International Civil Aviation Organization

FIFTEENTH MEETING OF THE ADS-B STUDY AND IMPLEMENTATION TASK FORCE (ADS-B SITF/15)

Bangkok, Thailand, 18 - 20 April 2016

Agenda Item 4: Review States' activities and interregional issues on implementation of ADS-B and multilateration

PERFORMANCE OF CURRENT ADS-B VERSION 2 SYSTEMS

(Presented by United States/Federal Aviation Administration)

SUMMARY

This paper presents a recent analyses of observed ADS-B Version 2 quality parameters in comparison to the requirements of the U.S. ADS-B Out rule.

1. INTRODUCTION

1.1 The FAA is analyzing outputs from current ADS-B Version 2 avionics during flight operations in the U.S., to understand the availability of ADS-B quality parameters required by 14 CFR 91.227.

1.2 The ADS-B Aviation Rulemaking Committee in 2008, which advised FAA on the U.S. ADS-B Final Rule (14 CFR 91.225 and 14 CFR 91.227), performed an analysis of GPS signal-in-space availability. This analysis showed that GPS receivers which are unaware that GPS Selective Availability (SA) has been deactivated (so called "SA-On" GPS receivers) will fail to achieve the requirements of 14 CFR 91.227 (specifically, for the Navigation Integrity Category, NIC, parameter) with high availability (equal to or greater than 99.9% availability) under many expected GPS constellation conditions. GPS receivers which are aware that SA is deactivated (so called "SA-Aware" GPS receivers) will have improved performance and are likely to meet the requirements of 14 CFR 91.227 for GPS constellations with large numbers of satellites (more than 27 operational satellites). For more information, see Appendix Z in the 2008 "Report from the ADS-B Aviation Rulemaking Committee to the FAA," http://www.faa.gov/nextgen/programs/adsb/media/arcReport2008.pdf.

1.3 FAA requires ADS-B Version 2 for ATC separation and has created the following table (Table 1) describing the U.S. ATC operational impacts of various Navigation Integrity Category (NIC) and Navigation Accuracy Category for Position (NACp) conditions:

Table 1: U.S. ATC Impacts of Various NIC/NACp conditions

Degraded condition of NIC/NACp	Airspace with operational Terminal MSSR or SSR backup	Airspace with operational En Route SSR/WAM backup	"ADS-B Only" airspace (including caused by an SSR outage)
Condition 1: NIC/NACp are less than U.S. rule requirements, but still adequate for display ≥5 NIC ≥7 ≥7 NACp ≥8	No impact on ATC operations	No impact on ATC operations in 5-nm separation en route airspace. In 3-nm separation airspace, controller must apply 5-nm separation, potential transition and capacity impacts.	No impact on ATC operations in 5-nm separation en route airspace. In 3-nm separation airspace, controller must apply 5-nm separation, potential transition and capacity impacts.
Condition 2: NIC<5/NACp<7 *(not sufficient for display to controller in "ADS-B Only" condition)*	No impact on ATC operations	No impact on ATC operations in 5-nm separation en route airspace. In 3-nm separation airspace, controller must apply 5-nm separation, potential transition and capacity impacts.	Controller must apply procedural separation; larger transition and capacity impacts than above

1.4 The FAA gathers and records the performance of ADS-B emitters that are detected by the current operational ADS-B radio stations in the U.S. The FAA has identified air carrier aircraft with ADS-B Version 2 equipage configurations for study, which includes aircraft operated by both US and international air carriers. US air carriers included in this analysis are: JetBlue, American, FedEx, Alaska, Delta, United and UPS. Some of these carriers have only new production aircraft equipped with ADS-B Version 2, while other carriers have retrofitted ADS-B Version 2 in their aircraft in cooperation with FAA as described in a separate Information Paper. FAA's current analysis tools and database allows the make/model of the US air carrier aircraft to be identified, but not non-US-registered aircraft. Therefore, all non-US-registered aircraft flying for identifiable international air carriers are grouped together in a "Foreign" category – based on historic sampling, FAA knows that most of these aircraft are A380s, but other aircraft models built by Airbus and Boeing are also included. Since all U.S-registered Embraer and Bombardier aircraft currently identified as ADS-B Version 2 emitters are new production configurations, FAA chose to group these aircraft by airframe for analysis.

1.5 This paper focuses on the operational availability of Navigation Integrity Category (NIC) greater than 6 (a radius of containment less than 0.2 nautical miles), averaged over 2 months of flight operations, for aircraft with more than 10,000 ADS-B reports during the period. Through GPS analyses performed during the FAA's rulemaking process for the U.S. ADS-B mandate (described in section 1.2) and validated by FAA data monitoring over the past two years, the most stringent ADS-B quality parameter in the U.S. ADS-B mandate is the NIC>6 requirement. The data quoted in this paper is collected at the aircraft level for the period indicated on each figure and table.

1.6 All JetBlue (JBU) aircraft covered by this analysis use the Rockwell Collins GLU-920 Multi-Mode Receiver (MMR). The GLU-920 calculates Horizontal Protection Limit (HPL) as SA-On (assumes a User Range Error consistent with GPS Selective Availability being “on”, even though it is not).

1.7 American Airlines (AAL) aircraft covered by this analysis are mostly a mix of A330s equipped with Thales SA-Aware GPS MMRs and a few B787s. All B787s are equipped with Honeywell Integrated Navigation Receivers (SA-Aware).

1.8 FedEx (FDX) aircraft covered by this analysis are new production B767s or B777s equipped with Rockwell Collins GLU-925 MMRs. The GLU-925 is a GPS Selective Availability aware (SA-Aware) receiver and calculates HPL (which converts to NIC) accordingly.

1.9 The Embraer 170 (E170) aircraft covered by this analysis are equipped with Honeywell Satellite-Based Augmentation System (SBAS) GPS receivers.

1.10 The Foreign aircraft covered by this analysis are mostly a mix of either new production aircraft from Boeing and Airbus, or recently produced Airbus/Boeing aircraft able to achieve ADS-B Version 2 equipage via application of a software service bulletin. These aircraft include A380s equipped with a Honeywell GPS-IRU-coupled navigation system and A350s equipped with an SBAS-capable variant of the Rockwell Collins GLU-925 MMR. This fleet may also include a small number of aircraft with SA-On GPS receivers.

1.11 Alaska Airlines (ASA) aircraft covered by this analysis are all new production B737-900s with Rockwell Collins GLU-925 MMRs.

1.12 Delta Airlines (DAL) aircraft covered by this analysis are B757s and B767s that were retrofitted with ACSS ADS-B Version 2 transponders, but which retained their pre-existing position sources. These position sources are a mix of Rockwell Collins GLU-920 MMRs and GLU-925 MMRs.

1.13 The Bombardier CRJ-900 (CR9) aircraft covered by this analysis are equipped with Rockwell Collins SBAS receivers.

1.14 United Airlines (UAL) aircraft covered by this analysis are almost entirely B787s, with one new production 737-900 equipped with Rockwell Collins GLU-925 MMRs.

1.15 UPS aircraft covered by this analysis have either the Rockwell Collins GLU-925 or the Rockwell Collins GLU-920. UPS is allowed to intermix these MMRs on their wide-body aircraft, so a given aircraft can report different nominal NIC values from flight-to-flight. Additionally, UPS has several B757s equipped with a Rockwell Collins GPS/SBAS receiver.

1.16 In Table 2, Operational Availability values are shown for various aircraft fleets during the analysis period. For this paper, NIC>6 Operational Availability is defined as the number of ADS-B reports with NIC>6 divided by the total number of ADS-B reports. NIC>6 Operational Availability is calculated at the aircraft level and averaged at the aggregate level for each aircraft fleet. The first NIC>6 Operational Availability column shows the results for each given fleet of aircraft by averaging the Operational Availability for these aircraft during the analysis period. The following two columns show the minimum and maximum Operational Availability achieved by the aircraft in that fleet of aircraft. A pink shaded cell with red text indicates an Operational Availability value less than 99.9%.

1.17 The FAA also analyzed NIC<7 “outage” durations for various aircraft fleets during the analysis period to understand the implications on Condition 1 in Table 1 above. In ADS-B Only airspace where terminal separation or 3-nm separation is being applied, NIC<7 outages must exceed 15 seconds to have a significant operational impact (in FAA terminal ATC automation systems, tracks will coast for up to 15 seconds without a surveillance update). Tables 3 and 4 shows the results of this analysis of NIC<7 events.

1.18 Similarly, the FAA analyzed NIC<5 outage durations for various aircraft fleets to understand the potential for reaching Condition 2 in Table 1 above. In ADS-B Only terminal airspace, NIC<5 outages exceeding 15 seconds will cause the target to disappear from the display. In ADS-B Only en route airspace, NIC<5 outages exceeding 36 seconds will cause the target to disappear from the display. Table 5 and 6 shows the results of this analysis of NIC<5 events.

1.19 In this paper, all date and time references are to UTC unless otherwise noted. Further, the timing of sequences of events described in this paper is indicative – the data examined is processed ASTERIX CAT033 data from the FAA’s ADS-B network (the FAA network does not record raw 1090 extended squitters). Due to characteristics of the FAA’s ADS-B receivers in converting the received 1090ES signals to CAT033 reports, time periods described herein may be inaccurate by a few seconds.

2. DISCUSSION

2.1 The data in Table 2 shows that, as expected, the lowest average operational availability of NIC>6 is seen in the JBU, DAL and UPS fleets, at 99.7242%, 99.5885%, and 99.6038%, respectively, as these fleets have the largest fraction of aircraft with SA-On GPS receivers. The JBU and UPS fleets performed better than seen in an early 2015 FAA analysis (these are largely the same fleets, though each fleet has 5-10 more aircraft than the early 2015 analysis). The DAL and UPS fleets have such a large range of NIC>6 availability since their aircraft use both SA-Aware and SA-On GPS MMRs; the UPS fleet also includes SBAS-equipped aircraft as described above in section 1.15. The AAL, ASA, FDX and UAL fleets are all equipped with SA-Aware MMRs, with a mix of manufacturers and models, yet these results are roughly comparable. However, the AAL fleet performed slightly less well than in the early 2015 FAA analysis (this fleet grew from 18 aircraft in early 2015 to 23 aircraft in this analysis). The average NIC>6 performance of Embraer aircraft equipped with an Satellite-Based Augmentation System (SBAS) appears roughly equivalent to the average NIC>6 performance of aircraft equipped with SA-Aware MMRs, even though the U.S. SBAS service, the Wide-Area Augmentation System (WAAS) had no notable service outages during this period. The Foreign fleet had excellent average performance, but the larger range of performance across this fleet appears to suggest that at least a few of these aircraft are equipped with SA-On GPS receivers. The best performing fleets were the CR9s, UAL, and FDX fleets, with a minimum average operational availability of 99.998% or better.

2.2 Tables 3 and 4 show both expected and unexpected results. The NIC<7 time periods for JBU, DAL and UPS were expected for fleets with significant numbers of SA-On receivers and consistent with the Table 2 results. The NIC<7 time periods for the Foreign fleet were also consistent with the results from Table 2 and provide further evidence to support the hypothesis that several aircraft in this fleet have SA-On GPS receivers. The SBAS-equipped CR9s fleet was the best performing, with no NIC<7 time periods of more than 10 seconds. The FDX and UAL fleet showed expected results for SA-Aware GPS receivers given the current GPS constellation – almost no operationally meaningful periods of NIC<7 performance. However, the results for AAL, ASA, and E170s were surprising, as NIC<7 time periods were observed that were not consistent with expectations and models for SA-Aware and SBAS receivers. Therefore, the NIC<7 time periods for these fleets were examined further.

2.3 For AAL, the longest time periods where NIC<7 were principally attributable to single operations of about seven aircraft during the period March 11-18. For these operations, NIC=6 (radius of containment between 0.2nm and 0.6nm) for a period in excess of 36 seconds, and in several cases was 2-3 minutes in duration. These events occurred in multiple areas – the terminal area around KCLT (2 events), en route airspace about 100-200 nm north of KCLT (Charlotte) on March 18th (two aircraft encountering the same RAIM degradation), en route airspace over the southeastern portion of the U.S. state of Georgia, and en route airspace over New Brunswick, Canada (northeast of the U.S. state of Maine, in airspace controlled by NavCanada but seen by FAA's ADS-B ground station network). The archives of GPS RAIM performance at http://www.nstb.tc.faa.gov/DisplayDailyPlotArchive.htm were examined and no obvious RAIM events were observed that would explain these observed behaviors.

2.4 For ASA, the results were largely attributable to a two time periods on two separate aircraft. The first time period occurred on January 29th for a flight from PAFA (Fairbanks, Alaska) headed SE towards the U.S. West Coast, at FL390 from just SE of Stephen's Passage (SE of Juneau) to a point NE of Annette Island (near the Alaska/Canada border) where NIC<7 for almost 20 minutes. The archives of GPS RAIM performance revealed that there was a period of GPS RAIM degradation in this part of Alaska on January 29th that is the likely explanation for this event. The second time where NIC<7 for more than 120 seconds occurred on March 11th. This event occurred at FL340 over the western portion of the U.S. state of Nevada, approximately between Grapevine Peak and Montezuma Peak (aircraft was heading NNW). The event began with a drop from NIC=8 to NIC=6 for 5 seconds, then NIC=8 for 15 seconds, dropping to NIC=6 and then quickly to NIC/NACp/NACv=0 before loss of reported position. After about 18 seconds, position reporting began again. The aircraft then went through two consecutive periods where it reported NIC=7 for about 6 seconds and NIC=6 for about 5 seconds. Then about 40 seconds elapsed with NIC=7, followed by a period of about 15 seconds where NIC=6. NIC/NACp/NACv=0 was then reported for a period of just over 20 seconds. NIC=6 was then reported again for over a minute before position reports stopped for about 10 seconds. Position reports resumed again for a short period of approximately 10 seconds (with NIC never exceeding 6) and then stopped for a period of approximately 210 seconds. When position reports were again received, the aircraft quickly returned to reporting NIC=8. While some sort of avionics system issue cannot be ruled out, this event has many characteristics that might be expected during a GPS interference event. However, FAA safety archives contain no notices for GPS interference testing during this period.

2.5 Time periods of NIC<7 in excess of 15 seconds were not expected for the E170s, as these aircraft have SBAS position sources. Yet there were at least seven periods when NIC<7 for 100 seconds or greater during the analysis period. Examinations of these events revealed that all but one of them appear unrelated to position source performance. These six events occurred in all phases of flight, including just after takeoff, climb out, en route level flight, and approach to landing. The "signature" of these six events is that the aircraft quits reporting Barometric Altitude (switching to Geometric Altitude) and reports NIC=0, while reporting NACp=10/NACv=2. Per DO-260B/ED-102A, section 2.2.3.2.3.1.1.c, this indicates that the ADS-B system has lost Barometric Altitude information and is reporting Type Code 22. Given that these events account for less than 900 seconds of NIC<7 out of over 168 million seconds of flight operations data for these aircraft, this is a rare event whose cause is not yet understood. The remaining time period of NIC<7 occurred on March 9th at FL330 in cruise flight over New Mexico (the aircraft was on an West to East track that passed directly over Albuquerque) from just south of to just south of Cedar Crest. The event was characterized by an immediate drop from NIC=8 to NIC=4; NACp/NACv were not affected, and NACp even increased from NACp=9 to NACp=10 after the drop in NIC. This NIC=4/NACp=10/NACv=2 condition lasted for about 275 seconds and then position reports ceased for over 300 seconds as the aircraft flew over Albuquerque to just south of Cedar Crest, where position reports resumed at NIC=8/NACp=9/NACv=2 and no further NIC<7 periods were observed for this flight. FAA safety archives contain no notices for GPS interference testing during this period.

2.6 A final event of note was observed for an A380 aircraft in the Foreign fleet. This event occurred on January 28th (the evening of January 27th local time) for a flight from KLAX to Europe, with effects beginning east of Victorville, California, and ending just SW of St. George, Utah (in NW Arizona). Just prior to the event, the aircraft was climbing through FL270 with NIC=8, NACp=10, NACv=1, SIL=3, and reportable Geometric Altitude (in the 'difference from Barometric Altitude' format used by 1090ES). The event begins when SIL=0 and Geometric Altitude (Geo Alt) is no longer reported – however, all other ADS-B quality parameters are unchanged. Ten minutes later, the aircraft is level at FL370 and NIC=7, NACp=7 (SIL=0, Geo Alt not reported). Nine minutes after that, as the aircraft crosses over Las Vegas (KLAS), NIC=6, NACp=6 (SIL=0, Geo Alt not reported). Seven minutes after that, NIC=5, NACp=5 (SIL=0, Geo Alt not reported). When the event ends 27 minutes after it began, with SIL=3 and Geo Alt reported as 37,825 ft, NIC=6, NACp=5. Within a short period of time, NIC=8, NACp=9. FAA safety archives contain no notices for GPS interference testing during this period. While the cause of the GPS position source loss is unknown, it appears that the observed temporal degradation of the ADS-B quality parameters is a beneficial feature of the A380's GPS-IRU-coupled navigation system.

2.7 Tables 5 and 6 show both expected and unexpected results. The expected results for all of the aircraft analyzed was that there would be few, if any, NIC<5 time periods in excess of 36 seconds. This was generally true except for the E170s, DAL, and UPS.

2.8 Given the apparent cause of the NIC<7 time periods described earlier in section 2.5, the E170s results are predictable (when NIC=0, it is counted in both a NIC<7 and a NIC<5 "outage" time).

2.9 The DAL results for NIC<5 time periods in excess of 120 seconds are attributable to two 757 aircraft in their fleet. Both aircraft had entire flights in U.S. airspace where they reported ADS-B positions, but with NIC=NACp=NACv=0 for all position reports. The cause for these occurrences is unknown, but it was a temporary condition that has not since recurred. Analysis of the remaining NIC<5 time periods in excess of 36 seconds for the DAL fleet is continuing.

2.10 Analysis of the UPS results for NIC<5 time periods in excess of 36 seconds focused on two aircraft with the largest aggregate NIC<5 time periods during the analysis period. One aircraft is a B767-300 and the other is an MD-11F.

2.11 On March 11th, the B767 was flying WSW at FL360 just NE of Valmore, NM (east of Santa Fe) when it ceased ADS-B position reports for over 3 minutes. Position reporting began again for about 45 seconds before again ceasing. The next "position gap" lasted for almost two minutes. When ADS-B position reporting resumed, NIC=NACp=NACv=0 was reported for about 10 seconds before resuming NIC=7, NACp=9, and NACv=1. Just over 5 minutes later, another position gap occurred for over 45 seconds. Position reporting resumed for about 5 seconds, and then ceased again for about 30 seconds. Then position reporting began again for about 10 minutes before ceasing for about 5 minutes. This was followed by a 5 seconds of position reports, followed by another position gap of about 13 seconds, followed by a 75 second period of NIC=NACp=NACv=0, and ending, near New Mexico's border with Arizona, when the aircraft ADS-B reports return to NIC=7, NACp=9, and NACv=1 for the remainder of the flight. Also observed were a few cases where position reports seemed to have infeasible time stamps for the position reported. FAA safety archives contain no notices for GPS interference testing during this period.

2.12 On March 9th, the MD-11F, flying from KONT to KPHL and at FL390 over western Arizona and central New Mexico, experienced two significant periods where NIC values fell below 7, where NIC=NACp=NACv=0, some periods where NACp, NACv, and Geo Alt were not reported, and multiple position reporting gaps. Also observed were brief reports where NIC and NACp values did not seem aligned, and cases where position reports seemed to have infeasible time stamps for the position reported. FAA safety archives contain no notices for GPS interference testing during this period.

2.13 Based on this data and the parameters examined, for the GPS satellite constellation as of early 2016, it appears that ADS-B systems using SA-Aware GPS receivers will achieve average NIC>6 operational availability values and experience NIC<7 time periods that are nearly equivalent to ADS-B systems using SBAS receivers. It appears that ADS-B systems using SA-On GPS receivers will achieve average NIC>6 operational availability values and experience NIC<7 time periods that airline operators may find unacceptable once the U.S. ADS-B rule (14 CFR 91.225 and 14 CFR 91.227) compliance date (1 Jan 2020) has been reached. Airline operators with either SA-Aware or SA-On GPS receivers will likely benefit from requesting FAA Exemption 12555. A separate paper in this meeting will describe this further.

2.14 Note that the results described in this paper are expected to be different if the GPS satellite constellation has fewer operational satellites than the current number (31). In particular, the study described in section 1.2 indicated that SA-Aware GPS receiver performance would fall below FAA goals (99.9% availability of NIC>6) if the number of operational GPS satellites falls below 27 in a well-distributed geometry (i.e., good satellite slot/plane distribution).

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) note the information contained in this paper; and

b) discuss any relevant matters as appropriate.

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Table 2

NIC>6 Operational Availability (%)
2 months ending 18-Mar-2016

	Avg Avail	Min Avail	Max Avail	# A/C
JBU	99.7242	99.3400	99.9410	39
AAL	99.9860	99.9220	99.9990	23
FDX	99.9990	99.9930	100.0000	21
E170s	99.9973	99.9520	100.0000	109
Foreign	99.9881	99.3100	100.0000	242
ASA	99.9945	99.9600	100.0000	13
DAL	99.5885	96.8050	100.0000	80
CR9s	99.9998	99.9990	100.0000	12
UAL	99.9987	99.9940	100.0000	21
UPS	99.6038	98.3500	100.0000	174

Table 3

Total Outage Times (seconds) for NIC<7 Outage Events
2 months ending 18-Mar-2016

Time Bin (seconds)	JBU	AAL	FDX	E170s	Foreign	ASA	DAL	CR9s	UAL	UPS
0-10	14,913	482	134	1,717	2,736	478	23,777	35	44	31,865
11-15	3,660	55	10	169	412	134	5,271	0	10	13,890
15-24	1,377	142	104	222	568	103	2,591	0	0	4,401
24-36	1,102	0	0	132	361	151	2,939	0	55	3,016
36-60	1,817	131	40	243	336	94	4,320	0	0	4,428
60-120	3,300	363	0	614	927	80	10,940	0	0	13,068
120+	165,259	1,385	0	1,156	11,246	1,250	304,414	0	0	395,378

Table 4

NIC<7 Outage Time Summary (seconds)
2 months ending 18-Mar-2016

	Avg Outage Time per Aircraft	Min Std Dev	Max Std Dev	# A/C
JBU	26.2	21.3	277.3	39
AAL	8.4	0.0	133.9	23
FDX	3.0	0.0	19.4	21
E170s	2.7	0.0	113.7	109
Foreign	2.9	0.0	347.6	242
ASA	9.8	0.0	271.9	13
DAL	22.3	0.0	1178.9	80
CR9s	0.7	0.0	1.6	12
UAL	1.9	0.0	9.0	21
UPS	22.4	0.0	319.2	174

Table 5

Total Outage Times (seconds) for NIC<5 Outage Events
2 months ending 18-Mar-2016

Time Bin (seconds)	JBU	AAL	FDX	E170s	Foreign	ASA	DAL	CR9s	UAL	UPS
0-10	5,283	473	129	1,700	2,055	440	4,879	35	44	7,351
11-15	325	55	23	133	315	138	685	0	10	7,791
15-24	296	142	81	152	494	172	456	0	0	1,599
24-36	404	0	0	157	334	112	665	0	55	1,016
36-60	116	72	40	243	119	54	397	0	0	497
60-120	0	0	0	380	0	0	76	0	0	176
120+	0	0	0	1,023	0	0	19,675	0	0	0

Table 6

NIC<5 Outage Time Summary (seconds)
2 months ending 18-Mar-2016

	Avg Outage Time per Aircraft	Min Std Dev	Max Std Dev	# A/C
JBU	1.9	0.8	5.2	39
AAL	2.1	0.0	9.2	23
FDX	2.8	0.0	19.4	21
E170s	2.5	0.0	113.7	109
Foreign	1.8	0.0	24.8	242
ASA	3.6	0.0	13.5	13
DAL	10.1	0.0	1482.7	80
CR9s	0.7	0.0	1.6	12
UAL	1.9	0.0	9.0	21
UPS	3.1	0.0	14.3	174