Future Airspace Strategy Electronic Conspicuity: Simultaneous Transmission Study

CAA trial for simultaneous operation of Mode S transponders and ADS-B transceivers

Prepared by:
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Notices

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Accepted	Head of Airspace Systemisation	B Kelly	[illegible]	2/10/18.

Publication history

Issue	Month/Year	Change Requests in this issue
Draft 0.1	20/08/2018	Draft for Peer Review
Draft 0.2	23/08/2018	Draft for Initial Review
Draft 0.3	06/09/2018	Review comments addressed
Draft 0.4	11/09/2018	Review comments addressed
Issue 1.0	21/09/2018	Formal delivery
Draft 2.0a	14/12/2018	Draft of Reissue
Issue 2.0	09/01/2019	Address review comments and reissue
Issue 2.01	08/03/2019	Update recommendations in line with CS-STAN issue 3

Reviewers

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Executive Summary

The CAA conducted a trial to help determine whether the simultaneous operation of a transponder and an ADS-B transceiver by the same aircraft causes interference. NATS was asked to support the trial by gathering data and performing high level checks to determine if there were any obvious signs of interference.

There was no noticeable increase of data corruption during signal transmission but there was evidence of data corruption after the data was received because the ground system merged conflicting data from separated devices to form a single track.

Initial analysis highlighted anomalous ADS-B data recorded for one particular airframe. Further analysis revealed the anomalous data was due to the inadvertent and simultaneous operation of a portable ADS-B transceiver together with a Mode S extended squitter (ES) (i.e. ADS-B capable) transponder that only transmitted ADS-B under certain conditions.

Mitigation of the MAC risk needs to be balanced against the potential to increase ATS workload due to misleading data to provide an overall safety benefit. The benefits and drawbacks of a portable ADS-B device being used simultaneously with a transponder can be summarised as follows:

<u>Benefits</u>

When position, level and/or identity data are not available from the transponder, dual surveillance can;

1) Enable air to air traffic information to alleviate the mid-air collision risk
2) Provide level data and aircraft identity, which helps mitigate the CAS infringement risk,
3) Provide a greater chance of detecting the aircraft in some cases.

<u>Drawbacks</u>

The simultaneous operation of a portable ADS-B transceiver and an ADS-B capable transponder has the potential to cause credible corruption of data hence robust mitigation needs to be in place to prevent aircraft from operating ADS-B sources simultaneously. A new standard change, CS-SC005a, permits an ADS-B capable transponder to be connected to a GNSS position source. Aircraft owners should be encouraged to investigate whether this standard change can be implemented if they already own an ADS-B capable transponder. These owners should only consider using a portable ADS-B transceiver as a last resort.

It was noted that signal propagation from the portable ADS-B transceivers was highly variable. Availability of the ADS-B signal nearly matched the transponders for some aircraft but there was virtually no signal availability for other airframes. If cooperative surveillance is required to mitigate a hazard or to facilitate airspace access, then performance criterion must be put upon signal propagation to ensure its reception by the airborne and ground receivers. For this reason, it is recommended that owners of portable ADS-B transceivers should be encouraged to check their transmission efficiency and improve the effectiveness of the antenna and cabling if necessary.

Some surveillance trackers use the Mode A code to help identify unique tracks. The portable ADS-B transceivers usually broadcast either 7000, which often conflicted with the Mode A code broadcast by the transponder. It is possible that split tracks might be developed in some systems, or that ATS staff are presented by a Mode A code that changes continually between two values. It is recommended that the transmission of the Mode A code by the portable ADS-B transceiver should either be suppressed or made to match the Mode A code of the transponder during simultaneous transmission.

Acronyms and Terminology

Acronym	Description
A/C	Aircraft
ACAS	Airborne Collision Avoidance Systems
ADS-B	Automatic Dependant Surveillance – Broadcast [IN / OUT]
AMSL	Above Mean Sea Level
ARTAS	ATM Surveillance Tracker and Server
ATS	Air Traffic Services
CAS	Controlled Airspace
CRC	Cyclic Redundancy Check
CRISTAL RAD HD (aka CRISTAL)	**C**o-ope**R**ative validat**I**on of **S**urveillance **T**echniques and **A**pp**L**ications (ADS-B network)
CTA	Control Area
CTR	Control Zone
EC	Electronic Conspicuity
EvAcq	Enhanced Visual Acquisition (application)
FAS EC	Future Airspace Strategy – Electronic Conspicuity
FEC	Forward Error Check
FIS	Flight Information Service
FRUIT	False Replies Unsynchronised in Time
GA	General Aviation
MAC	Mid-Air Collision
MRT	Multi-Radar Track
MST	Multi-Sensory Track
NIC	Navigational Integrity Category
NODE	NATS Operational Display Equipment
RCE	Reduced Capability Equipment
SDA	System Design Assurance
SIL	Source Integrity Level

1. Introduction

1.1. Purpose of this document

The purpose of this document is to describe the analysis undertaken to support the CAA trial for simultaneous operation of transponders and separate ADS-B equipment on-board general aviation aircraft operating in uncontrolled airspace. See reference 4 for more information regarding the CAA trial. The objectives for this analysis are to:

1) Perform high level checks/assurances to determine whether there was any noticeable mutual interference between two signals being emitted from the same aircraft on the same frequency.
2) Provide further analysis and comment upon any anomalies encountered during the high level parsing of available data.

1.2. Scope of analysis

The analysis consisted of two methodologies:

1) To monitor engineering and ATC reports for any indication of unusual track behaviour by uncontrolled aircraft outside of controlled airspace.
2) To examine surveillance recordings for the aircraft involved in the CAA trial and attempt to identify instances of single and/or multiple data corruption, which could be attributed to the simultaneous operation of an ADS-B transmitter and a transponder by the same aircraft.

The surveillance recordings consisted of;

- ADS-B data from the CRISTAL system operated by NATS' R&D,
- Mode S track data in CAT048 format from the Pease Pottage and Debden Radars, and,
- NATS Operational Display Equipment (NODE) Multi-Radar Track (MRT) data.

Since the CAA's brief was to provide high level assurances, mitigations against potential hazards are also discussed in this paper.

Out of scope: Potential impact on Airborne Collision Avoidance Systems (ACAS)[1]

[1] It is known that hybrid ACAS uses ADS-B reports to reduce transponder interrogations. The consequences for ACAS receiving DF17 (interrogatable) and DF18 (non interrogatable) transmissions from two devices with the same airframe address but with different interrogation capabilities are unknown to the author of this document.

Concerns about "spoof ADS-B" have been discussed by the aviation industry and there has been some discussion about ACAS using the strength of the received signal to help validate the targets' ranges and eliminate ADS-B transmissions if the received signal strength does not correlate with the deduced range.

2. Background

This section details the background of the key issues relating to the simultaneous broadcast of data on the same frequency and using the same encoding format, although there is a significant difference between the power levels used in each signal. i.e. one signal is approximately four times stronger than the other (equivalent to ~6dBW difference between the signal strengths).

2.1. CAA Trial

The publication of CAP1391 Electronic Conspicuity (EC) [reference 5] devices enabled the development and deployment of a range of low-power Automatic Dependent Surveillance-Broadcast (ADS-B) transceivers for use by General Aviation. The ADS-B equipment transmits on the same frequency as Mode S and Mode A/C transponders, which is 1090 MHz, hence CAP1391 specifically prohibits operators from using an ADS-B transceiver on board an aircraft that is already operating a Mode S or Mode A/C transponder to help prevent interference.

Data corruption in the existing radar based systems such as False Responses Unsynchronised In Time (FRUIT), garbling, reflections, Mode-C errors etc are well documented and surveillance trackers are engineered to be resilient to these errors.

In response to increasing interest for ADS-B by pilots that were already operating transponders that were not capable of ADS-B OUT, the CAA held a trial that enabled selected aircraft operators to operate an ADS-B transceiver and their transponder simultaneously for a limited period. For more information regarding this trial please see reference 4.

The objective of the trial was to gather evidence that supports the theory there is a very low probability a Low Power ADS-B Transceiver (LPAT) causing data corruption when operated simultaneously with a transponder because enhanced ADS-B reception techniques have been developed that provide the ability to receive ADS-B with multiple overlapping Mode A/C FRUIT[2].

The CAA tasked NATS with monitoring daily reports for potential indications of mutual interference.

2.2. Channel loading

The portable ADS-B transceivers operate on 1090 MHz, which is already a heavily used frequency. Any increase in the transmission rate on this frequency will have some degree of impact on the overall channel loading, which is discussed in Appendix B.

[2] See overview in section 2.2.4.4.2 and Appendix I of ED102A

3. Analysis Description

3.1. Analysis overview

The high level task was to monitor the CAA's simultaneous transmission trial and attempt to identify instances of single and multiple data corruption, which could be attributed to the simultaneous operation of an ADS-B transmitter and a transponder by the same aircraft. There were two threads to the analysis conducted by NATS

1) The first level of analysis consisted of examining engineering and ATC logs for reports of unusual track behaviour by uncontrolled aircraft outside of controlled airspace.
2) The second level of analysis involved examination of surveillance recordings derived from NERL's R&D CRISTAL ADS-B network, NODE MRT, Pease Pottage and Debden Mode S radars.

Although this paper was never intended to weigh the benefits and drawbacks of dual surveillance, some benefits were noted and are reported here for completeness.

3.2. Methodology

The methodology used for examining engineering and ATC logs is self-evident and does not require explanation.

The original intent was to analyse eight flights made by two aircraft over five selected days, however, it quickly became apparent that ADS-B data was received from only one of these aircraft and that data had anomalous properties, see section 3.3.2 for further details. There appeared to be no ADS-B data recorded from the other aircraft because it flew mainly between West Dorset and Devon, which is outside of the CRISTAL coverage.

The sample was increased to examine data from all the participants who responded to the CAA's trial in order to gain useful information. Surveillance data was collected for 64 flights made by 17 aircraft over 12 selected days. Even so, some of these aircraft flew without appearing to broadcast ADS-B every time they flew and some did not appear to broadcast any ADS-B data at any time. See also section 3.3.1

It was envisaged that missing or corrupted data would be a reasonable indicator of interference, however, it transpired that the ADS-B signal received by the CRISTAL network was typically no more than -85dB and dropped out at -92dB, which is the limit of the receiver sensitivity. i.e. loss of the ADS-B data was much more likely to be due to weak signal of the transmitter rather than data corruption. If there was data loss when the received signal strength was -68dB then it would have been a more credible indicator of interference.

The remainder of the analysis focussed on searching for potential corruption by comparing the values from the different surveillance sources for the following data items:-

1) Derived track position.
2) Derived level (height).
3) Aircraft parameters; Callsign, ICAO address and Mode A code.

3.3. Results

The simultaneous operation of a portable ADS-B transceiver and a transponder would seem to have the potential to cause data corruption during transmission because both devices are transmitting on the same frequency and using the same pulse characteristics, e.g. pulse duration and rise time. However, there was no noticeable increase of data corruption for any of the trial aircraft. This should not be interpreted as there is no corruption of messages during this phase only that it is extremely hard to identify such instances in the operation because the surveillance systems are resilient to occasional data corruption such as False Responses Unsynchronised In Time (FRUIT), garbling, reflections and Mode-C errors.

Data corruption is more likely to occur after both sets of transmissions have been successfully received and then merged into a single track by the ground surveillance system. The most common types are disparate Mode A octal values and up to 200' difference between the barometric altitudes.

The less common but potentially more serious problem is when the portable transmitter is operated simultaneously with a Mode-S ES transponder that is also squittering ADS-B, which happened once during the trial. It seems to constitute a credible hazard because the Source Integrity Level (SIL) & System Design Assurance (SDA) message is broadcast independently from the position & Navigational Integrity Category (NIC) message, which meant the NATS CRISTAL system assigned the SIL/SDA value from the transponder to the position/NIC message from a portable transmitter. This problem is discussed further in section 3.3.5.

Because this paper considers potential consequences for other ANSPs as well as NERL, some assertions are made regarding hypothetical problems that may exist now or in the future, which could affect one or more ANSPs.

3.3.1. Limitations of results

As mentioned in the previous section, data was examined for 17 airframes that were notified as participating in the ADS-B trial. Of these 17, 9 airframes appeared to fly with a portable ADS-B transceiver on at least one day, although no ADS-B data was recorded for 5 of these airframes when they flew on other days. 8 participating airframes flew without appearing to transmit any ADS-B data via a portable ADS-B transceiver. The following table indicates which flights were recorded by the surveillances systems.

Date	Airframe	Duration of recorded flight	Flights with no recorded ADS-B
26/01/2018	AC1 AC2	00:15:05 01:28:29	AC3, ACA, ACB, AC4
04/02/2018	AC3,	01:33:52	ACC, ACB, ACD, ACE
24/02/2018	AC3 AC4	01:39:20 00:25:18	ACB , ACD, ACE
25/02/2018	AC1 AC5[3]	00:45:10 01:58:06	ACF, ACA, AC8, ACB, ACD, ACE, AC3
08/03/2018	AC6 AC7	01:05:40 00:24:42	ACC, ACE
13/03/2018	AC7	01:01:33	ACF, ACG[4]

[3] ADS-B data broadcast from this airframe had anomalies, which are discussed further in the next section.

Date	Airframe	Duration of recorded flight	Flights with no recorded ADS-B
14/04/2018	AC7 AC3	01:25:12 02:01:13	ACF, AC2, ACB, ACD, ACE, ACH
12/05/2018	AC7 AC3 AC8	01:06:44 02:02:39 01:00:00[5]	AC6, ACD, ACE
17/05/2018	AC7	00:55:24	AC6, ACD, ACE, ACG[3]
30/11/2018	AC5, AC9	01:07:00	
10/12/2018	AC7, AC9	01:06:00	

Table 1: Duration of surveillance recordings logged for each flight

The total duration of the recorded flights by the 8 participating airframes was 18:10:27. This figure is derived from the duration of the NODE MRT recordings, which were almost contiguous. The ADS-B data recorded on CRISTAL was fragmented by comparison, hence the duration of the ADS-B surveillance data recorded for these flights was less.

Given the small sample size, no statistical significance is claimed for the analysis performed in this paper.

3.3.2. Application or forward error checking

The Mode S radars operated by NATS apply forward error checks (FEC) of transponder responses to detect and where possible correct Mode C errors in received messages i.e. they apply cyclic redundancy checks (CRC). The "Mode C garbled" flag indicates FEC was applied successfully and the "Mode C Not Validated" flag indicates FEC was applied but the data may still be in error.

It was originally hypothesised that the presence of the FEC flags in the Mode S report could be a symptom of data corruption caused by the simultaneous operation of a transponder with an ADS-B transceiver. This hypothesis has been withdrawn because the application of FEC seems more likely to be due to overlapping transmissions, possibly caused by the number of ground interrogators, and is a feature of current operations.

A single instance of FEC being applied but with an erroneous Mode C remaining was observed in the radar recordings from Pease Pottage during 12/05/2018. The following table highlights the erroneous data in context with other recordings made before and after the event.

Long	Lat	Time	Md A	Md C	Md C Not Validated	Md C Garbled	Trk Nmr
-0.021	51.247	09:46:56	3767	1200	FALSE	FALSE	1185
-0.017	51.247	09:47:02		1200	FALSE	FALSE	1185
-0.013	51.246	09:47:08	3767	**2300**	**TRUE**	FALSE	1185
-0.009	51.246	09:47:14	3767	1100	FALSE	FALSE	1185
-0.005	51.246	09:47:20	3767	1200	FALSE	FALSE	1185

Table 2: Erroneous Mode C on 12/05/2018

[4] The ADS-B data broadcast from this airframe appears to have been transmitted by a Mode S (ES) transponder, hence it was excluded from the examination for disparate data and interferences.
[5] The ADS-B data received from this airframe only lasted about 20 seconds..

Further investigation revealed instances of the application of FEC are quite common, hence an individual event such as the example above cannot be viewed as evidence of false or misleading data caused by interference.

Examination of all Pease Pottage and Debden radar recordings made during 12/05/2018 revealed there were 4388 instances of FEC being applied. The following table shows a small sample of these events involving Mode S and Mode A/C transponders.

Long	Lat	Time	Md A	Md C	Md C Not Validated	Md C Garbled	Trk Nmr
0.686	51.587	09:46:50	4575	1900	FALSE	TRUE	1944
-0.607	52.048	09:46:55	7000	1950	TRUE	FALSE	969
1.650	51.039	09:46:56	1177	3000	FALSE	TRUE	3347
-0.013	51.246	09:47:08	3767	2300	TRUE	FALSE	1185
-2.441	50.915	09:47:24	1177	-900	TRUE	FALSE	218
0.014	52.682	09:47:24	7000	-200	TRUE	FALSE	423

Table 3: Sample data showing application of forward error checking during 12/05/2018

3.3.3. Examination of engineering and ATC logs

No reports were made of spurious surveillance data or compromised performance.

3.3.4. Potential to cause increase in FRUIT

An increase on the number of transmissions on 1090Mhz has the potential to cause transponder FRUIT. The probable probability of increased FRUIT caused by a large number of portable ADS-B transmitters has been researched separately and is discussed in Appendix B.

3.3.5. Anomalous ADS-B transmissions

The airframe identified by the address AC5 appeared to transmit inconsistent ADS-B data for a 2 hour period, which seemed to have been due to the aircraft transmitting ADS-B data from two sources. However, this assumption could not be validated on the data available at that time hence the first iteration of this report recommended further testing.

A full description of the symptoms found during analysis of the original 2 hour flight can be found in Appendix A along with the steps taken during the follow-up analysis, which proved the hypothesis that the aircraft's transponder was an ADS-B source under certain conditions described in Appendix A. The causes of the anomalous data can be summarised as:

- When the Garmin GNS430 was in route mode, it provided GNSS position data to the KT74 transponder installed in AC5.
- When enabled, the KT74 transmitted the GNSS position with NIC=3[6] and quality metrics of SIL & SDA=3, a Mode-A code of 1730 and level 1800.
- The portable SkyEcho unit transmitted the GNSS position with NIC=0 and quality metrics of SIL & SDA=0, a Mode-A code of 7000 and level 1950.
- Four separate message types are used to broadcast position & level, Mode A, Aircraft callsign and assurance metrics, which are broadcast at separate intervals. Hence it becomes difficult for a receiving system to attribute the correct callsign, Mode A and assurance with the appropriate position report. See the following table for an example.

[6] GNSS Position and NIC are broadcast together using ADS-B message types 9 to 19, SIL and SDA are broadcast independently in message type 31.

Trk	Time	Lat	Long	NIC	NACv	NIC B	SIL	NACp	SDA	GVA	Vers	Md A	Flt Lvl	Amplitude
2155	09:51:57.80	50.800	0.054	3	0	0	0	3	3	0	2	1730	1800	-66
2155	09:51:58.37	50.800	0.054	3	0	0	0	3	3	0	2	1730	1800	-85
2155	09:51:59.87	50.801	0.053	0	0	0	0	3	3	0	2	1730	1950	-82
2155	09:52:00.84	50.801	0.052	0	0						2	1730	1800	-65
2155	09:52:01.93	50.802	0.052	0	0						2	1730	1800	-65

Table 4: Example of data corruption caused by merging two sources of data into a single track

The ADS-B message composition means the NIC value is an integral part of the position message but the SIL, SDA and NACp are distributed across separate messages.

For the data highlighted by the orange box in table 4, NIC=0 indicates the GNSS position was derived from the portable ADS-B source whereas NACp & SDA=3 were derived from the KT74 transponder. This false assignment of assurance to the GNSS position for the portable transmitter occurred 2 to 3 times a minute and is classed as credible corruption of data. Note also the wrong Mode A code was also assigned the portable unit for three of the updates per minute.

As stated in section 1.2 mitigations are proposed as a means to provide high level assurances to reduce the effects of interference when a portable ADS-B transceiver is operated in an aircraft that is also broadcasting ADS-B from a Mode S (ES) transponder:

1) Owners of aircraft fitted with ADS-B capable transponders (e.g. All Trig txprs, Bendix King KT74, Garmin GTX 330ES/GTX33/GTX3x5, funke TRT800A/H, Becker BXP640x), should be encouraged to investigate whether they could use standard change CS-SC005a to connect their transponder with a suitable GNSS position source. If they cannot apply CS-SC005a, owners of such aircraft must positively establish they do not transmit ADS-B via the transponder before considering using simultaneous surveillance.
2) ADS-B position messages are embedded with either NIC (ADS-B versions 1&2) or NUNC (ADS-B version 0). ATS Providers need to ensure ADS-B tracks with values of NIC <= 6 or values of NUNC <=5 are not used for safety critical services.

3.3.6. Potential confliction between aircraft ID and address

The possibility of assigning a fixed block of discrete 24 bit addresses to all portable ADS-B transceivers to mitigate the consequences of a transceiver being used on an aircraft that already has ADS-B OUT was discussed by NATS' surveillance specialists. This option had to be ruled out because there would be a high probability of a multi-sensory tracker (MST) generating split tracks for that aircraft. i.e. one track for the ADS-B address and the other for the Mode-S address. It may also cause the ADS-B traffic receiver to continually alert against its own transponder, which could be unacceptable to the pilot.

Split tracks could also be caused if a portable ADS transceiver was swapped between airframes without changing the aircraft ID and address such as one might expect when hiring club aircraft. That said, there were no observed instances where the aircraft identification (ID) and address in the ADS-B data mismatched the Mode-S data.

3.3.7. Examination of possible false track position

ADS-B, Mode-S and NODE MRT tracks were compared to determine if there was a possibility that simultaneous broadcasting might affect the apparent track position for interrogator based surveillance.

The following limitations of tracker performance were observed for interrogator based tracking.

1. The examined Mode S radar tracks exhibited “jitter” of up to 350m whilst the targets were more than 40NM form the head, this was particularly exacerbated because they were also near the base of radar cover.
2. NODE MRT tracks can be prone to errors of up to 250m particularly when aircraft initiate or terminate turn manoeuvres.

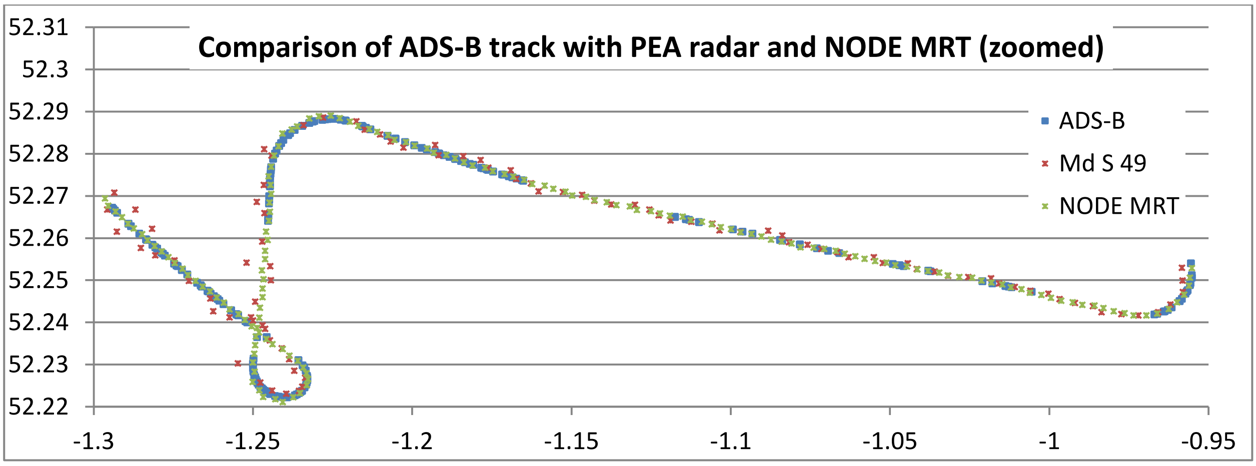

Figure 1: Example of Mode-S “track jitter” for a target more than 40NM from the radar head.

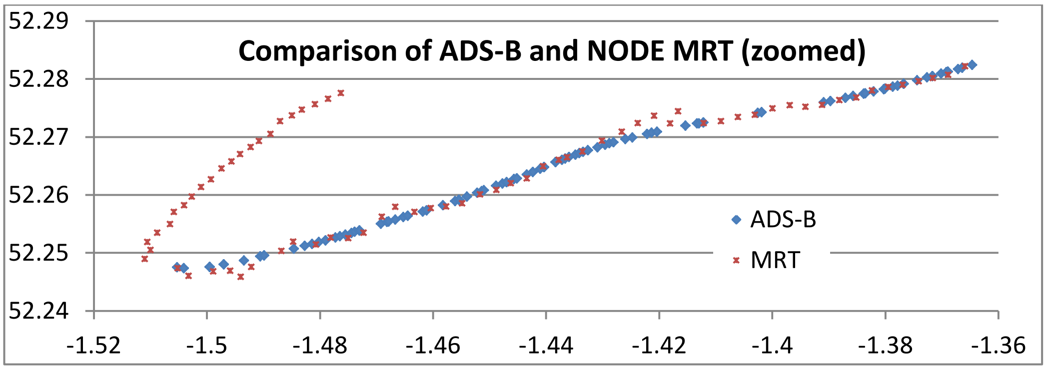

Figure 2: Example of apparent MRT track error compared to ADS-B track.

Similar variations in the tracking performance were also observed for some aircraft that were not participating in the trial. Figure 3 shows a comparison of the NODE MRT against ADS-B data, which was transmitted by a Mode-S (ES) transponder. i.e. the ADS-B broadcasts were synchronised to the Mode-S responses to eliminate the possibility of interference.

It seems more likely that small variations in observed track such as those shown in Figure 1 and Figure 2 are due to the performance limitations of surveillance trackers based on rotating radars rather than being caused by interference from portable ADS-B transceivers.

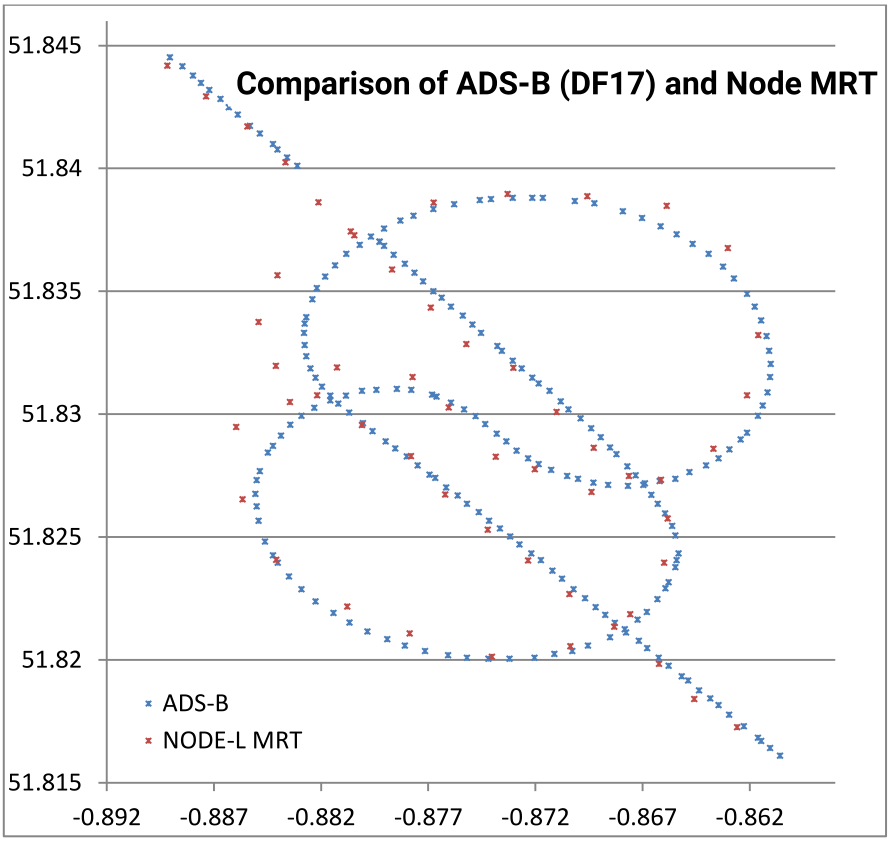

Figure 3: Example of apparent MRT track error (ADS-B & transponder transmissions synchronized).

3.3.8. Disparate Mode A codes

GA pilots are encouraged to use the conspicuity Mode A codes that are dedicated as “Listening squawks”. These codes indicate to Air Traffic Service (ATS) providers that the pilot is maintaining a listening watch on their frequency without necessarily establishing two-way contact.

The portable ADS-B transceivers usually broadcast either 7000 (general conspicuity code) or a null Mode A code, whereas the transponders squawked a variety of Mode A codes depending on the airspace where the aircraft was flown. i.e. It was not uncommon for the transponder to response with a “listening squawk” to radar interrogations while the portable ADS-B transceiver was broadcasting 7000.

The existing generation of surveillance trackers often use Mode A codes along with the derived position to create and maintain their track databases. Even the ARTAS system[7] which is a relatively modern system would be susceptible to this problem. The most probable outcomes are:

- If the airframe address was common to both input streams, then one track may be created but the SSR code assigned to that track would alternate continually between the two values because the input streams have different update rates.
- Two tracks might be created in the same location if the airframe address in the ADS-B data was inconsistent with the Mode S data. It seems likely that each track would be assigned with a Mode A code according to the input stream.

[7] ARTAS (ATM suRveillance Tracker And Server) is a system designed by Eurocontrol in order to help in Aerial surveillance and Air traffic control

Either of these outcomes could be undesirable in the ATC operation because of the potential to cause confusion. To mitigate this problem it is proposed that portable ADS-B transceivers do not broadcast ADS-B register 6,1[8] when the unit is operating in an aircraft that also has an operational transponder, unless the system needs to broadcast an emergency condition.

3.3.9. Mode-C vs ADS-B level offset

The portable ADS-B transceiver has its own barometric capsule to determine altitude above a 1013hPa pressure datum and this value is broadcast to other aircraft and ground receivers. Being portable equipment, the devices are not connected to the aircrafts' static vents hence each unit is broadcasting cabin altitude rather than aircraft altitude. The following graph represents how the ADS-B level data is slightly different to the transponder Mode C data.

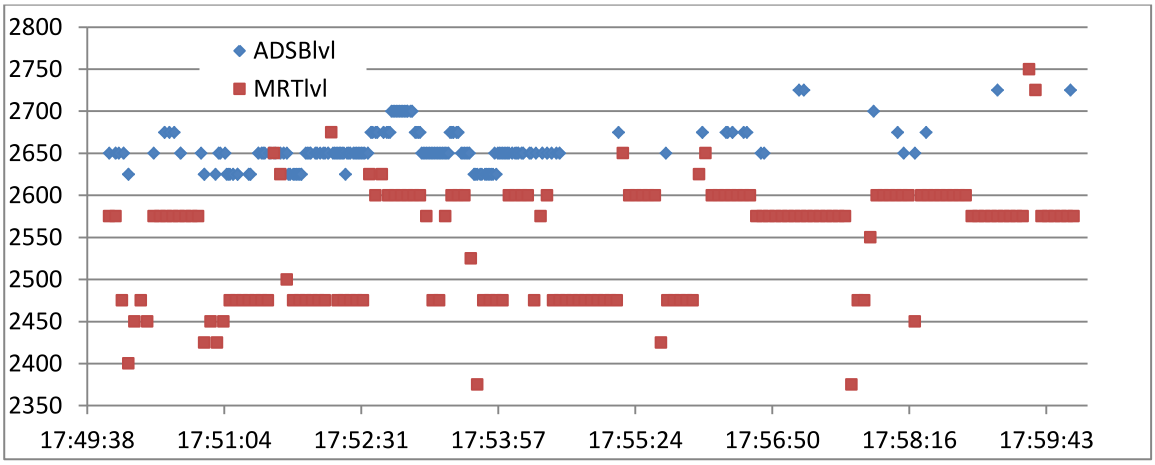

Figure 4: Comparison of ADS-B and Transponder Mode C level data.

Level data from ADS-B and transponders were compared for all flights. Where there was 5 secs or less between the timestamps of the ADS-B report and the NODE MRT report, the difference between the ADS-B level report and the level assigned in the NODE MRT was compared. At the end of the flight the average difference between the ADS-B and MRT level reports along with the standard deviation for each airframe was calculated. Finally, the average difference for all flights was calculated and the results are shown in the following table. All units are in feet.

Addr	Mean_tot	Mean1	Stddev1	Mean2	Stddev2	Mean3	Stddev3	Mean4	Stddev4
AC2	116.92	116.92	35.34						
AC1	166.48	158.43	34.14	174.54	35.17				
AC3	42.66	36.16	47.09	31.55	34.72	48.17	34.86	54.76	28.59
AC4	163.81	163.81	34.36						
AC5[9]	67.29	67.29	94.29						
AC6	131.10	131.10	50.63						
AC7	73.44	47.01	41.00	99.88	51.86				
AC7[10]	-39.81	-50.62	42.92	-34.13	39.54	-34.68	40.88		
All equip	90.24								

Table 5: Differences between ADS-B and MRT level reports

[8] Extended Squitter Aircraft Status (Subtype 1: Emergency/Priority Status and Mode A Code)
[9] This is the airframe that appeared to transmit anomalous data, see also section 3.3.2
[10] The owner of this airframe had access to two portable ADS-B transceivers and it is believed he flew with different units on different days.

These results show that on average, the level data transmitted by the portable ADS-B units are about 90' above the level data transmitted by the corresponding transponder. This may not seem much but unnecessary CAS infringement warnings may be generated for aircraft that regularly fly 100' below the base of the London TMA.

It is recommended that manufacturers of portable ADS-B equipment should introduce a default reduction of 100' for the barometric level data to allow for the deviation caused by measuring cabin altitude. Consideration should also be given to the implementation of a feature that allows owners to input a level offset themselves.

3.3.10. Variable probability of detection

It was noted that the reception of the ADS-B signal from most of the participants was fragmented even for those aircraft within good ADS-B coverage. For example, on 12/05/2018 AC8 departed Redhill for a one hour sortie and was tracked continually by its Mode A/C transponder. The aircraft also operated a portable ADS-B transceiver but its ADS-B transmissions were recorded for only 20 seconds for the entire flight despite the aircraft flying within a few miles of the nearest CRISTAL receiver at Reigate. The Reigate station was confirmed to be on line during this flight by checking the runway movements at Gatwick which are only visible on CRISTAL from the Reigate receiver.

In the following figure the red section of the aircraft track indicates where ADS-B data was received from airframe AC8 on 12/05/2018 and the black line indicates the radar track. It should be noted that the state of battery charge for the airborne equipment is unknown and the transmitter may have shut down or gone into a low power mode if the charge was depleted.

Figure 5: Duration of ADS-B data recorded from AC8

Two aircraft produced reasonably good sets of recordings, AC1 and AC7. The ADS-B data transmitted by AC7 on 13/03/2018 was particularly good and nearly matched the NODE MRT track for availability. In the following diagram the red section of the aircraft track indicates where ADS-B data was received from this airframe and the black line indicates the NODE MRT track.

Figure 6: Duration of ADS-B data recorded from AC7

The operator of airframe AC7 was interviewed, he explained he had carefully situated the transceiver and ensured the antenna was upright. This extra diligence could account for the improved performance of this particular unit compared to other portable ADS-B transceivers. NATS R&D has a report that shows the installation of antennas is also critically important to FLARM performance and it is noted that FLARM users often install equipment antennas where they are not obstructed by the hull or the aircrew.

If the reception of the surveillance transmission is not required to mitigate a hazard, then the performance of portable transmitter can be accepted on a no credit no hazard basis and no performance criterion needs to be put upon signal propagation. Conversely if cooperative surveillance is required to mitigate a hazard or access surveillance mandatory airspace, then performance criterion must be put upon signal propagation to ensure its reception by the airborne and ground receivers.

It is recommended that owners of portable ADS-B transceivers should be encouraged to check the efficiency of their portable transceivers and if necessary install improved/external antenna(s) to mitigate the possibility of signal loss.

3.3.11. Positive benefits from dual surveillance

It was noticed during the course of this analysis that a few GA aircraft operate with Mode A/C or even Mode A only transponders. The simultaneous operation of an ADS-B transceiver alongside a transponder could be beneficial:

1) ADS-B provides level data for transponders with no Mode C capability, or with inadvertent deselection of Mode C,
2) ADS-B provides aircraft identification for non Mode S aircraft, and,

3) In some cases there is complimentary coverage provided by ADS-B and radar meaning a greater chance of detecting the aircraft when both surveillance systems are in use in the aircraft and on the ground.

The ADS-B level data will help identify potential mid-air collision (MAC) risks and CAS infringements. The provision of aircraft callsign can also help ATS staff to establish communications with any aircraft that has or is about to potentially infringe CAS. The following graphic shows examples of these benefits for aircraft operating near Gatwick.

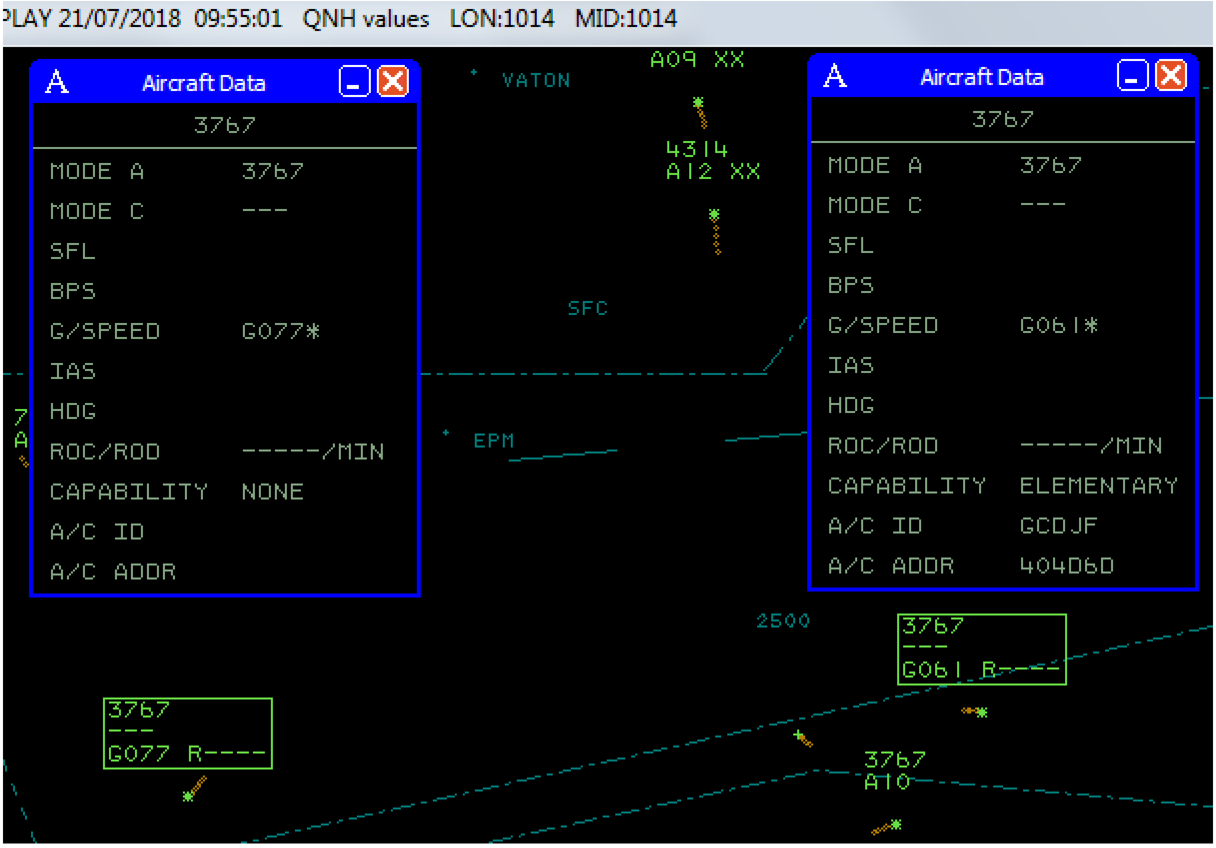

Figure 7: Examples of dual surveillance benefits.

In the graphic above, the ‘Aircraft Data’ box for the target on the left indicates that the transponder is responding to Mode A interrogations only meaning the Mode C and aircraft identity fields are unpopulated. The base of CAS is 2500’ above mean sea level (AMSL) and it is presumed the aircraft is remaining below CAS. The data box on the right shows responses by a Mode S transponder where the pilot has deselected the Mode C reports. The base of CAS 1500’ AMSL and the aircraft is presumed to be below CAS also.

4. Summary of analysis

4.1. Analysis of ATS benefits and drawbacks for dual surveillance

It should be evident that the main benefit of allowing all aircraft to use a portable ADS-B transceiver with a transponder is to enable the exchange of air to air traffic information to help mitigate the MAC risk. For simultaneous surveillance to be acceptable, this benefit needs to be balanced against the risk of increasing ATS workload due to the corruption of data to provide a net safety benefit.

The following table summarises the benefits and drawbacks to ATS providers for the simultaneous operation of a portable ADS-B transceiver together with each of the following transponder types.

Portable ADS-B transceiver together with:	Benefit to ATS providers	Drawbacks to ATS providers
Mode A transponder	Aircraft callsign, ICAO address and level data now available to MST. Cheap alternative to radar for airfield ATS units	Potential conflict(s) in MST: Mode A
Mode A/C transponder	Aircraft callsign and ICAO address data now available to MST. Cheap alternative to radar for airfield ATS units	Potential conflict(s) in MST: Mode A and level data[11]
Mode S transponder	Cheap alternative to radar for airfield ATS units	Potential conflict(s) in MST: Aircraft callsign, ICAO address, Mode A and level data[12]
Mode S (ES) ADS-B capable transponder	Cheap alternative to radar for airfield ATS units	Potential conflict(s) in MST: SDA, proposed RCE flag[13], aircraft callsign, ICAO address, Mode A and level data

Analysis demonstrates that aircraft fitted with a transponder that is NOT ADS-B capable (e.g. KT76A, GTX328, GTX330) or any legacy Mode A/C transponders, would seem to present a low risk to the ATS operation if they operated simultaneously with a portable ADS-B transmitter[14].

[11]Hence the recommendations to inhibit broadcast of Mode A code when ADS-B transceiver is used in conjunction with a transponder and to adjust the ADS-B level reports to be closer to the transponder Mode C reports.

[12] Conflicting aircraft callsigns and ICAO addresses were not observed in data collected during the trial but if the situation was to occur in the future it may cause split tracks in the MST. Split tracks are more likely to constitute a workload issue than a safety issue and the problem may be mitigated if an ATS unit is able to instruct the operator to cease ADS-B transmissions.

[13]The System Design Assurance (SDA) and the proposed Reduced Capability Equipment (RCE) will both be contained in the Aircraft Operational Status message (BDS register 6,5) which is broadcast at separate intervals (2.5 secs ±0.5 secs) to the airborne position (BDS register 0,5). i.e. it may be difficult for surveillance tracking systems to determine what assurance level should be applied to the position reports.

[14] It is not known if the simultaneous operation of a transponder and non transponding ADS-B emitter will affect hybrid TCAS.

5. Conclusions

Given the small sample size, no statistical significance is claimed for the analysis performed in this paper. The findings can be summarised as; no evidence was found to indicate that simultaneous broadcast causes interference during signal transmission rather than evidence was found to show simultaneous broadcast does not cause interference.

Instances of lost and corrupt signal transmissions were found but it seems more likely these were part of the normal surveillance performance. Mode-S radars are prone to “jitter” when the aircraft are more than 40nm from the radar head and there are thousands of instances per day where Mode C may have been corrupted. It would seem that the simultaneous operation of a portable ADS-B transceiver alongside a transponder adds little or possibly no extra probability of signal corruption to an environment where minor and single instances of signal corruption are considered “normal operation”.

The only method to truly detect interference during signal transmission would be to test with closed laboratory conditions, however, this could be viewed as an artificial environment that does not match real world operations.

There was reliable evidence of data corruption after signals had been received and decoded. It was established that during one flight a portable ADS-B transceiver operated simultaneously with a Mode-S ES transponder that was also broadcasting ADS-B data. The two sources of conflicting ADS-B data were combined into one track leading to the corruption of the GNSS position accuracy and quality metrics, plus level data and Mode A code.

These results show that on average, the level data transmitted by the portable ADS-B units are about 90’ above the level data transmitted by the corresponding transponder. This may seem insignificant but unnecessary CAS infringement warnings may be generated by aircraft that regularly fly 100’ below the base of the London TMA.

The reception of the ADS-B signal from most of the participants was fragmented even for those aircraft within good ADS-B coverage. In the worst case there was little or no ADS-B data received, although this could have been due to a loose antenna or the battery charge being depleted. Conversely, the two best aircraft produced reasonably consistent ADS-B data transmitted, which nearly matched the NODE MRT track for availability.

If electronic surveillance is not required to mitigate a hazard, then the performance of portable ADS-B transmitters can be accepted on a no credit no hazard basis. Conversely if cooperative surveillance is required to mitigate a hazard or for airspace access, then performance criterion must be put upon signal propagation to ensure its reception by the airborne and ground receivers.

Although this paper was not intended to weigh the benefits and drawbacks of dual surveillance, some benefits were noted and are reported here for completeness. When position, level and or identity data are not available from the transponder, dual surveillance can;

1) Enable air to air traffic information to alleviate the mid-air collision risk,
2) Provide level data and aircraft identity, which helps mitigate the CAS infringement risk,
3) Provide a greater chance of detecting the aircraft in some cases.

Aircraft that are fitted with a transponder that is NOT ADS-B capable or any legacy Mode A or A/C transponder, would seem to present a low risk to ATS if they used portable ASD-B transceiver.

This paper cannot assess potential interference or performance problems caused to hybrid ACAS by the simultaneous operation of a Mode S transponder and a low power ADS-B transceiver.

6. Recommendations

Recommendation 1: Reducing risk spurious CAS infringement warnings

It is recommended that manufacturers of portable ADS-B equipment should introduce a default reduction of 100' for the barometric level data to allow for the deviation caused by measuring cabin altitude. Consideration should also be given to the implementation of a feature that allows owners to input a level offset themselves.

Recommendation 2: Reducing risk of split tracks

To mitigate the risk of causing split tracks when the portable ADS-B transceiver broadcasts a different Mode A code to the transponder, it is recommended portable transceivers do not broadcast ADS-B register 6,1 when the unit is operating in an aircraft that also has an operational transponder, unless the system needs to broadcast an emergency condition.

Recommendation 3: Reducing risk of GNSS position being given false assurance.

In order to mitigate the risk of the GNSS position being given false assurance if the portable transceiver is inadvertently operated simultaneously with a transponder that is squittering ADS-B, it is recommended that:

1) Owners of aircraft fitted with ADS-B capable transponders (e.g. All Trig txprs, Bendix King KT74, Garmin GTX 330ES/GTX33ES/GTX3x5, funke TRT800A/H, Becker BXP640x), should be encouraged to investigate whether they could use standard change CS-SC005a to connect their transponder with a suitable GNSS position source. If they cannot apply CS-SC005a, owners of such aircraft must positively establish they do not transmitting ADS-B via the transponder before considering using simultaneous transmission surveillance.
2) ADS-B position messages are embedded with either NIC (ADS-B versions 1&2) or NUNC (ADS-B version 0). ATS Providers need to ensure ADS-B tracks with values of NIC <= 6 or values of NUNC <=5 are not used for safety critical services.

Recommendation 4: Encourage owners to check transmission efficiency.

It is recommended that owners of portable ADS-B transceivers should be encouraged to check the efficiency of their portable transceivers and, if necessary, install improved/external antenna(s) to mitigate the possibility of signal loss.

Recommendation 5: Seek industry expertise to assess potential impact on hybrid TCAS

It is recommended that the regulatory body should solicit the informed opinion from a suitable organisation with expertise to assess the potential interference or performance problems caused to hybrid TCAS systems by the simultaneous operation of a Mode S transponder and a low power ADS-B transceiver.

7. Referenced documents

List of documents referenced in this document:

1 Low Power ADS-B Transceiver (LPAT) RF Environment Modelling Study – Phase 2. QINETIQ 2012.

2 Low Power ADS-B Transceiver (LPAT) RF Environment Modelling Study. QINETIQ 2014

3 ED-73E, Minimum operational performance specification for secondary surveillance radar Mode S transponders Vol 1, EUROCAE, May 2011

4 Simultaneous Transmission by Electronic Conspicuity Devices and Mode S Transponders, CAA, August 2017

5 CAP1391 Electronic conspicuity devices, CAA, April 2018

Appendix A Anomalous data analysed during trial

A.1 Initial symptoms observed during analysis

This appendix provides a detailed description of all the anomalous data that was observed in the recordings of a 2 hour flight by AC5, together with the follow-up analysis.

At 08:17:26 on 25/02/2018 AC5 started transmitting ADS-B data with Mode A code 7000 and initially appeared to be giving normal information with the GNSS position accuracy and quality indicators set to zero.

At 08:23:43 the Mode A code changed to 1730 for most of the remaining ADS-B transmissions, which coincided with a change to the Mode A code in the NODE MRT recordings. This event could be explained if the same device was transmitting the ADS-B data and the Mode S data, although this does not seem to be the complete answer.

Between 08:23:43 and 10:10:06 there were sporadic anomalies in the ADS-B data that seemed to indicate the presence of two devices transmitting ADS-B data with the same airframe address and following the same trajectories.

1) The ADS-B level data was around 175’ higher than the MRT mode C for most of the time. The ADS-B data had a precision of 25’ whereas the Mode C had a precision of 100’. Both of these factors indicate a portable ADS-B unit transmitting cabin altitude was the source of the level data.
2) Between 08:23:43 and 10:05:35, the ADS-B Mode A code appeared to change randomly from 1730 back to 7000 whereas the Mode A code in NODE MRT remained consistently at 1730.
3) From 09:49:36 the GNSS accuracy and integrity metrics were mostly populated in a similar manner that might be expected by a Mode S (ES) transponder that is connected to a non certified GNSS source, although there were times when no quality metrics were indicated.
4) In the same period, the strength of the received ADS-B signal appeared to fluctuate by up to 20dB
5) In the same period, the ADS-B level mostly matched the MRT Mode C, which has 100’ precision although it occasionally jumped about 175’ above and returning to its original value within a 3 second period.

It was noted the CRISTAL track number remained the same for the period of the flight.

The following table contains a sample of the anomalous data received from airframe AC5. The changing state of the GNSS position quality and the systems assurance items are of particular concern.

Trk	time	lat	long	nic	nacv	nicb	sil	nacp	sda	gva	vers	Md A	flt_lvl	amp
2155	09:51:55.70	50.799	0.055	3	0	0	0	3	3	0	2	1730	1800	-81
2155	09:51:56.67	50.800	0.054	3	0	0	0	3	3	0	2	1730	1800	-82
2155	09:51:57.80	50.800	0.054	3	0	0	0	3	3	0	2	1730	1800	-66
2155	09:51:58.37	50.800	0.054	3	0	0	0	3	3	0	2	1730	1800	-85
2155	09:51:59.87	50.801	0.053	0	0	0	0	3	3	0	2	1730	1950	-82
2155	09:52:00.84	50.801	0.052	0	0						2	1730	1800	-65
2155	09:52:01.93	50.802	0.052	0	0						2	1730	1800	-65
2155	09:52:02.46	50.802	0.051	0	0						2	1730	1800	-65
2155	09:52:03.56	50.803	0.051	3	0	0	0	3	3	0	2	7000	1800	-82
2155	09:52:04.10	50.803	0.051	3	0	0	0	3	3	0	2	7000	1800	-84
2155	09:52:05.63	50.803	0.050	0	0						2	7000	1800	-65
2155	09:52:06.68	50.804	0.049	0	0						2	1730	1800	-82
2155	09:52:07.70	50.804	0.049	3	0	0	0	3	3	0	2	1730	1800	-83
2155	09:52:08.84	50.805	0.048	0	0						2	7000	1975	-85
2155	09:52:09.79	50.805	0.048	0	0						2	7000	1800	-64
2155	09:52:10.78	50.806	0.048	0	0	0	0	3	3	0	2	7000	1975	-81
2155	09:52:11.80	50.806	0.047	3	0	0	0	3	3	0	2	1730	1800	-65
2155	09:52:12.86	50.806	0.047	3	0	0	0	3	3	0	2	1730	1800	-81
2155	09:52:13.80	50.807	0.046	3	0	0	0	3	3	0	2	1730	1800	-65
2155	09:52:14.89	50.807	0.046	3	0	0	0	3	3	0	2	1730	1800	-80
2155	09:52:15.88	50.808	0.045	3	0	0	0	3	3	0	2	1730	1800	-63
2155	09:52:16.86	50.808	0.045	3	0	0	0	3	3	0	2	1730	1800	-63
2155	09:52:17.92	50.809	0.044	3	0	0	0	3	3	0	2	1730	1800	-82
2155	09:52:19.02	50.809	0.044	3	0	0	0	3	3	0	2	7000	1800	-62
2155	09:52:19.92	50.810	0.044	0	0	0	0	3	3	0	2	7000	1975	-64
2155	09:52:20.63	50.810	0.043	3	0	0	0	3	3	0	2	7000	1800	-63
2155	09:52:21.92	50.810	0.043	0	0	0	0	3	3	0	2	1730	1975	-85
2155	09:52:22.96	50.811	0.042	3	0	0	0	3	3	0	2	1730	1800	-64
2155	09:52:23.54	50.811	0.042	3	0	0	0	3	3	0	2	7000	1800	-63
2155	09:52:25.02	50.812	0.042	3	0	0	0	3	3	0	2	7000	1800	-79
2155	09:52:25.43	50.812	0.041	0	0						2	7000	1800	-64

Table 6: Comparison of ADS-B level and Mode C for airframe AC5

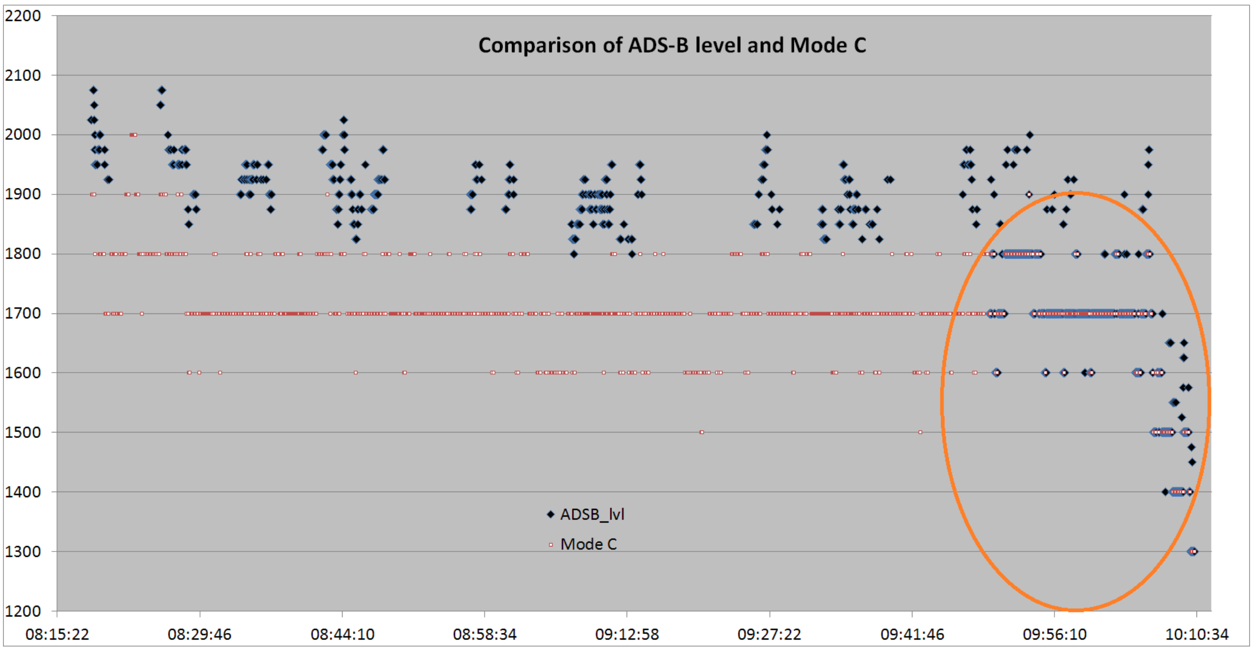

Figure 8: Comparison of ADS-B level and Mode C for airframe AC5

The above graphic shows the ADS-B and NODE MRT level data were identical from 09:49:36 onwards (orange highlight), before this time the ADS-B level data had been approximately 150' above the Node MRT level. This behaviour suggests that the transponder had an ADS-B function, which became fully active from about 09:49:36 onwards.

A.2 Additional analysis to explain observed behaviour

The following text describes the additional steps that were taken to explain the observed behaviour.

1) The owner of AC5 was contacted and he stated that on start-up, his Bendix King KT74 transponder always reported "No ADS-B Position" and provided the following photograph.

Figure 9: Photograph of KT74 transponder in AC5 indicating "No ADS-B Position"

2) The aircraft had flown 16 times in a four month period since the trial without a portable ADS-B transceiver. No ADS-B data was recorded by the NATS' CRISTAL system from AC5 during that period.
3) AC5 was also fitted with a Garmin GNS430 navigation system. The Trig/Bendix King technical support staff observed that the GNS430 could provide GNSS information to the transponder when it was set in "Route mode". This information proved crucial for replicating the symptoms experienced during the trial.
4) The owner of AC5 reported that they rarely flew with the GNS430 in Route Mode but confirmed they may have done so towards the end of the flight on the 24th February.
5) The owner of the AC5 agreed to perform a ground test and flight with the KT74 transponder, SkyEcho and GNS430 with the configurations according to a test script. The results confirmed the KT74 transmits the full set of ADS-B messages when the GNS430 was in Route Mode in this particular aircraft.

However, despite the success of this test it did not explain why the ADS-B Mode A octal code appeared to change randomly from 1730 back to 7000 during the 1½ period prior to the GNS430 being set in Route Mode.

Airframe AC4 exhibited the same fluctuations on the Mode A code without any apparent corruption of the position quality metrics. For example, on 24/02/2018 the Mode A code for AC4 switched between 5076 and 7000 then 5077 and 7000. During the follow-up investigation for AC5 on 30/11/2018 it was observed that the Mode A code for AC9 switched between 7011 and 7000 then 3677 and 7000.

Subsequent ground tests with AC5 and AC9 showed that even when some Mode S ES transponders are not connected to a GNSS position source, the transponder squittered ADS-B messages for Aircraft Identity (msg type 4 sub type 1) and Mode A octal (msg type 28 sub type 1). The owner of AC9 has a Trig TT31 transponder, which is in the same family as the Bendix King KT74.

The consequences of data corruption caused by two sources of Aircraft Identity are discussed in section 3.3.6 and the consequences of data corruption caused by two sources of Mode A octal are discussed in section 3.3.9.

Appendix B 1090MHz Channel loading

It is expected that voluntary carriage of ADS-B by GA will increase as GA users see the direct safety benefits it provides, hence the CAA's and NATS' ambition to promote the use widespread use of ADS-B on 1090 MHz, including operators of aircraft that already have a transponder.

This section is reproduced from the NERL concept for GA surveillance because it examines the consequences for the radio frequency (RF) spectrum if a large number of ADS-B transmitters are introduced into the operating environment.

One of the two radio frequencies used for secondary surveillance, 1090MHz, is already known to suffer from high levels of occupancy caused by responses to Mode S radar and Traffic Alert and Collision Avoidance System (TCAS) interrogations (on 1030MHz). ADS-B uses the same reply frequency and there has been a concern that a significant increase in the number of devices using 1090MHz may reduce the probability that ground radars will detect:

- A single response to a selective interrogation, which may cause further interrogations. The update of the track may be delayed while an additional interrogation is made and the possibility of False Replies Unsynchronised in Time (FRUIT) is increased. FRUIT is a term used to describe the situation when the transponder response is received by a radar that did not make the initial interrogation, and,

- Responses to a Roll Call, because failure to register responses to the roll call may delay the initiation of a radar track.

QinetiQ were contracted to simulate the impact on Roll Call Round Trip Probability (RTP) and Probability of Detection (PD), which will be experienced by existing radars when the RF environment changes. Their model simulated the effects of introducing 828 Low Power ADS-B Transceivers (LPATs) prototypes into the operating environment at any one time. The full results are published in references 1 and 2.

The conclusions of these reports indicate that, provided the transmitted power of LPAT was limited to a maximum of 20W, there is likely to be:

1) A measurable increase (46.3Hz to 58.0Hz) in the rate of long format Mode S FRUIT. However, this is a small percentage (~1%) of the total FRUIT in the scenario, which remains stable.
2) A slight drop (0.42ppts to 0.52ppts) in RTP for all Interrogators of Interest (IoI). However, reference 2 shows there is likely to be a significant decrease in RTP if the effective transmitted power is increased to 45W for each ADS-B device.
3) An insignificant drop (0.010ppts to 0.019ppts) in PD for all the IoI.

In summary, the widespread use of LPAT type systems by the GA fleet does not significantly compromise the performance of ground radar interrogators, provided the maximum transmitted power is limited to less than 40W when measured at the antenna. This finding is reflected maximum transmitted power requirement in the CAP1391 (reference 2) standard published by the CAA in 2016 which permits the maximum as 40W at the antenna port.

It should be noted that the modelled GA aircraft in the simulations could alternatively all equip with low power Mode S transponders (Class 2) which have a minimum peak power output of 18.5 dBW (70W) at the antenna port, see reference 3. Furthermore, these Class 2 Mode S transponders would also be ADS-B OUT capable, likely providing the same message rates as modelled above, and additionally producing replies to ground and airborne TCAS interrogations as well as contributing to the occupancy of 1030MHz.

It can therefore be reasoned that although not explicitly modelled, equipping GA aircraft that currently have no secondary surveillance capability with Mode S transponders, instead of ADS-B only transmitters, would detrimentally impact the 1090MHz spectrum occupancy. Hence the portable ADS-B transceivers would seem to be the preferred option if the majority of GA aircraft were to adopt cooperative surveillance.

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