International Civil Aviation Organization

The 17th Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/17)

Bangkok, Thailand, 28 – 31 August 2012

Agenda Item 5: Airspace Safety Monitoring Activities/Requirements in the Asia/Pacific Region

PROGRESS ON THE USE OF ADS-B DATA TO MONITOR ASE

(Presented by Monitoring Agency for Asia Region)

(Prepared by MAAR and AAMA)

SUMMARY

This paper presents Monitoring Agency for Asia Region (MAAR) progress on the use of ADS-B data to monitor aircraft Altimetry System Error (ASE) as a result of a collaborative program with the Australian Airspace Monitoring Agency (AAMA). With the help from the AAMA, MAAR is able to calculate some ASE results based on ADS-B data collected from one ADS-B station located in Bangkok during a period of November 2011 to June 2012. The calculation yielded ASE results of 2,412 airframes, 1,045 of which also appeared in AAMA's data. A comparison of AAMA and MAAR's results showed that MAAR's data behaved coherently with that of AAMA. A further analysis done by AAMA also demonstrated that calculations based on the combination of both data sets provided both RMAs with an improved capability to identify the correct height reference used by each airframe. The latter reinforced the importance of regional sharing of ADS-B data.

This paper relates to –

Strategic Objectives:

*A: **Safety** – Enhance global civil aviation safety*

Global Plan Initiatives:

GPI-2 Reduced vertical separation minima

1. INTRODUCTION

1.1 The Australian Airspace Monitoring Agency (AAMA) gained ICAO endorsement to use Automatic Dependent Surveillance-Broadcast Data (ADS-B) for monitoring Aircraft Altimetry System Error (ASE) in 2011. This followed a period of collaborative research with the US FAA as described in a series of ICAO papers [1, 2, 3, 4] which demonstrated the feasibility of the method.

1.2 After the endorsement, MAAR started collecting ADS-B data from an ADS-B station, located at the Aeronautical Radio of Thailand (AEROTHAI) headquarters in Bangkok, Thailand. During a technical-interchange meeting at the FAA Technical Center in September 2011, MAAR also had a chance to discuss and learn FAA's systems and ASE calculation method.

1.3 In July 2012, AAMA kindly paid a visit to MAAR at AEROTHAI's headquarters to brief MAAR on the ADS -B Height Monitoring System (AHMS) and assist MAAR in establishing AHMS using AAMA's software suites. The FAA Technical Center permitted MAAR to use the FAA's ASE processing software, which was embedded in AAMA's software suites.

1.4 The trial runs were successful. AAMA and MAAR then processed all available data and produced some results as presented in this paper.

1.5 It was shown previously that aircraft can transmit geometric height referenced to either Mean Sea Level (HAMSL) or to the Ellipsoid (HAE) [3]. To obtain an accurate ASE estimate, it is necessary to know which reference is being used by an aircraft. AAMA's current methods to determine the correct geoid are partly based on the differences in geoid contours each fight is flying across [4]. The bigger the differences, the more evident it is to conclude the correct geoid assumption.

1.6 It is shown here that data sharing from States can greatly enhance the accuracy and interpretation of ASE calculations based on ADS-B, particularly in the determination of the height reference assumption for each aircraft.

2. DISCUSSION

Data Source and Data Preparation

2.1 The first usable set of data started from 10 November, 2011. For this paper, MAAR used the data up to June 2012. Also, due to technical reasons, there were some discontinuities in the data stream, of which the longest one spanned the whole month of February 2012.

2.2 AEROTHAI's ADS-B binary data was in ASTERIX CAT21 format, with User Application Profile Edition 0.26. MAAR decoded the binary data and stored it in ASCI I text files. During this process, the following records were filtered out:

a) Records missing the fields necessary for ASE calculation and target identification.
b) Records whose flight levels are not within the 290-410 flight level band.
c) Records whose NUC values are less than 5.

The ASCI I text files were formatted according to AAMA's software suites.

2.3 The coverage of AEROTHAI's ADS -B station is shown in Figure 1

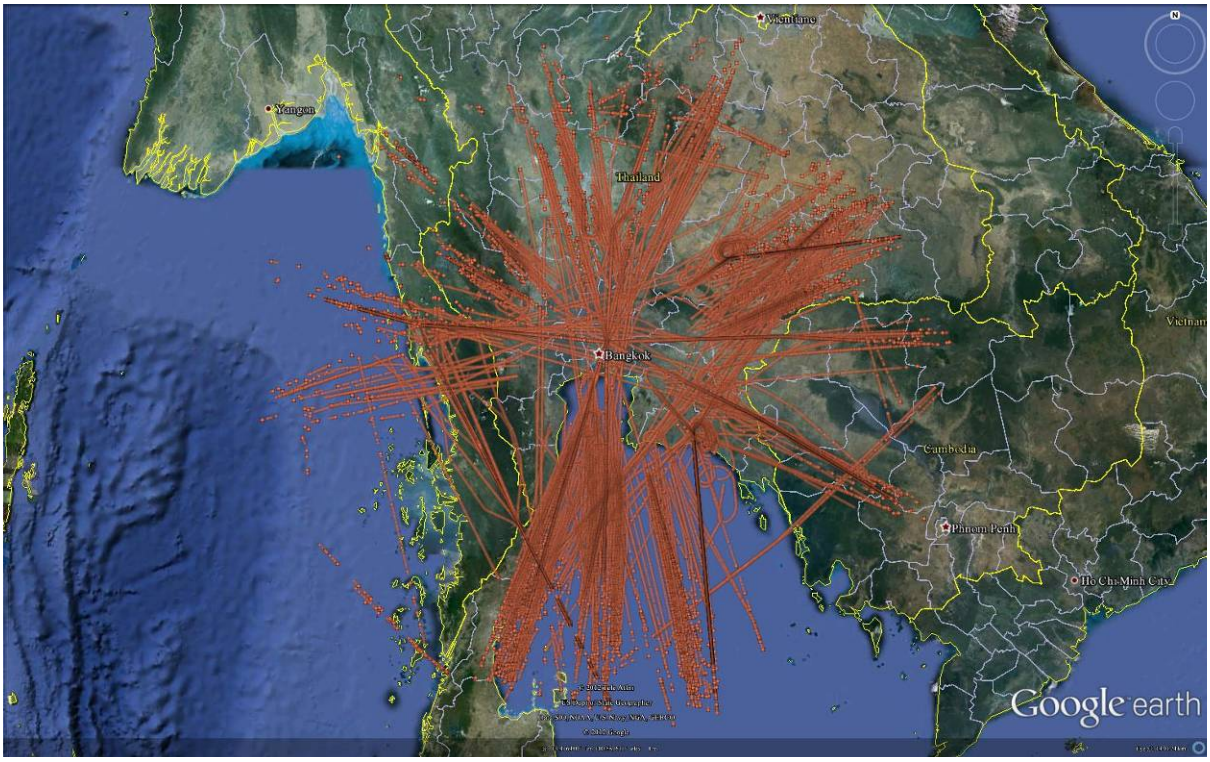

Figure 1: ADS-B targets during 15 June 2012 plotted on Google earth

Comparison between AAMA and MAAR Results

2.4 The MAAR data was compared with the AAMA data. The calculations of MAAR data yielded ASE results for 2,412 airframes. The AAMA processed MAAR's data set (supplied to the AAMA in late July) and found 1,045 airframes in common with AAMA's 1,807 airframes discovered over 2 years, resulting in a 43% and 57% overlap in airframes.

2.5 Of the 1,045 common airframes, 850 had height references which could be identified. Figure 2 shows a scatter plot of all calculated ASE values of all common airframes from AAMA and MAAR data. The slope of the regression line shows a very high correlation between both sets of results.

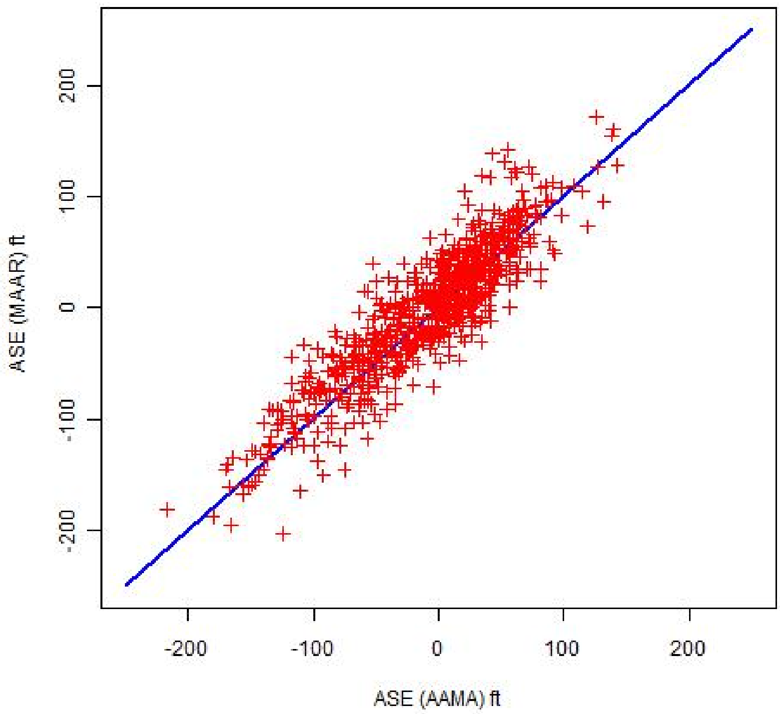

Figure 2: Scatter plot of daily average ASE (ft) of common airframes (with known height assumption) from AAMA and MAAR data

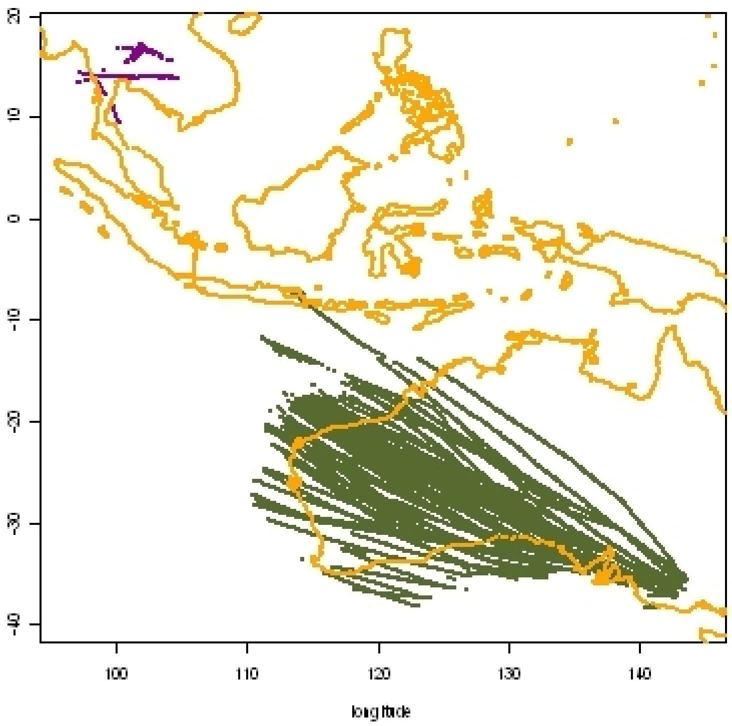

Figure 3: A visual representation of Airframe X’s positional data with the MAAR data in purple and the AAMA data in green.

2.6 As an example, Figures 3 to 6 show plots of a typical common airframe (Airframe X) with data from both MAAR and AAMA data sets. Figure 3 shows flight paths of the airframe. The positional data of AAMA (in green) is a good enough sample size, allowing this airframe to be a good benchmark for the comparison.

2.7 Figure 4 shows the ASE calculations of Airframe X from both AAMA and MAAR data sets, using both HAMSL and HAE assumptions. In this case, the red symbols, which represent HAE assumption, are the correct ASE values. The plot shows that the MAAR data (solid triangles) gives very similar results to that of the AAMA data (open circles).

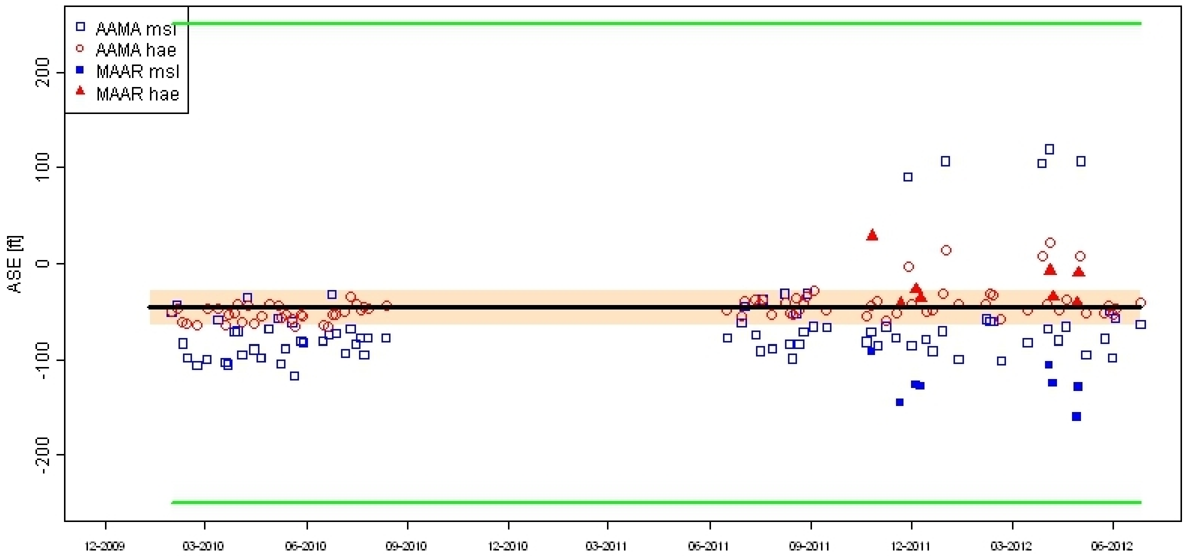

Figure 4: Daily average ASE (ft) versus date for Airframe X, calculated based on both height assumptions. The open symbols represent AAMA data; solid symbols show the results from MAAR data.

2.8 Figure 5 shows the ASE calculations from using both HAMSL and HAE assumptions plotted against the geoid difference (HA MSL-HAE). ASE values based on the correct assumption should be independent of their positions (latitude, longitude), and thus their regression line should have a slope equal to zero, which is shown here for the ASE(HAE) (red circles). On the contrary, the regression line through the blue squares has the slope of 1, which is to be expected when incorrect ASE values are dependent on different geoid. Sample density distributions for both sets of data are plotted vertically to help better determine any unusual behavior due to an aircraft switching geoid assumptions or where location data has a bias. The distributions give an indication of the typical spread of results which are -50 ft with a standard deviation of approximately 20 ft. The plot shows that the combined AAMA-MAA R data still yields the expected pattern, which means that MAAR's results behave coherently with that from a larger data set of AAMA.

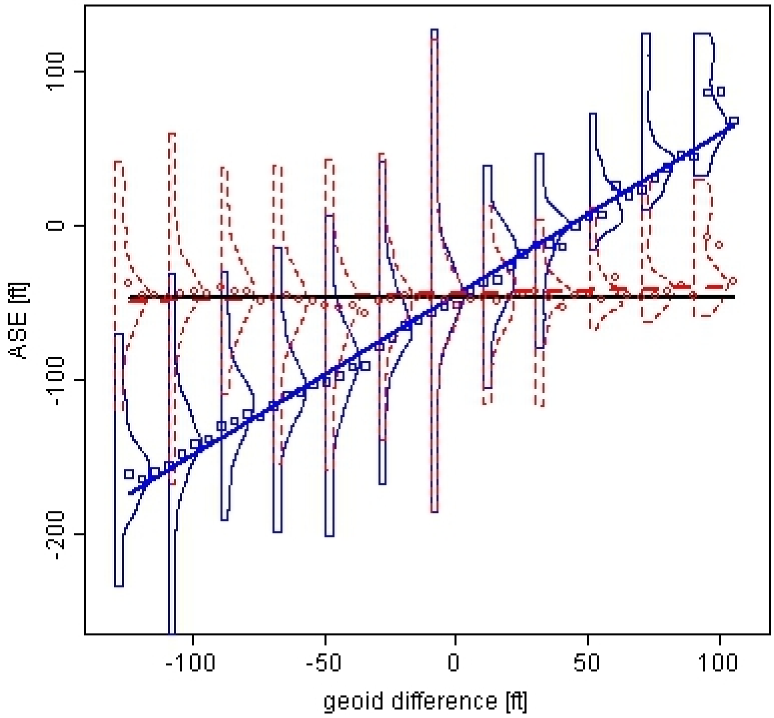

Figure 5: ASE (ft) versus geoid difference HAMSL-HAE for Airframe X using both AAMA and MAAR data; data using HAMSL or HAE are plotted in blue and red respectively.

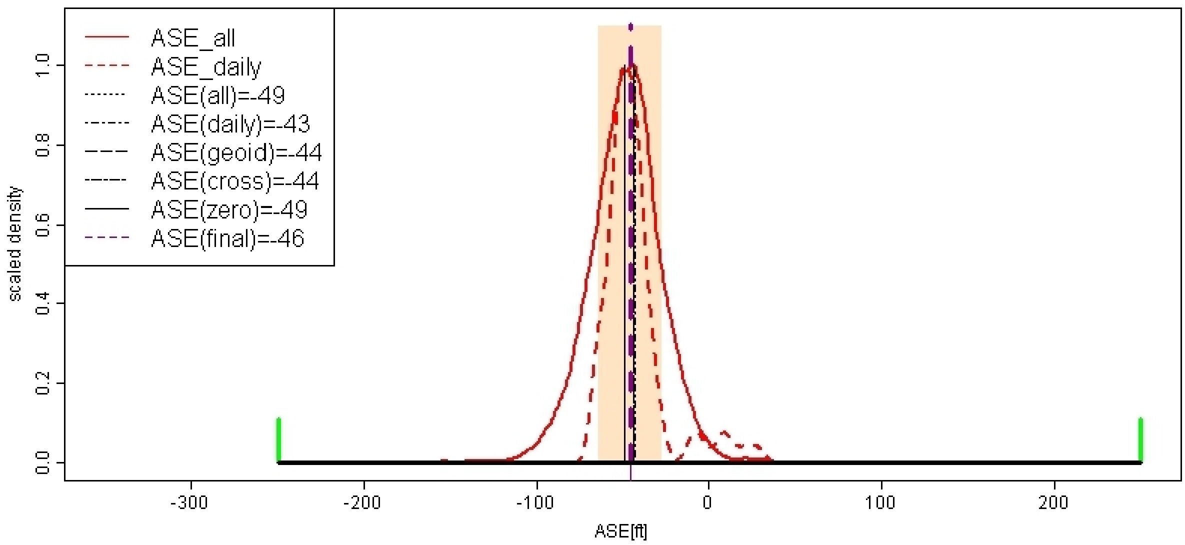

Figure 6: The distribution of ASE values of Airframe X in feet, scaled to have maximum height of unity. The two distributions are from all ASE values and from the daily means. The vertical lines are different measures of the ASE.

2.9 Figure 6 shows the distribution of ASE values (the solid red curve) and daily average ASE values (the dotted red curve) using the correct HAE assumption, along with various ASE estimates of what the true ASE value should be. The estimates are represented by different vertical lines as described below:

a) ASE(all) is the mean of all ASE(HAE) values.
b) ASE(daily) is the mean of the daily means.

c) ASE(geoid) uses the mean of the red squares in Figure 5, effectively a weighted mean of all ASE values.
d) ASE(cross) is the ASE value at the crossing of the two regression lines in Figure 5.
e) ASE(zero) is the mean of all data from the geographical region where HAMSL equals HAE (to within − 10 ft).
f) ASE(final) is the mean of all of the above means.

2.10 As expected, the two distributions of ASE values are typical, and all estimates are close to one another. The pink shaded region gives a ***very conservative*** estimate of the error in this ASE(final) value, based on the standard deviation of the daily ASE values (usually 20 ft).

Geoid Assumption

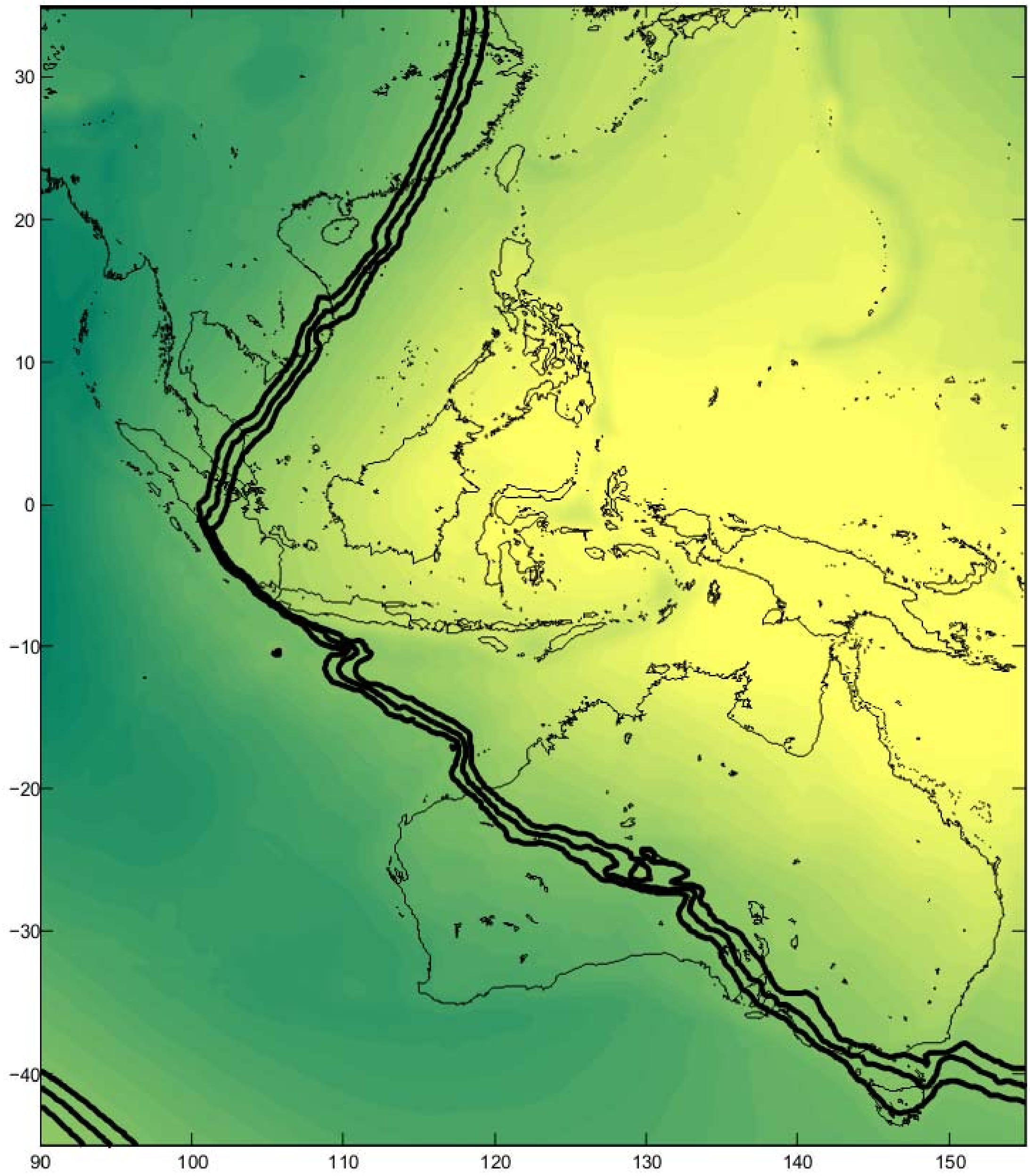

Figure 7: The geoid-ellipsoid separation from large negative values (dark green) to large positive values (light yellow). Also shown are the -10, 0 and 10 foot contours (dark curves, left to right).

2.11 Figure 7 shows geoid-ellipsoid separation in South-East Asia and Australia, starting from large negative values on the left (dark green) to large positive values on the right (light yellow). On the zero separation contour, however, values of ASE determined assuming either HAMSL or HAE are the same. Therefore regions near a zero contour have special significance for ADS-B height keeping monitoring. Figure 7 shows geoid contours for -10, 0 and 10 feet which reveal that ADS-B data collected from near Singapore, Vietnam or Hong Kong would be especially useful. A strong gradient in the geoid is also useful for determining the height reference. Geoid contours are strongly negative near India, and strongly positive over the Philippines, Sulawesi and Northern Australia. If data is available throughout the region, aircraft operating in MAAR airspace may give data over a large geoid variation.

2.12 The geoid difference in Thailand ranges from -150 to -50 feet. The fact that most flights discovered by AEROTHAI's ADS-B receiver do not sample a large range of geoid differences makes the task of establishing the correct geoid challenging. After initial runs of MAAR's ADS-B data, the results turned out as expected; most aircraft were initially identified as having 'Unknown (U)' height reference.

2.13 Fortunately, the AAMA and MAAR's data sets cover different geographical regions, and have different geoid (HAMSL-HAE). The combination of data allows a much stronger estimation of the geoid assumption and, therefore, a more robust calculation of ASE. In a large number of cases, the ASE would be impossible to be concluded without the combined data sets enabling the determination of the geoid.

2.14 Figure 8 to 10 show plots from a single airframe (Airframe Y) that has limited data from both MAAR and AAMA data sets. Figure 8 shows positional data of this airframe.

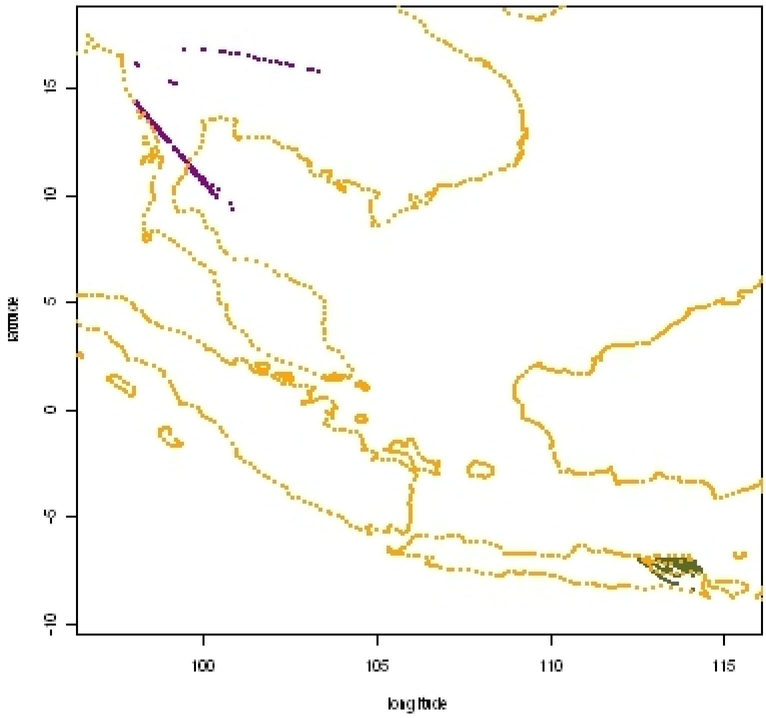

Figure 8: A visual representation of Airframe Y's positional data with the MAAR data in purple and the AAMA data in green.

2.15 Figure 9 shows the ASE calculations of Airframe Y from both AAMA and MAAR data sets, using both HAMSL and HAE assumptions. In this case, neither the AAMA nor MAAR data alone can be used to determine the geoid assumption of such airframe. However, as a combined data set, the geoid assumption is obvious and the correct ASE can easily be determined. As shown in the combined plot, the solid blue symbols representing the MAAR ASE(HAMSL) values are diametrically opposed to the corresponding AAMA data as open blue squares, since they come from very different geoid regions. The red symbols representing HAE assumption can be clearly identified as the correct ASE values.

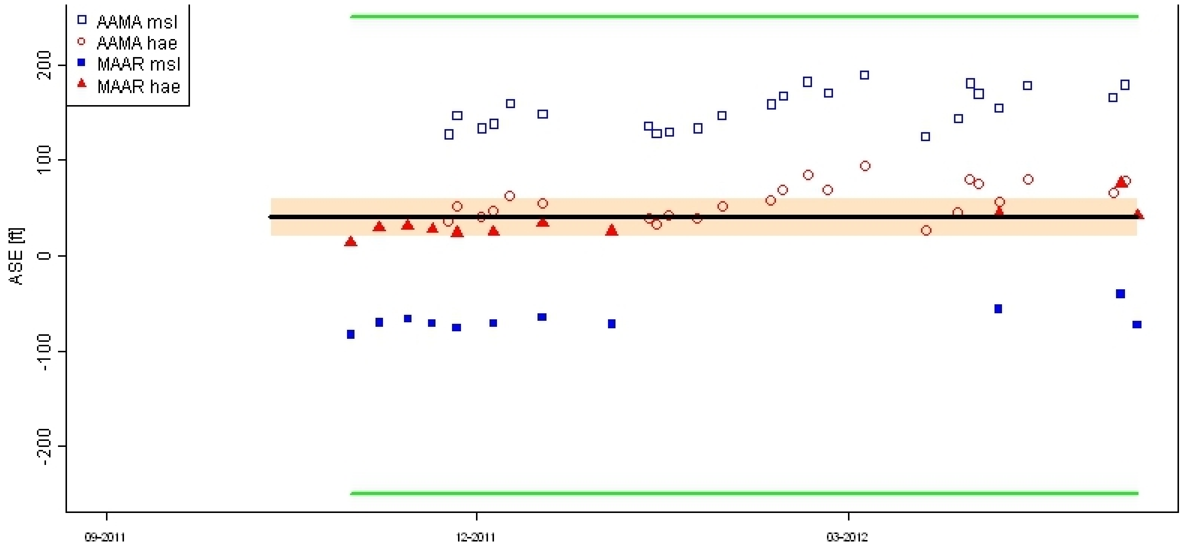

Figure 9: ASE (ft) versus date for Airframe Y from AAMA and MAAR data sets. The blue symbols represent ASE(HAMSL); the red symbols represent ASE(HAE).

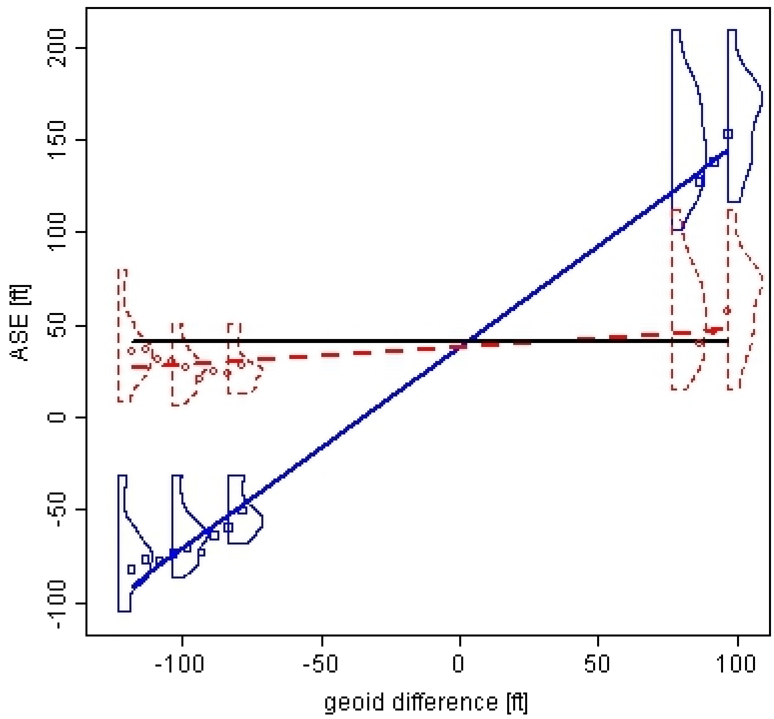

Figure 10: ASE (ft) versus geoid difference HAMSL-HAE for Airframe Y using both AAMA and MAAR data; data using HAMSL or HAE are plotted in blue and red respectively. The ASE using the correct geoid assumption has a slope near zero while the incorrect ASE estimate gives a slope close to 1.

2.16 Figure 10 shows ASE calculations from using both HAMSL and HAE assumptions plotted against the geoid difference (HAMSL-HAE). The data on the negative geoid difference (left) is from MAAR data and on the positive geoid difference (right) is from the AAMA. ASE values based on the correct assumption should be independent of their positions (latitude, longitude), and thus their regression line has the slope equal to zero. On the contrary, the regression line of the blue squares has the slope of 1, which is to be expected when incorrect ASE values are dependent on different geoid. It is apparent from the combined data that the red HAE data has a slope near zero while the blue HAMSL data has a slope close to 1, which means that the correct assumption is HAE. The pattern would not emerge from using MAAR data or AAMA data alone since each data set would not encompass a big enough range of geoid.

List of discovered operators and fleets

2.17 MAAR mapped their November 2011 - July 2012 daily average ASE results to the latest combined approval database. Appendix A lists the number of airframes shown in MAAR data that have 5 or more daily average ASE values by each operator and ICAO aircraft type.

Conclusion

2.18 The comparison between AAMA and MAAR's results shows that MAAR's data behaves in a similar way to that of AAMA, and, therefore, can be used for height monitoring purposes.

2.19 The analysis in Section 4 clearly demonstrates that ASE results from several regions help to identify an airframe's height reference, and hence, to obtain correct ASE estimates. Therefore, MAAR strongly encourages States who have ADS-B receivers installed to provide their ADS-B data to their responsible RMA. The willingness of Singapore to allow experimental processing of its ADS-B data is particularly appreciated by MAAR. Sharing ADS-B data will not only alleviate the long-term height monitoring burden for operators, but it also allows better safety monitoring of the airspace where the data is collected.

2.20 States should also be aware that ADS-B data is usable even though it may not be being actively used for surveillance. MAAR is willing to work with States on any issues regarding the provision of data.

Acknowledgements

2.21 This ADS-B Height Monitoring program in the Asia region is made possible with the support from the AAMA, especially Robert Butcher, Geoff Aldis, and Steve Barry. MAAR is extremely thankful for their help both in setting up this program and the analyses done for this paper.

2.22 Furthermore, MAAR greatly appreciates the kind supports from the FAA Technical Center, especially Dale Livingston, Christine Falk, Juan Gonzalez, Jose Perez and Manuel Gonzalez for the necessary knowledge on ASE calculation methods, their ASE calculation software, and the continuous supply of the meteorological data.

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) discuss the information contained in this paper;

b) endorse MAAR on the provision of an ADS-B Height Monitoring Service; and

c) draft a conclusion to APANPIRG requesting ADS-B data from States to be given to their RMAs for height monitoring purposes when available.

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References

[1] Robert Butcher, Christine Falk and Geoffrey Aldis, *Trial-Use of the Automatic Dependent Surveillance-Broadcast Data for Monitoring Aircraft Altimetry System Error*, ICAO SASP WG/WHL/16 WP/24, Auckland, November 2009.

[2] Geoffrey Aldis, David Tulloh, Robert Butcher and Christine Falk, *An Update to the Investigation into the Use of Automatic Dependent Surveillance-Broadcast Data for Monitoring Aircraft Altimetry System Error*, ICAO SASP WG/WHL/17 WP/21, Montreal, May 2010.

[3] Christine Falk, Geoffrey Aldis and Robert Butcher, *Progress on the Research Conducted to Determine the Use of Automatic Dependent Surveillance-Broadcast Data for Monitoring Aircraft Altimetry System Error*, ICAO SASP WG/WHL/18 WP/12, Brussels, November 2010.

[4] S Barry, R Butcher, C Falk and G Aldis, *Large-scale Study of the Use of Automatic Dependent Surveillance-Broadcast Data for Monitoring Aircraft Altimetry System Error*, ICAO SASP WG/WHL/19 WP/16, Montreal, May, 2011.

Appendix A: Number of discovered airframes by each operator and ICAO aircraft type (1/2)

Op. Code	A306	A310	A319	A320	A321	A332	A333	A343	A345	A346	A388	B737	B738	B744	B748	B74D	B752	B763	B772	B773	B777	B77L	B77W	CL60	MD11	Unk.	Total
AAR							6												1								7
ABD														6													6
AEA						1																					1
AFL							7											7									14
AFR																			10				5				15
AIQ			1	21																							22
AJX																		3									3
ALK						5		6																			11
ANA																		21									21
AUA																			4								4
AWQ				16																							16
AXM				57																							57
BAW														27					7								34
BBC																							2				2
BER						3																					3
BIE					1																						1
BKP			7	3																							10
CAL							20	1						28													49
CCA			17										12						5								34
CEB			8	14																							22
CES				40		5	5			5		20	11														86
CHH													21														21
CKK														1													1
CKS														2													2
CLX														8	2												10
CPA							23							37					5	15			3				83
CRK				2		8							3														13
CSC				9	5																						14
CSN				16	7	3							11														37
DAL						10	15																				25
DHK																		1									1
DLH								2			7			22													31
ELY														6					5								11
ETD						1														5							6
ETH																		5	4								9
EVA						2								7						15							24
FDX	1	8																							28		37
FFM													4														4
FIN							3	7																			10
GEC																									4		4
GFA						2		1																			3
GIA													38														38
GSS															2												2
GTI														9													9
HDA				2			3							2													7
HKE													1														1
HVN					24														3								27
IAC			6		17	1																					24
IGA*			1										2	1			1		5		3			2			15
IGO				13																							13
JAI						2		1					6														9
JAL																		9	7				5				21
JSA				14																							14
JST						10																					10
KAC								4																			4
KAL							16							18					5	4							43
KFR				1																							1
KLM														11					10	1			4				26

Appendix A: Number of discovered airframes by each operator and ICAO aircraft type (2/2)

Op. Code	A306	A310	A319	A320	A321	A332	A333	A343	A345	A346	A388	B737	B738	B744	B748	B74D	B752	B763	B772	B773	B777	B77L	B77W	CL60	MD11	Unk.	Total
KQA																		1	4								5
KZR																	1										1
MAS						3	9						21						1								34
MAU							2																				2
NCA														8													8
NOK													4														4
NWS																	1	1									2
OEA														1													1
OMA						2	2																				4
PAL				11			3																				14
QAF			1																								1
QFA						1	2							11													14
QTR						22	6												4	5			3				40
REU																			1								1
RJA						2																					2
SAA								5		2																	7
SAS								6																			6
SCO																			2								2
SIA							19		5		17			3					35	27							106
SLK			4	9																							13
SOO																						1					1
SQC														13													13
SRQ			2																								2
SVA														4											4		8
SWR								9																			9
TAY														4					1								5
TGW				21																							21
THA				1			11		4	6						18			14	6			5				65
THY						5	7	7															3				22
TSO														5				1	3	2							11
TUA													1														1
TVL													1														1
UAE						7													1	56							64
UAL																			24								24
UPS														12				1							15		28
UTA																	2										2
UZB																		1									1
VLK							1																				1
XAX							8																				8
YZR						1																					1
Unknown																										160	160
Total	**1**	**8**	**47**	**250**	**54**	**96**	**168**	**49**	**9**	**13**	**24**	**20**	**136**	**246**	**4**	**18**	**5**	**51**	**161**	**136**	**3**	**1**	**30**	**2**	**51**	**160**	**1743**

* A generic code for General Aviation