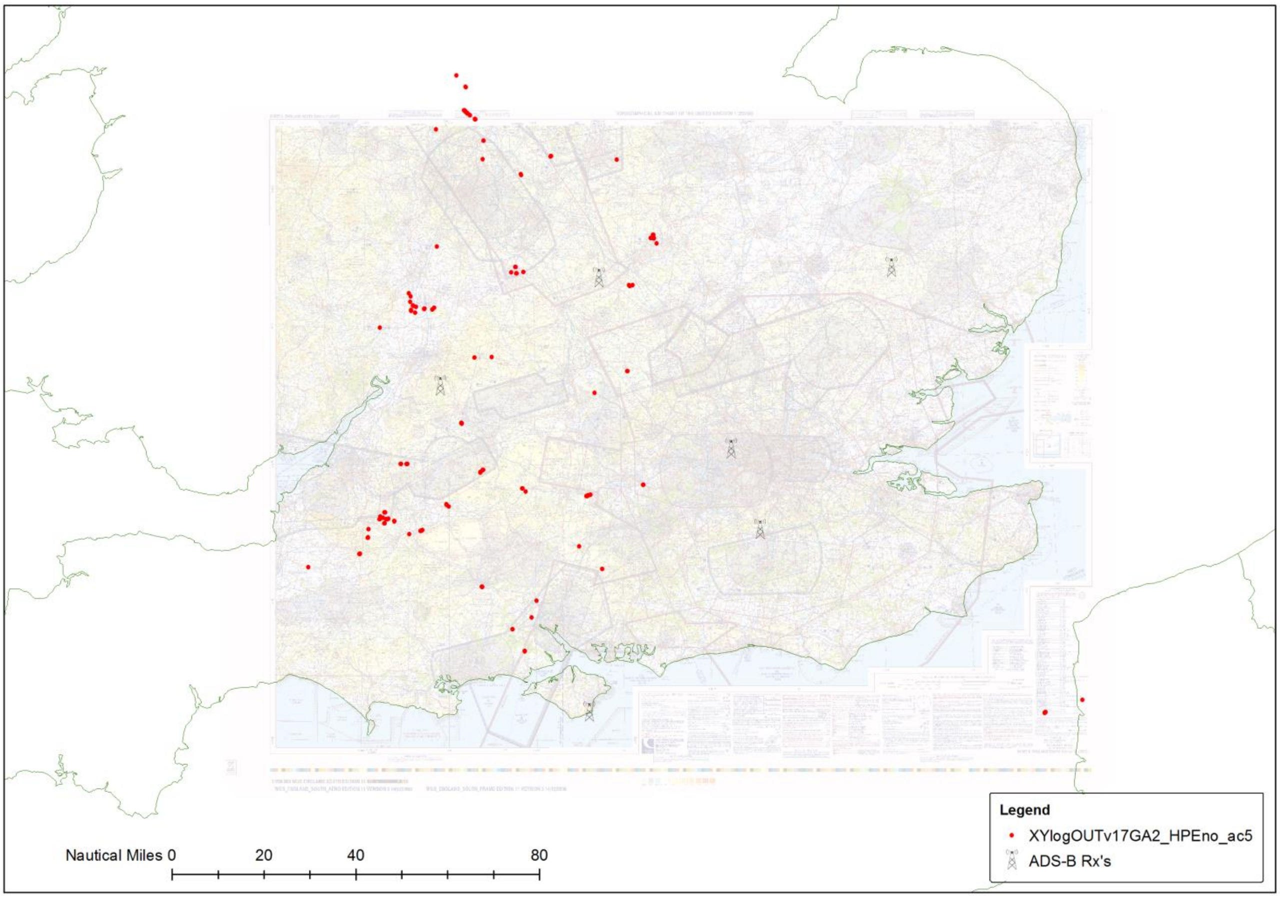


Figure 23 Location of GA Fleet HPE's with A/C #05 omitted

Figure 24 below is a scatter plot of the bearing of the ADS-B reported position in relation to the tracked plot position against horizontal position errors greater than 300m. This plot highlights that there is clustering of errors that are 0, 90, 180, 270 and 360 degrees bearing away from the tracked position.

This suggests that there is an effect of 'quantisation' errors along the latitude and longitude coordinates in addition to the seven very large sign bit swaps errors.

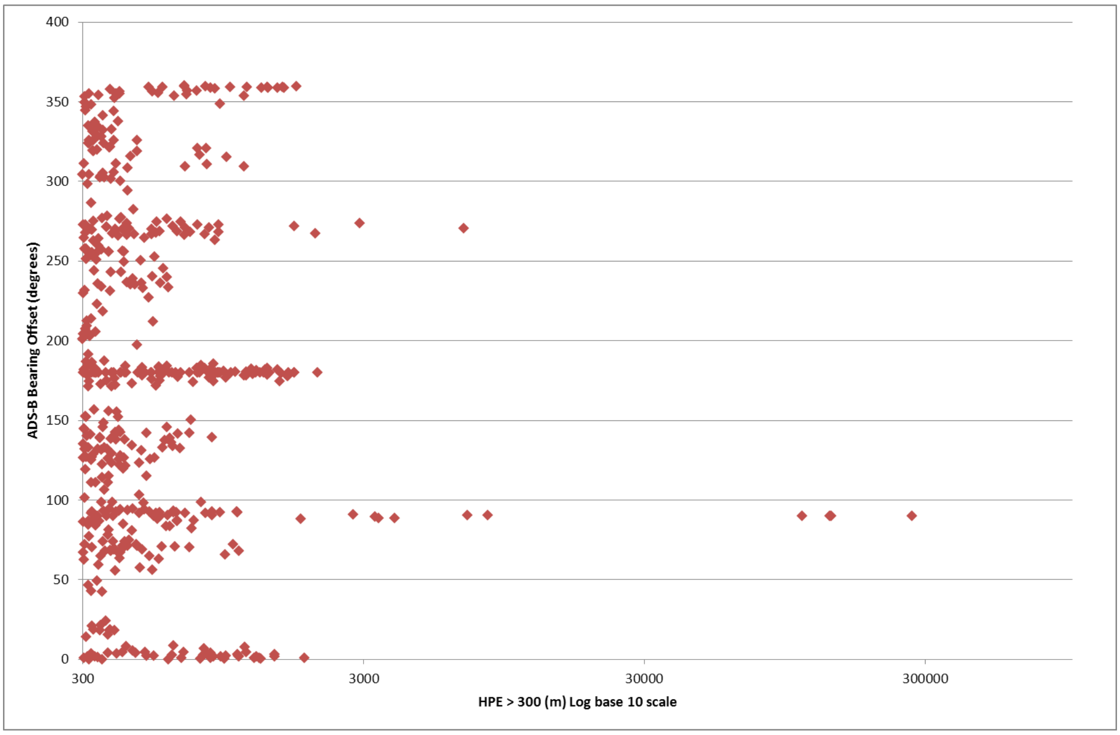


Figure 24: Scatter plot of GA fleet ADS-B offset bearing (*y axis*) against HPE > 300 m (*x axis log 10 scale*)

When focusing specifically on airframe #05 which generated the seven very large sign bit swaps and majority of large horizontal position errors; it can be seen in Figure 25 below that the clustering previously observed in Figure 24 can be largely attributed to airframe #05.

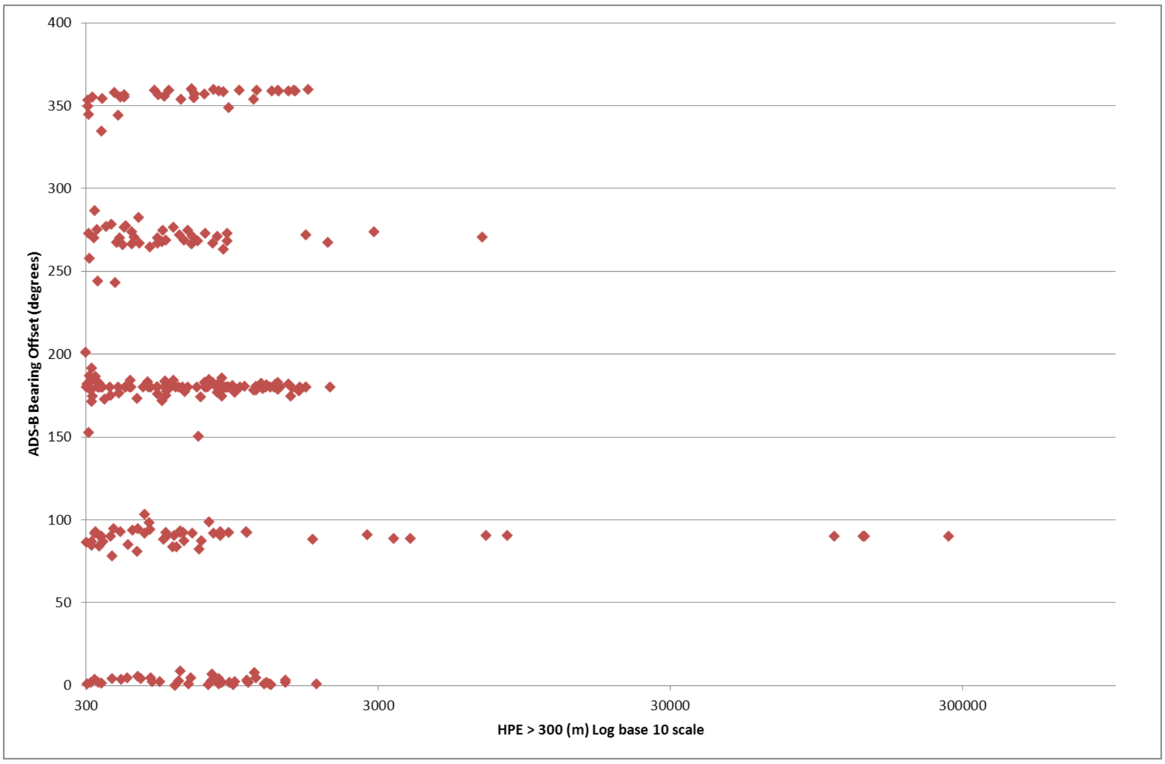


Figure 25: Scatter plot of ADS-B offset bearing (*y axis*) vs HPE > 300 m (*x axis log 10 scale*) for Trial Airframe #05

It should be noted that the WGS84 latitude and longitude is encoded using the compact position reporting (CPR) format in consecutive odd /even ADS-B reports to reduce the bandwidth required to continually broadcast what are essentially small changes in position from the aircraft. Consequently the ADS-B message does not transmit a longitude 'sign bit'.

Further investigation would be necessary to ascertain whether it is the GPS source causing this issue, a degradation of the signal of the NMEA via RS-232 from the GPS source to the transponder, or the ADS-B message assembly function encoding of the CPR format that is causing this issue.

4.15.2 Mode S Address Identification

As noted in section 4.2, a particular airframe was noted as contributing the majority of very large horizontal position errors in the comparator fleet dataset.

Removing this Mode S address from the comparator dataset provides the following high level statistics in Table 8 below and location of HPE's in Figure 26.

Metric	Including Address '123456'	Omitting Address '123456'
Mean HPE (m)	40.35	35.2
HPE Standard Deviation (m)	702.7	313.5
Max HPE (m)	215,600	52,076.14
Total HPE's > 300 m	23,237	22,471
Percentage of HPE's	0.275	0.268
Mean Across Track Error (m)	-1.02	-1.04
Max Across Track Error (m)	-51,893.45	50,097.55
Across Track Error Standard Deviation (m)	261	262.14
Mean Along Track Error (m)	-19.5	-14.40
Max Along Track Error (m)	-215,585.95	50,146.76
Along Track Error Standard Deviation (m)	653	175.07

Table 8: Comparator fleet metrics with address '12345' included and omitted respectively

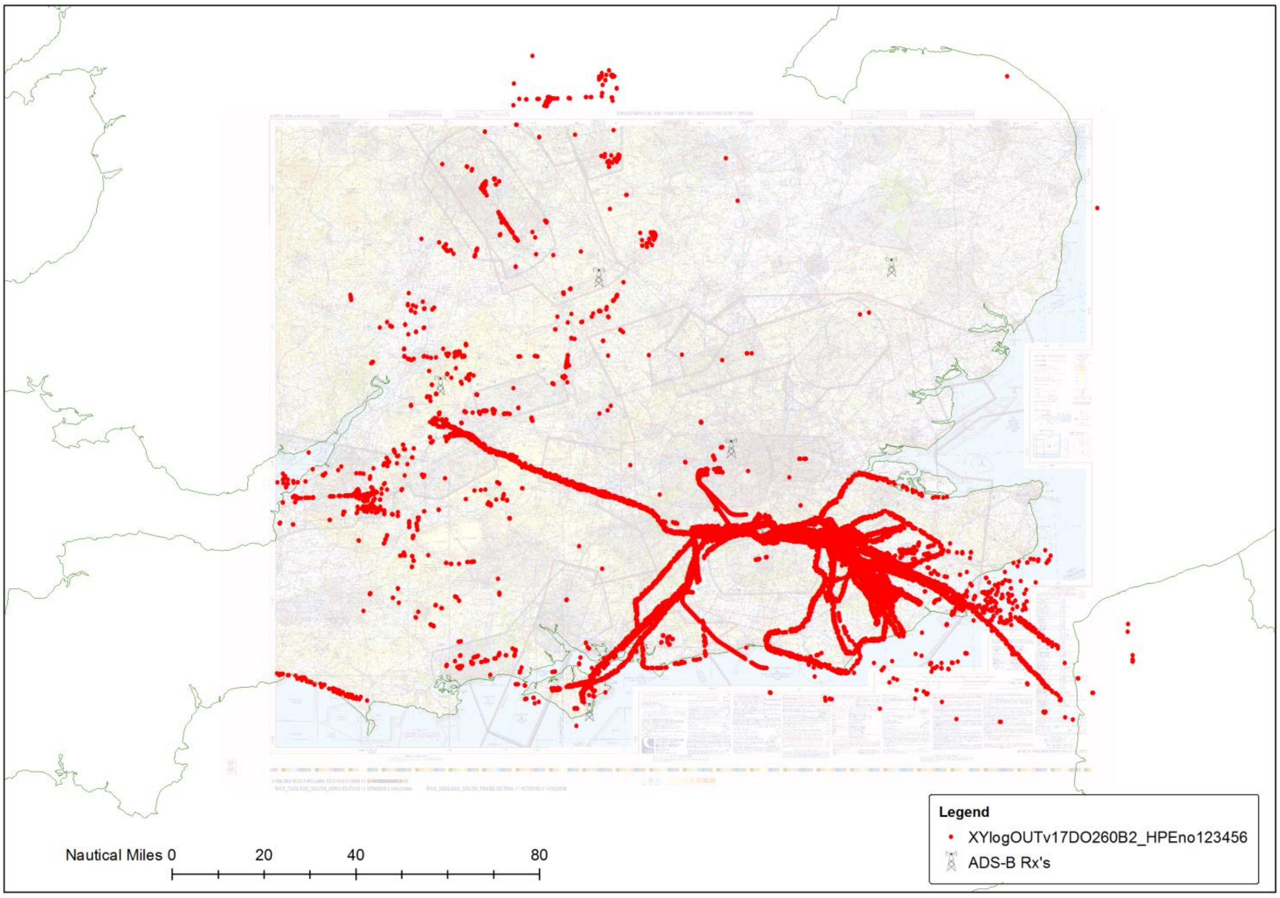


Figure 26: Location of Comparator fleet HPEs > 300 m with address '123456' omitted

In addition to the very large HPE's generated by Mode S address '123456', another airframe 'X' contributed to the majority 18,204 (78.3%) of the 23,228 of HPE's albeit with an average HPE of 442m.

Figure 27 below provides a close up inspection of this Mode S address' HPE's indicates that all of the positions are randomly offset along the north and/or south axis, suggesting a quantisation error.

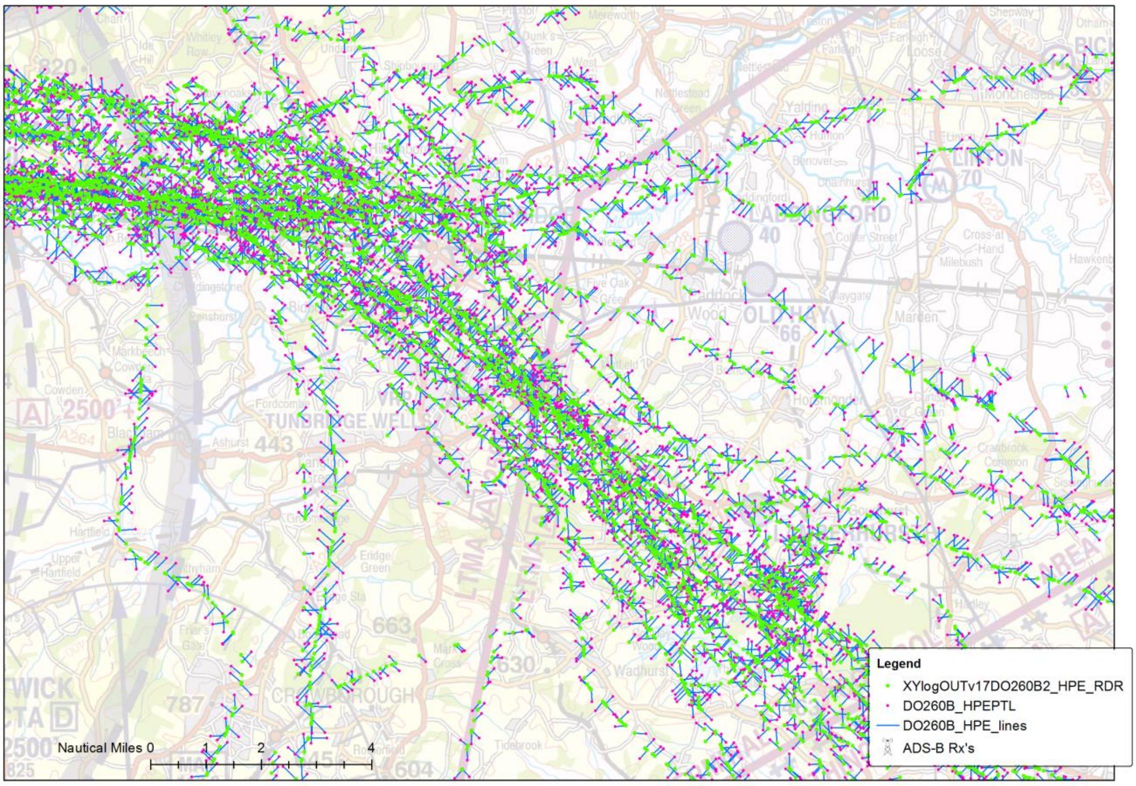


Figure 27: Close up of 'quantisation' effect from Address 'X' (*Radar track plots in green, ADS-B position updates in purple and error in blue*)

Figure 28 containing all airframes and Figure 29 with 'X' omitted highlight this quantisation effect with plots visibility clustered around 0, 45, 90, 135, 180, 225, 270, 315 and 360 degrees in the figure with 'X' included and notability reduced in the figure with it omitted, reinforcing the latitude and / or longitude quantisation error.

The 'whitelist' used to identify the comparison fleet was provided by EUROCONTROL. The Mode S address responsible for the very large deviations was '123456'. Given the sequence of numbers in the address it is extremely likely that the airframe responsible for the very large errors was not the airframe that had passed the quality criteria set by EUROCONTROL to be added to the whitelist, but instead, the Mode S address broadcast was in error.

The broadcast of an incorrect address highlights a deficiency in the use of a whitelist to approve the quality of ADS-B positions and further reinforces the need for continual or recurrent validation of the broadcast positions if used for separation provision.

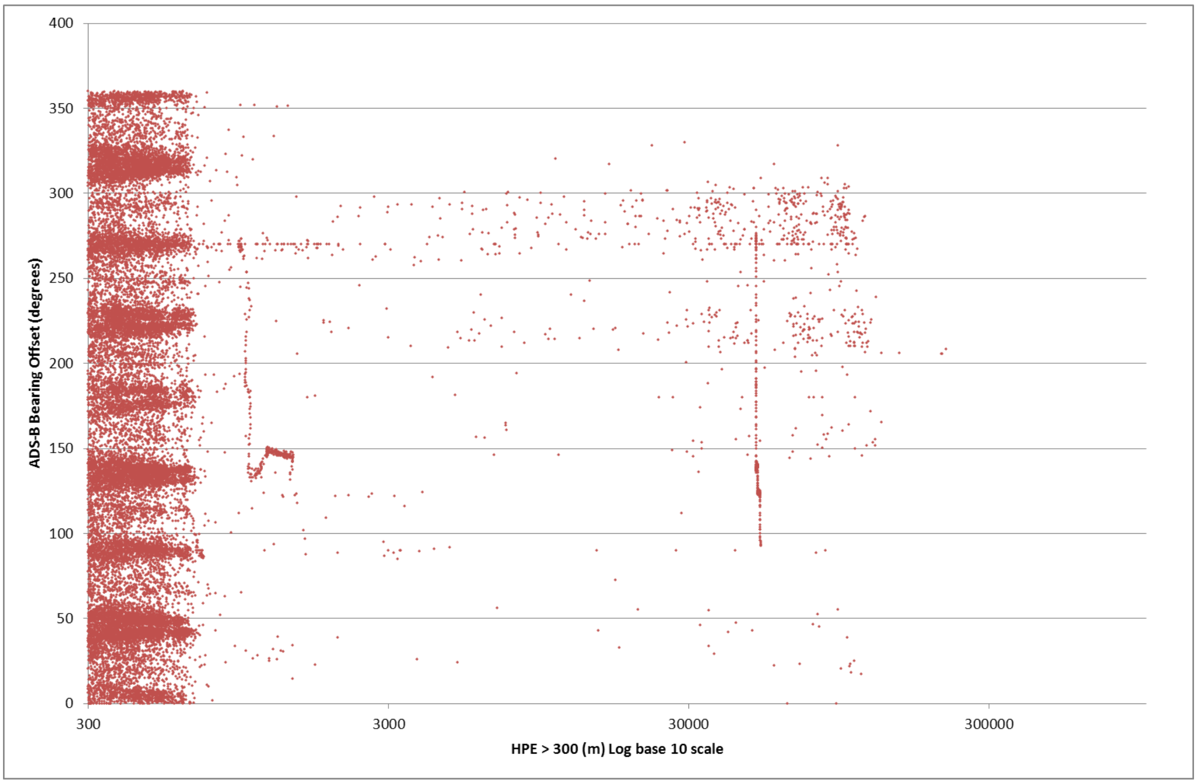


Figure 28: Scatter plot of Comparator fleet ADS-B offset bearing (*y axis*) vs HPE > 300 m (*x axis log 10 scale*)

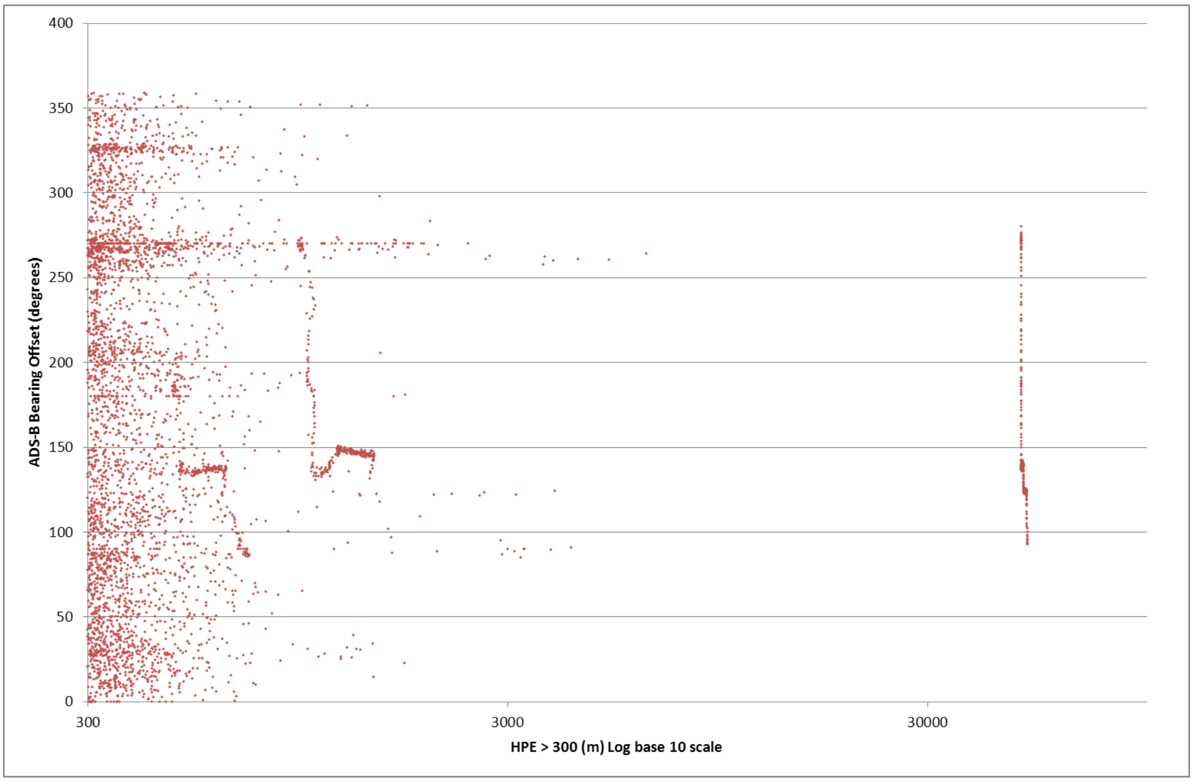


Figure 29: Scatter plot of Comparator fleet ADS-B offset bearing (*y axis*)vs HPE > 300 m (*x axis log 10 scale*) with A/C 'X' omitted

4.15.3 GA responses and applications to the trial

Several GA pilots expressed their disappointment that a minor modification would be required to participate in the trial. This most probably, was the main reason that there was not a larger uptake particularly from owners of EASA aircraft types. The aircraft owners highlighted that the process for submitting a minor modification through EASA typically takes six weeks. Anecdotally, one aircraft engineer stated that he usually spent a total of two days just on administration when applying for a minor modification.

Some owners of Garmin products queried whether the minor modification was necessary, especially as a factory cable is used to connect the transponder to the GPS source. One owner pointed out that a defective cable could be replaced under a maintenance schedule. Note that the EASA CS-STAN SC002a ref (8)) provides for a standard modification but it cannot be made by the aircraft owner. This regulatory mechanism became available during the course of the trial but was not exercised within it.

Some members of the community were unaware of the difference between Mode S and Mode S (ES) and a number of Garmin users were disappointed to learn that most of the Garmin transponders do not have extended squitter capability.

Three users had old (but not obsolete) ADS-B versions ('0' & '1'). There were two applicants with funke TRT800A transponders that had 'version 0' data i.e. no NIC and SIL hence they did not qualify for our trial. Most CAT are still using 'version 0' and several have NUCp=0 position quality. The third had a 'version 1' Trig transponder and Trig have promised to provide a free update to version 2, this participant was included in the trial.

One applicant had initially set the wrong 24-bit address although this was rectified within a couple of days and was allowed to participate in the trial.

Another applicant thought they had enabled ADS-B OUT but their ADS-B data could not be observed, despite searching for their Mode S address in the NATS radar feeds to correlate a secondary radar plot with any ADS-B reported position.

As mentioned in the observations above, one participant with a TM250 as a GPS source seemed to have a high degree of error in their GPS position. The owner was contacted, however a remedial action of modifying the GPS antenna made no discernible difference to the position quality provided.

5 Summary

This study has undertaken a comparative assessment of the quality of ADS-B data provided by general aviation aircraft equipped with capable Mode S (ES) transponders connected to non-certified GPS position sources. The assessment was conducted against key ESASSP requirements using NATS NODE-L multi-radar track data as the truth track for conformance.

As may be seen from **Table 9**, the data collected in the trial met three of the six ESASSP requirements against which it was assessed, despite the necessary constraint of using the NODE-L track data as the truth track. It should be noted that 99.84% of the GA ADS-B position reports were less than 300 m in error, with an average HPE of 43.94m, well within the 300m ESASSP 3N_C-R4 requirement and the recommended value of 210m.

This generally positive outcome, was also despite a small percentage of position reports that had very large horizontal position errors. The very large errors were infrequent and more importantly not consecutive, reducing the likelihood of possible credible corruption.

Investigation into the nine largest horizontal position errors recorded in the GA trial, found that they were all from one airframe and six were attributable to a longitude 'sign swap' across the Greenwich meridian. Further investigation into the other large horizontal position errors reported by the same airframe suggests that other latitude and longitude quantisation effects were also occurring in addition to the sign swap. The horizontal position error assessment found no evidence of coasting by the non-certified GPS units, although this concern would only be borne out of GPS satellite failure conditions, or broadband interference on the GPS frequency. Given the availability of performance data for GPS, no impacting failures have been reported. Inspection of the NACp data suggests that the latter was unlikely to have occurred during the trial period. Furthermore there was no indication of any GPS performance degradation over the period of this trial.

Requirement ID	Description	Evaluation Criteria	GA Fleet	Comparison Fleet
3N_C-R2	Probability of update of horizontal position	Greater than or equal to 97% for 100% of the flights, any flight below 97% shall be investigated as defined in R22	78.6%	85.6%
3N_C-R3	Ratio of missed 3D position involved in long gaps (larger than 16.5 s = 3 x 5 s + 10%)	Less than or equal to 0.5 %	15%	12.2%
3N_C-R4	Horizontal position RMS error	Less than or equal to 300 metres global and less than 330 metres for 100% of the flights, any flight below 550m shall be investigated as defined in R22	Mean HPE: 43.93m and 99.84% < 300m	Mean HPE: 40.35m and 99.70% < 300m
3N_C-R5	Ratio of target reports involved in	Less than or equal to 0.03 %	0.0004%	0.0005%

Requirement ID	Description	Evaluation Criteria	GA Fleet	Comparison Fleet
	sets of 3 consecutive correlated horizontal position errors larger than 555 m - 0.3 NM			
3N_C-R11	Pressure altitude unsigned error (see Note 7 in § 3.4.5)	Less than or equal to 200/300 ft in 99.9% of the cases for stable flights and less than or equal to 300 ft in 98.5% of the cases for climbing/descending flights	99.99%	99.99%
3N_C-R14	Probability of update of aircraft identity with correct value (see Note 8 in § 3.4.5)	Greater than or equal to 98 % global	99.7%	99.94%

Table 9: Summary of compliance with assessed ESASSP requirements

Assessment of the interoperability of ADS-B data and system quality factors indicates that there is no expectation that the data may be consumed by MOPS compliant airborne safety nets. This is because the trial required that the Source Integrity Level be set to zero. It is to be noted that Trig Avionics TABS/TSAA device has an optional "de-rated" mode of operation. In this mode, the equipment may accept data which is not compliant with the requirements stated in the TSAA MOPS. Operation in this mode will render any certification technically invalid, but it may be more relevant to, and useful in, the current UK Class G Electronic Conspicuity environment.

A further limitation of the GA trial is that it assumes GPS fault free performance. The current reliability and over population of the GPS constellation, means that the performance exceeds the USA's ICAO Annex 10 commitments. This may not be true in the longer term as the GPS constellation ages and satellites reach their end of life and fail or are decommissioned. Whilst the faulted case falls outside the scope of this document, a brief consideration of this topic is given below.

The position accuracy under a GPS faulted condition may pose a risk for the non-certified units. Taking into consideration a credible visual range of acquisition of 2NM, and setting up emergent ADS-B IN aids to visual acquisition, position errors of between a hundred of meters up to 7.4km/4NM may be considered to be hazardously misleading information. In this range, the hazard arises from the direction of the focus of pilot's visual scan away from the true position of a conflicting aircraft, and outside the eyes area of greatest visual acuity. However, technical work from Helios suggests this risk is minor and acceptable.

Technical means to mitigate this specific risk include the use of SBAS capable GNSS devices, which should exclude a faulted satellite within six seconds of detection of the failure by the SBAS ground segment. However, without permanent installation of a GNSS antenna, most likely under CS-STAN, visibility of an SBAS satellite cannot be assured.

Overall, in the proposed air to air electronic conspicuity application that was within the scope of the trial, this risk is currently felt to be acceptable. However the impact of these, or greater errors if there were to be ground ATC presentation or use of ADS-B with no, or low integrity requires further investigation.

6 Conclusions

Based on the results of this trial, it can be seen that the quality of non-certified GPS is sufficient for use in enhancing visual acquisition / electronic conspicuity between participating general aviation aircraft outside controlled airspace.

There was no identified impact on the current or planned UK ATC use of 1090MHz, or regulated uses of surveillance on 1090MHz. However it would be prudent to undertake periodic monitoring of installations to ensure transmission and data content remain of suitable quality. This on-going monitoring role should be periodically reported to the certifying airworthiness authority for that a/c type.

It was interesting to note how closely the non-certified data matched the performance of the certified 'white-list' fleet.

All of these tests were performed in a GPS fault free environment. NATS safety analysis identified the risk and consequence of a faulty GPS for the enhancement of visual acquisition as minor and tolerable.

The use of this data in ground applications, whilst outside the scope of this study, should be examined for potential impact under GPS/GNSS faulted conditions.

Therefore, General Aviation should be encouraged to enable ADS-B from capable transponders to create an ADS-B based Electronic Conspicuity environment to support the introduction of dedicated ADS-B IN Electronic Conspicuity devices, such as NATS LPAT.

7 Recommendations

- Pilots equipping with GNSS for this application should be advised to ensure that any GPS antenna has an unobstructed view of the sky.
- Pilots to be advised to ensure that the ICAO address is set correctly in their transponder.
- Suggestion that "non-certified" or life expired certificated, but still functionally serviceable GPS antenna products could be installed under CS-STAN to support non-certified GNSS sources.
- Ask CAA to consider whether, and under what circumstances or installation context NIC, SIL and SDA may be set to non-zero values.
- Advise pilots that all new modifications shall be to ADS-B V2,as per RTCA-DO-260B Ch2/EUROCAE-ED-102A
- If low integrity ADS-B were to were, in the future, to be displayed to air traffic controllers, further work on the potential impact of GNSS failure scenarios should be undertaken.
- CS-STAN SC002a (8) can be used to connect a GPS source to a Mode-S ES transponder although this route cannot be used if the modification is carried out by the owner. It is suggested the transponder manufacturer be allowed to only recommend connection types that guarantee SIL & SDA are set to zero instead (e.g. NMEA protocol), pending any CAA consideration of requirements for non-zero values of ADS-B quality indicators.
- CAA, NATS and Airspace users organisations to investigate options to increase take up of low or no integrity ADS-B-OUT in the GA VFR community.

- NATS to assess the performance of a sample of ADS-B position information derived from non-certified GPS sources in the ARTAS tracker.
- NATS transition out of the initial verification check in favour of LAA, BMAA and BGA.
- The Associations should also build capability to the undertake post modification technical verification and also periodic re-verification activities for Annex II types post trial to ensure poor installations are detected and rectified.
- It is recommended that continual or recurrent periodic independent re-verification of ADS-B derived information is implemented, to ensure poor installations are spotted, notified for rectification. The results of this should be examined, and where appropriate actioned by the competent airworthiness approval organisation for the installation in question.

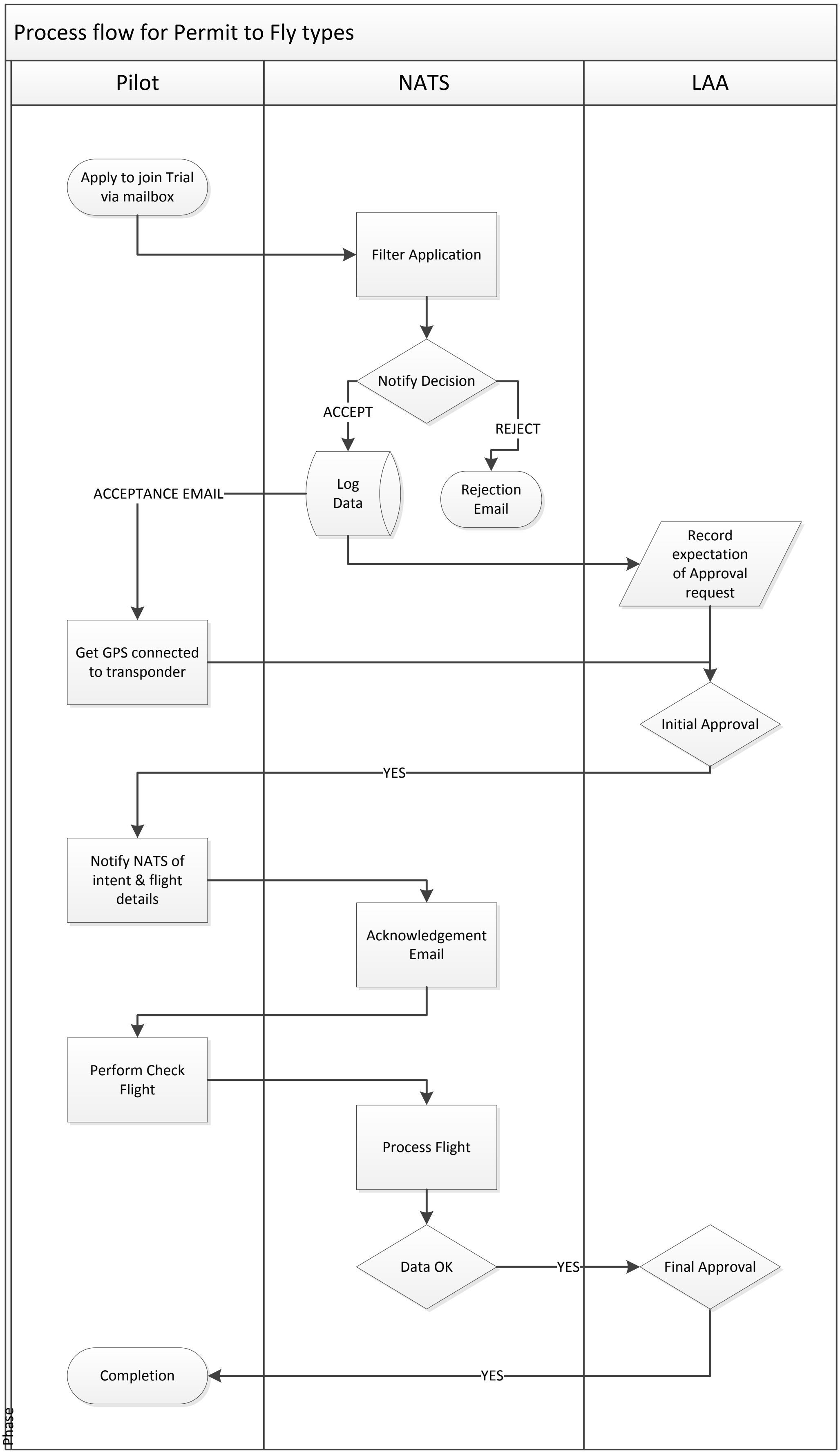
Appendices

A1 GA Trial Airframe & Equipment Details (anonamised)

ID	Aircraft type	Transponder	GPS Source	Trial Verification date
01	VANS RV-6	Trig TT21	Bendix Skyforce 3C	26/06/2015
02	Europa	Trig TT21	AVMAP V	19/04/2015
03	Bristell NG5	Trig TT21-V2	Dynon Skyview	20/05/2015
04	Europa	Trig TT21	PowerFlarm Core output	08/04/2015
05	Jodel DR100A	Funkwerk TRT800H	Funkwerk TM250 (ADSB Traffic Monitor)	22/04/2015
06	Skyranger (3 axis microlight)	Trig TT21	Garmin Aera 500	08/06/2015
07	VANS RV-12	Dynon SV-XPNDR-262	Dynon SkyView SV-GPS-250	22/04/2015
08	Falco F8L	Trig TT31	TruTrak Artificial Horizon	11/07/2015
09	P&M Quik 912 flexwing	Trig TT21	Garmin 96C	21/06/2015

Table 10: GA Trial Airframe & equipment Details

A2 Overview of process for LAA minor modification



Filter Criteria

<u>Transponders</u>
Trig TT-2x / TT-3x
FUNKE TRT-800

<u>GPS</u>
Any with NMEA 0183 output

<u>Geography</u>
Any

Data to log include:-
Name, Address, AC type, ICAO address, GPS type, XPDR type, Home airfield

NATS will pass a list of participants with LAA Permit types only to the LAA.

Acceptance E-mail contains LAA minor mod form with details for pilot to contact LAA.

On check flight, NATS verifies:-
- ADS-B received is correct version (1 or 2)
- Correct SIL are received (=0)

End of Document