International Civil Aviation Organization

The Fourteenth Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/14)

Bangkok, Thailand, 21-25 February 2011

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

Progress on the Research Conducted to Determine the Use of Automatic Dependent Surveillance-Broadcast Data for Monitoring Aircraft Altimetry System Error

(Presented by the United States and Australia)

SUMMARY

This working paper presents an update on the research undertaken by the United States and Australia to validate the use of Automatic Dependent Surveillance – Broadcast (ADS-B) for monitoring aircraft Altimetry System Error (ASE). The work is being progressed under a formal joint research activity between the FAA Technical Center and Airservices Australia.

1. Introduction

1.1 The ICAO Asia/Pacific Regional Airspace Safety Monitoring Advisory Group (RASMAG) has strongly encouraged work to continue that would assess the viability of using ADS-B geometric height data as a means of estimating ASE. To progress this work, both Australia (represented by Airservices Australia) and the United States (represented by the FAA) agreed to work cooperatively in a formally recognized research project that utilized data available from the extensive ADS-B network in Australia, and the software and expertise available in the United States used for estimating ASE.

1.2 At RASMAG/12, Australia and the United States informed the meeting that the FAA and Airservices Australia had presented WP/24 to SASP-WG/WHL/16 that provided details on progress with the investigation on the use of aircraft geometric height data derived from ADS-B sources for estimating aircraft ASE. The paper indicated that the research group had successfully processed ADS-B data using the FAA's AGHME processing software and provided initial results of the ASE estimates from various ADS-B ground stations in Australia.

1.3 The meeting was advised that the research would continue to determine the exact cause or causes for noted differences in the results from different ground stations and would be revisiting the assumptions related to ground height and the WGS-84 spheroid model used in the ASE software.

2. Discussion

2.1 During the period since RASMAG/12, the FAA and Airservices Australia have continued the research activity and presented WP/12 to SASP-WG/WHL/18 in November 2010. The paper, included as Attachment 1 to this paper, provided an update on the work of the research group and specifically how the ground station bias in terms of ASE differences, appears to be related to differences in the measurement of geometric height in different avionics.

3. Summary and Conclusions

3.1 The FAA and Airservices Australia have continued work under a cooperative research agreement to further progress the use of aircraft geometric height data derived from ADS-B sources for estimating aircraft ASE. The group now believes that they understand the cause of the observed ASE differences at different ADSB ground stations known as the lat-long effect, and are waiting for further feedback from avionics manufacturers in this regard. Additionally, work is proceeding to process large data sets of ADSB data to enable validation comparisons with aircraft group mean measurements from Eurocontrol and FAA monitoring systems.

3.2 The group intends to provide the results of this further work to SASP/WG/WHL in Montreal in May 2011.

4. Actions by the Meeting

4.1 The meeting is invited to review Attachment 1 and note the information provided in this working paper.

4.2 The meeting is invited to endorse the continued exploration of ADS-B derived geometric height as a data source for aircraft height-keeping performance monitoring.

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SASP-WG/WHL/18-WP/12
08/11/10

International Civil Aviation Organization

WORKING PAPER

SEPARATION AND AIRSPACE SAFETY PANEL (SASP) MEETING OF THE WORKING GROUP OF THE WHOLE

EIGHTEENTH MEETING

Brussels, Belgium, November 8-20, 2010

Agenda Item 2: En-route separation minima and procedures – vertical

Progress on the Research Conducted to Determine the Use of Automatic Dependent Surveillance-Broadcast Data for Monitoring Aircraft Altimetry System Error

(Presented by Australia and the United States)

(Prepared by Ms Christine Falk, Dr Geoff Aldis and Mr Robert Butcher)

SUMMARY

This working paper presents an update on the research undertaken by the United States and Australia to validate the use of Automatic Dependent Surveillance – Broadcast (ADS-B) for monitoring aircraft Altimetry System Error (ASE). The group met in August 2010 and made significant progress. This working paper summarizes the results of the research to date. An apparent latitude-longitude effect on ASE reported at the previous meeting of the SASP is now believed to be due to some aircraft GPS receivers reporting geometric height above mean sea level rather than above the WGS-84 ellipsoid. Using the appropriate height datum for each aircraft removes any latitude-longitude trend in ASE along a track and brings calculated group mean ASE values much closer to zero.

1. INTRODUCTION

1.1. The United States presented working paper WP/17 to SASP-WG/WHL/14 and information paper IP/06 to SASP-WG/WHL/15 that detailed results of test flights conducted to investigate the use of Automatic Dependent Surveillance – Broadcast (ADS-B) data for the estimation of aircraft Altimetry System Error (ASE). These flights were undertaken by the FAA Technical Center and were completed using GPS receivers equipped with Wide Area Augmentation System (WAAS) corrections and with WAAS corrections disabled. The results obtained showed that the WAAS-disabled data, or aircraft geometric height data obtained from a system without WAAS corrections, is sufficient for estimating aircraft ASE.

1.2. The SASP and the ICAO Asia/Pacific Regional Airspace Safety Monitoring Advisory Group (RASMAG) have strongly encouraged work to continue that would assess the viability of using ADS-B geometric height data as a means of estimating ASE. To progress this work, both Australia (represented by Airservices Australia) and the United States (represented by the FAA) agreed to work cooperatively in a formally recognized research project that utilised data available from the extensive ADS-B network in Australia, and the software and expertise available in the United States used for estimating ASE.

1.3. Work under this agreement began with a working group convened in Canberra, Australia during the week commencing the 31st of August 2009 and had as its aim to demonstrate the viability of using ADS-B data for height monitoring and to assess processing large batches of ADS-B data using the AGHME processing software. The results of the first meeting included modification of the existing ASE software to process large amounts of ADS-B data. Several ADS-B data sets were processed using the ASE software and the results were examined and presented to the SASP in [1] and [2]. Initial ASE results showed a variation in the data relative to latitude and longitude of the aircraft track.

1.4. The research group met again in Canberra, Australia during the week of 23 August 2010 to further investigate the apparent latitude and longitude bias in the ASE results. The purpose of this working paper is to present an update on the research conducted by the group.

METHODOLOGY

1.5. The current study used Australia-wide ADS-B data collected during the period 1 -10 January 2010 and 1 – 30 June 2010. A selection of aircraft tracks were processed through the FAA ASE software. The programs were adapted from the AGHME software to facilitate high volumes of data. Periods of flight which were outside RVSM flight levels, non-level or during a turn were automatically excluded.

1.6. The FAA ASE software used global weather data sets sourced from NOAA (the National Oceanic and Atmospheric Administration).

1.7. The flight tracks recorded through ADS-B are longer than those typically observed by HMU, AGHME or GMU. This is due to the coverage region of each ground station having a radius of approximately 200 NM at FL300, and also due to the overlapping coverage of the ground stations. Some ADS-B tracks exceed 2000 NM in length. ADS-B reports are transmitted by an aircraft at least once a second. This leads to a very large volume of available data.

1.8. Despite the difficulties in dealing with such large data sets, no attempt was made to sample the ADS-B data or to otherwise reduce its size. The processing was resource-intensive. More efficient data management is in progress and sampling strategies are planned. These will improve the efficiency of data processing significantly.

2. DISCUSSION

2.1. The research group presented [2] to the SASP/WG/WHL/17 meeting in Montreal, Canada. The results showed variation of aircraft ASE with latitude and longitude. The group began investigations into possible reasons for this apparent variation. The manner in which the meteorological data supplied by the United States for use in Australia was used in the ASE program, or the met data quality, were thought to be possible causes of the variation. In response to this possibility, Airservices Australia began work to utilize meteorological data obtained from the Australian Bureau of Meteorology in the ASE software.

2.2. Other possible causes for the ASE variation by latitude and longitude were investigated as well. The specifications in RTCA DO-260A [1] and RTCA DO-260B [2] contain descriptions for the *Difference From Barometric Altitude* subfield in the ADS-B airborne velocity messages. The *Difference From Barometric Altitude* subfield is extremely important to the work presented in this paper because this subfield contains the aircraft geometric height data needed to estimate aircraft ASE. The description of this subfield found in [1] and [2] follows:

> *The "Difference From Barometric Altitude" subfield is a 7-bit ("ME" bits 50 – 56, Message bits 82 – 88) field that is used to report the difference between Geometric (GNSS or INS) Altitude Source data and Barometric Altitude when both types o f Altitude Data are available and valid. The difference between barometric altitude and GNSS Height Above Ellipsoid (HAE) is preferred. However, GNSS Altitude (MSL) may be used when airborne position is being reported using TYPE Codes 11 through 18. If airborne position is being reported using TYPE Codes 9 or 10, only GNSS Height Above the Ellipsoid (HAE) may be used. For TYPE Codes 9 and 10, if GNSS Height Above the Ellipsoid (HAE) is not available, then the Difference from the Barometric Altitude subfield* ***shall*** *be set to ALL ZEROs.*

2.2.1. The above paragraph states that it is possible for the ADS-B derived geometric height of the aircraft to be given with reference to either Mean Sea Level (MSL) or Height Above Ellipsoid (HAE). It is very important for the ASE estimation process to identify exactly which reference (e.g., MSL or HAE) was used to provide the aircraft geometric height. If the wrong reference is assumed, significant errors can result in the estimate of aircraft ASE.

2.2.2. Figure 1 illustrates the difference between the WGS-84 ellipsoid and the geoid across the continent of Australia [5] in unit meters. The geoid is a close approximation of mean sea level. According to GeoScience Australia [5]:

> *"The* ***geoid*** *is an equipotential surface of the Earth's gravity field, which closely approximates mean sea level and is by definition perpendicular to the direction of the gravity vector at all points. Since the mass distribution of the Earth is not uniform and the direction of gravity changes accordingly, the resultant shape of the geoid is irregular".*

2.2.3. Figure 2 shows the difference between the WGS-84 ellipsoid and MSL for the latitudes and longitudes within Australia in unit feet as incorporated in the ASE program. Figures 1 and 2 show that the aircraft geometric height can be several hundred feet different depending on the reference (e.g. MSL or WGS-84 ellipsoid). If the reference used for the aircraft geometric height is identified incorrectly, this difference would be carried over into the estimation of aircraft ASE.

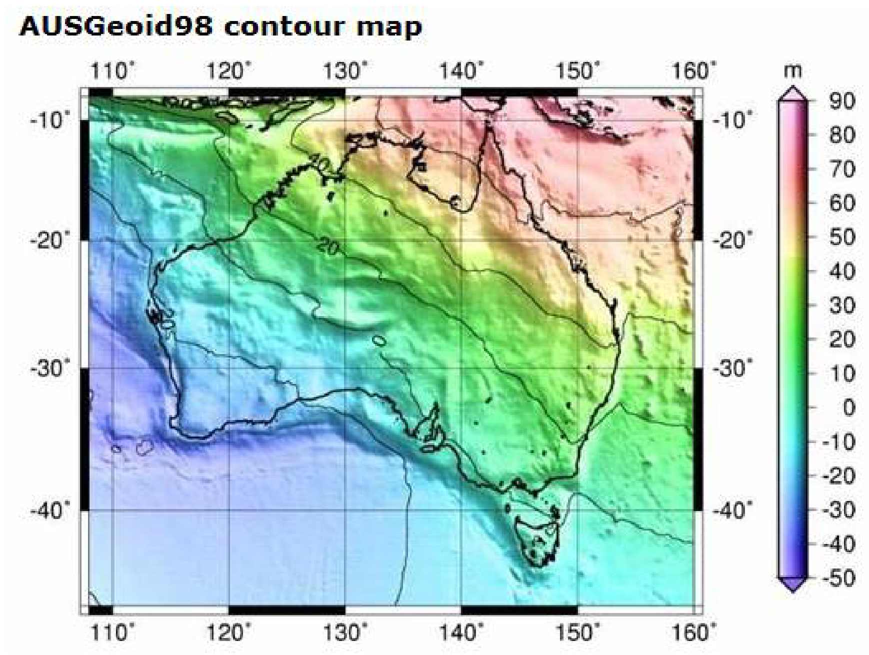

Figure 1. Separation Between Ellipsoid and Geoid (Height Above Ellipsoid (HAE) minus Height Above Geoid (HAG))

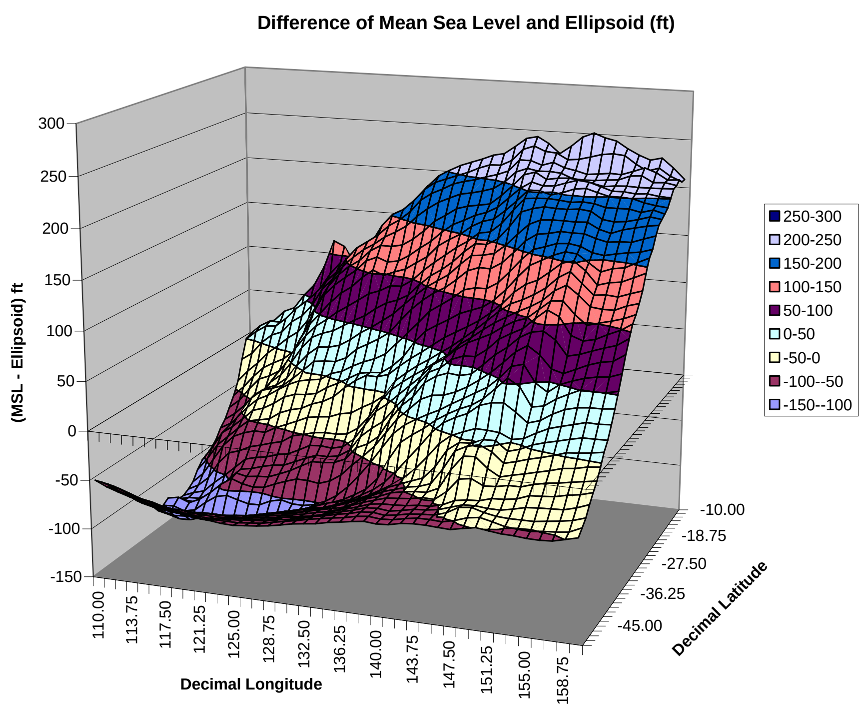

Figure 2. Difference between Mean Sea Level and Ellipsoid Across Australia.

2.2.4. Figure 3 shows the location of the Australian mainland ADS-B ground stations. A comparison of the locations of the ground stations shown in Figure 3 with the information provided in Figures 1 and 2, show that ADS-B ground stations are available in areas where the differences between MSL and the WGS-84 Ellipsoid are extreme. For example, an aircraft track joining Esperance and Thursday Island ground stations would have a difference between MSL and the WGS-84 Ellipsoid ranging over more than 300 feet. This consequence is evident for airframes observed at multiple ADS-B ground stations. If an incorrect assumption is made regarding the reference for the aircraft geometric height, large variations in the ASE estimates of the airframe can be observed by latitude and longitude.

Figure 3. Location of the Mainland ADS-B Ground Stations (Centers of Circles)

2.2.5. The group observed ASE measurements for single airframes obtained from data collected at various ADS-B ground stations throughout Australia. Figures 4 through 8 show the individual ASE estimates resulting from the different assumptions for the geometric height reference (HAE or MSL) versus time. Within each figure there is a smaller figure which includes the latitude-longitude path observed for the airframe.

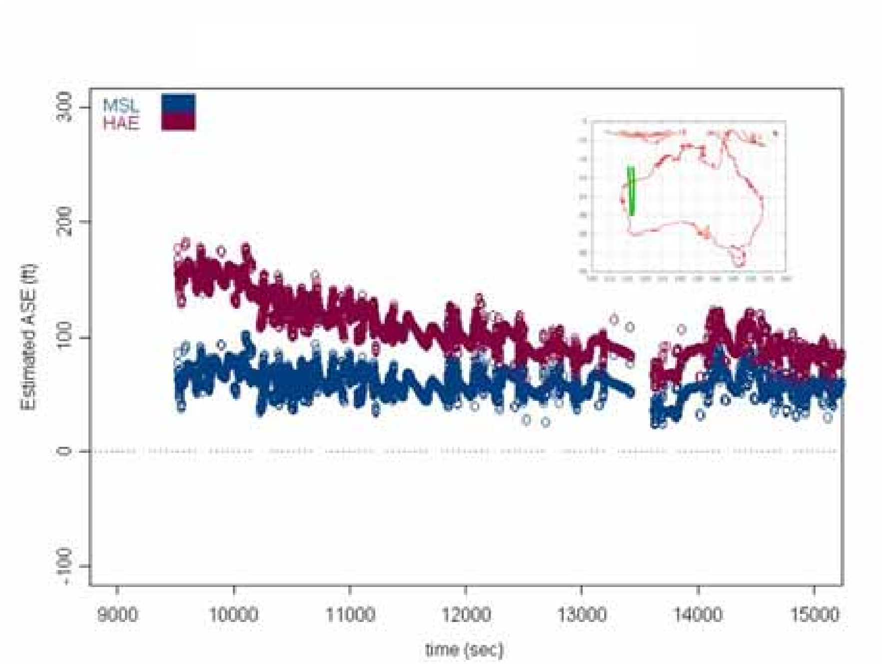

Figure 4. ASE Estimates by Time Assuming HAE and MSL for Height Reference for a Aircraft Track Observed Along a Longitude Meridian.

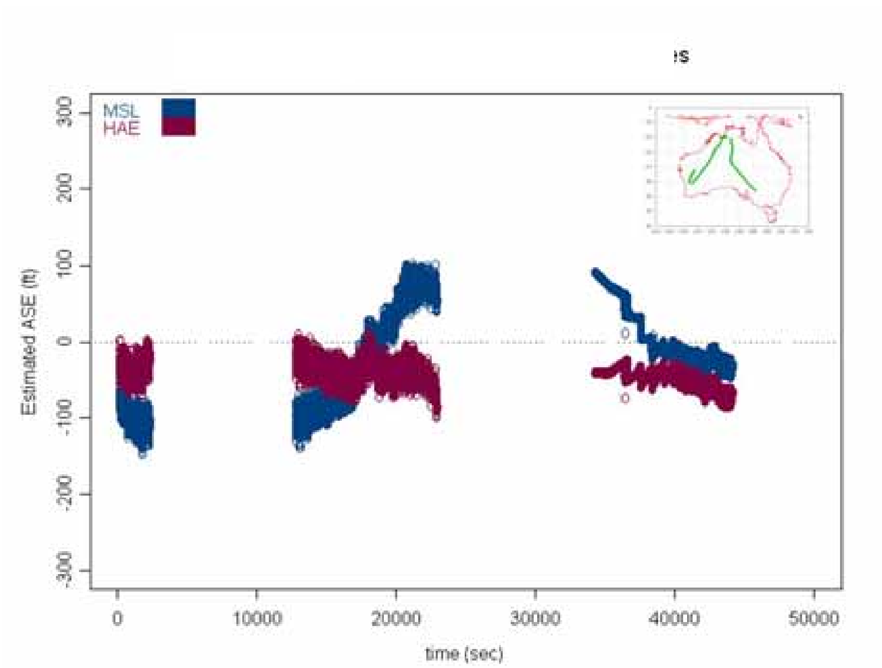

Figure 5. ASE Estimates by Time Assuming HAE and MSL for Height Reference for Aircraft Tracks with Significant Latitude and Longitude Variations.

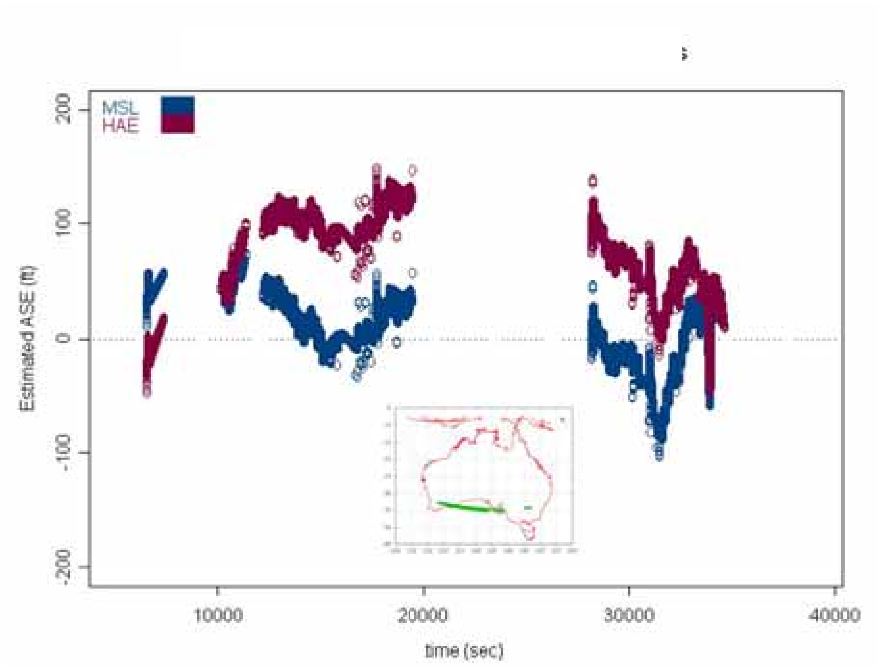

Figure 6. ASE Estimates by Time Assuming HAE and MSL for Height Reference for Aircraft Tracks at Approximately Constant Latitude and Significant Longitude Variation.

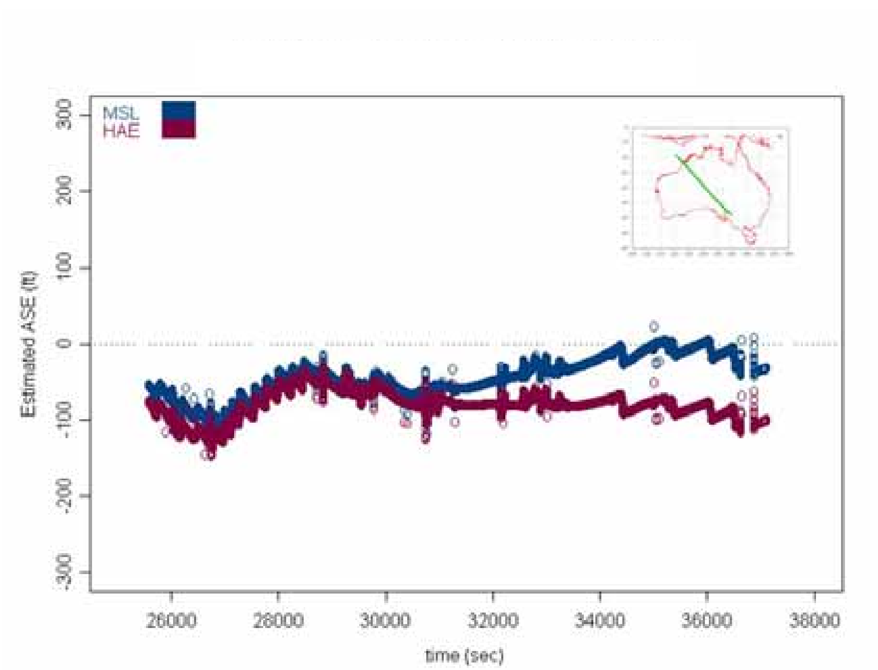

Figure 7. ASE Estimates by Time Assuming HAE and MSL for Height Reference for an Aircraft Track Roughly Along one of the Contours Shown in Figures 1 and 2.

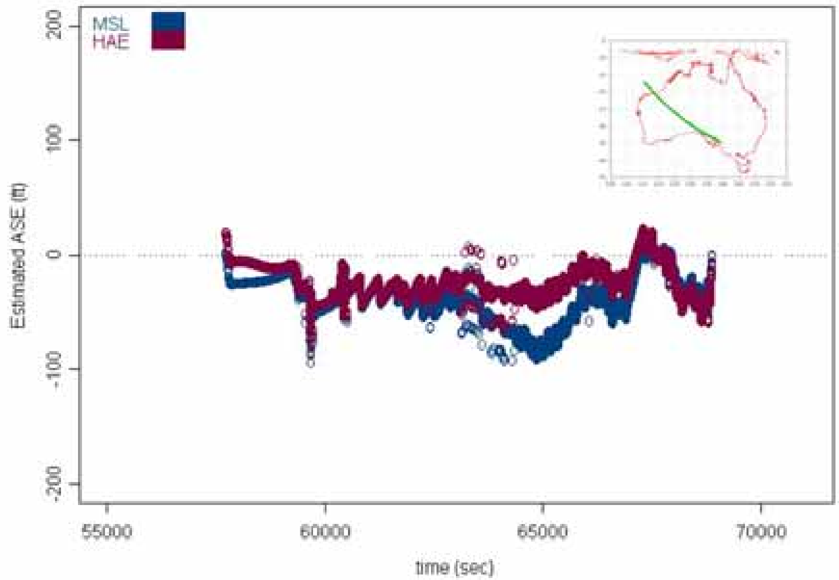

Figure 8. ASE Estimates by Time Assuming HAE and MSL for Height Reference for an Aircraft Track Roughly on one of the Contours Shown in Figures 1 and 2

2.2.6. The group also had the opportunity to consult with ADS-B experts within Airservices Australia during the August meeting. The ADS-B experts indicated that the difference is likely at the GPS receiver level. The experts suggested that older models of GPS receivers may be providing the geometric height with reference to MSL and the newer GPS receiver models may be providing the geometric height with reference to HAE. Information provided by one GPS manufacturer indicated that most of the older units they had manufactured provided only "MSL" data. Additionally, multiple tests undertaken on a common recently manufactured model of transponder showed that it consistently used the "HAE" as a reference.

2.2.7. Figures 9 and 10 provide box plots of ASE estimates by GPS receiver models. The box-widths are proportional to the number of data entries. Box plots shown on the top portion of each figure represent the ASE estimates by GPS receiver model with the assumption that HAE was the reference for the aircraft geometric height. The box plots shown on the bottom portion of each figure represent the ASE estimates by GPS receiver model with the assumption that MSL was the aircraft geometric height reference.

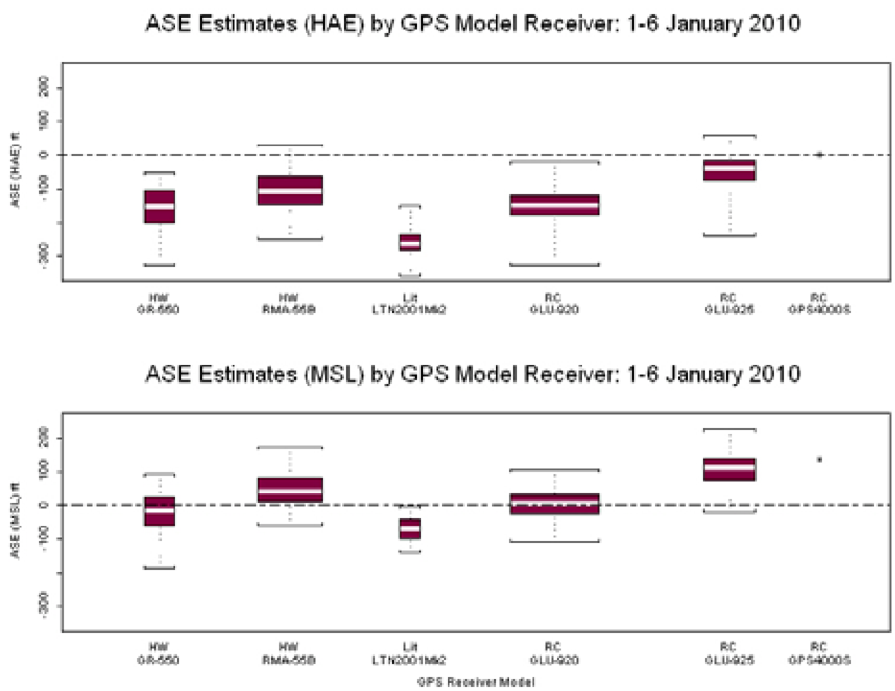

Figure 9. ASE Estimates by GPS Receiver Referencing MSL and HAE – January 2010

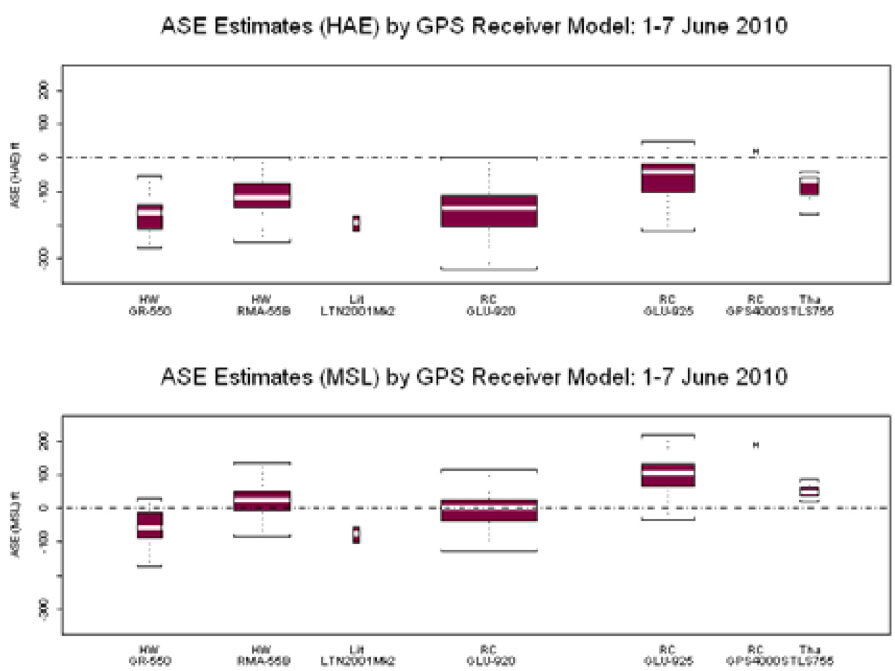

Figure 10. ASE Estimates by GPS Receiver Referencing MSL and HAE – June 2010.

2.2.8. The ASE results by GPS receiver model, presented in Figures 9 and 10, correlate well with the suggestion given by the ADS-B experts. Current indications are that only the most recent GPS receivers report HAE. The majority of the models (and aircraft) have been found to report geometric height with reference to MSL.

2.2.9. The group is awaiting confirmation from the various GPS receiver manufacturers stating which height reference is used for each receiver. Once confirmed, this information will be utilized by the ASE estimation process. However for ADS-B it seems prudent to calculate and record ASE separately for both possible height references. The final choice of ASE value from the results database would be based on aircraft GPS fitment, which is known from an ADS-B approvals database.

2.2.10. Airservices Australia has been utilising ADS-B data obtained from Royal Australian Air Force (RAAF) B300 aircraft under trial conditions to support the monitoring research activity. Data collected to the end of June 2010 was used to determine the following ASE measurements for the airframes identified by Mode S code and is detailed in Table 1 below:

Airframe	***Date of observation***	***Measured ASE***	***No. of data point observations***
Airframe 1	16 April 2010	4ft @FL290	191
	17 April 2010	8ft @FL310	7075
	29 May 2010	-6ft @FL300	4211
Airframe 2	20 April 2010	29ft @FL290	810
	17 May 2010	8ft @FL300	207
	16 May 2010	47ft @FL290	1339
Airframe 3	16 June 2010	26ft @FL330	8346

2.2.11. The FAA had undertaken monitoring of airframe 1 in 2009 using an AGHME. The ASE measured from that data was 5ft but that included a bias calculation specific to the use of AGHME systems. Therefore the raw ASE was estimated to be -6FT which matches that estimated for the same airframe using ADS-B on 29 May 2010.

3. FUTURE WORK

3.1. Based on the analyses completed to date, the research group believes that it will be necessary to have the specific GPS model receiver information for each individual airframe to be monitored using ADS-B.

3.2. The research group is awaiting responses from the various GPS receiver manufacturers to confirm the height reference (e.g. MSL or HAE) used by the individual avionic GPS receiver models.

3.3. The next step for the research is to formally validate the ASE results against existing ASE monitoring systems, such as the European HMUs, EGMUs, and U.S. AGHMEs.

3.4. Airservices Australia will need to refine data management and determine a data sampling strategy for long-term use of ADS-B for estimating aircraft ASE. This includes defining the database and storage requirements for monitoring results.

4. ACTION BY THE MEETING

4.1. The meeting is invited to note the information provided in this paper.

4.2. The meeting is invited to endorse the continued exploration of ADS-B derived geometric height as a data source for aircraft height-keeping performance monitoring.

References

1. Airservices Australia and the US FAA, "Trial-Use of the Automatic Dependent Surveillance-Broadcast Data for Monitoring Aircraft Altimetry System Error", SASP/WG/WHL/16, WP/24, Auckland, New Zealand, 9 – 20 November 2009.

2. Airservices Australia and the US FAA, "An Update to the Investigation into the Use of Automatic Dependent Surveillance-Broadcast Data for Monitoring Aircraft Altimetry System Error", SASP/WG/WHL/17, WP/21 , Montreal, Canada, 10 - 21 May 2010.

3. RTCA DO-260A, "Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B)", 2003.

4. RTCA DO-260B, "Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B)", December 2, 2009.

5. Australian Government – Geoscience Australia, **http://www.ga.gov.au/geodesy/ausgeoid/**