

# AIAA GNC Conference Session 139-GNC-49

## Paper AIAA-2008-7146: “Investigation into the use of Automatic Dependent Surveillance-Broadcast Data for Monitoring Aircraft Altimetry System Error ”

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# Overview

- **Introduction**
  - Altimetry System Error (ASE)
  - Automatic Dependence Surveillance Broadcast (ADS-B)
- **Background**
- **Data Sources and Descriptions**
- **Methodology**
- **Analysis and Results**
- **Conclusions**

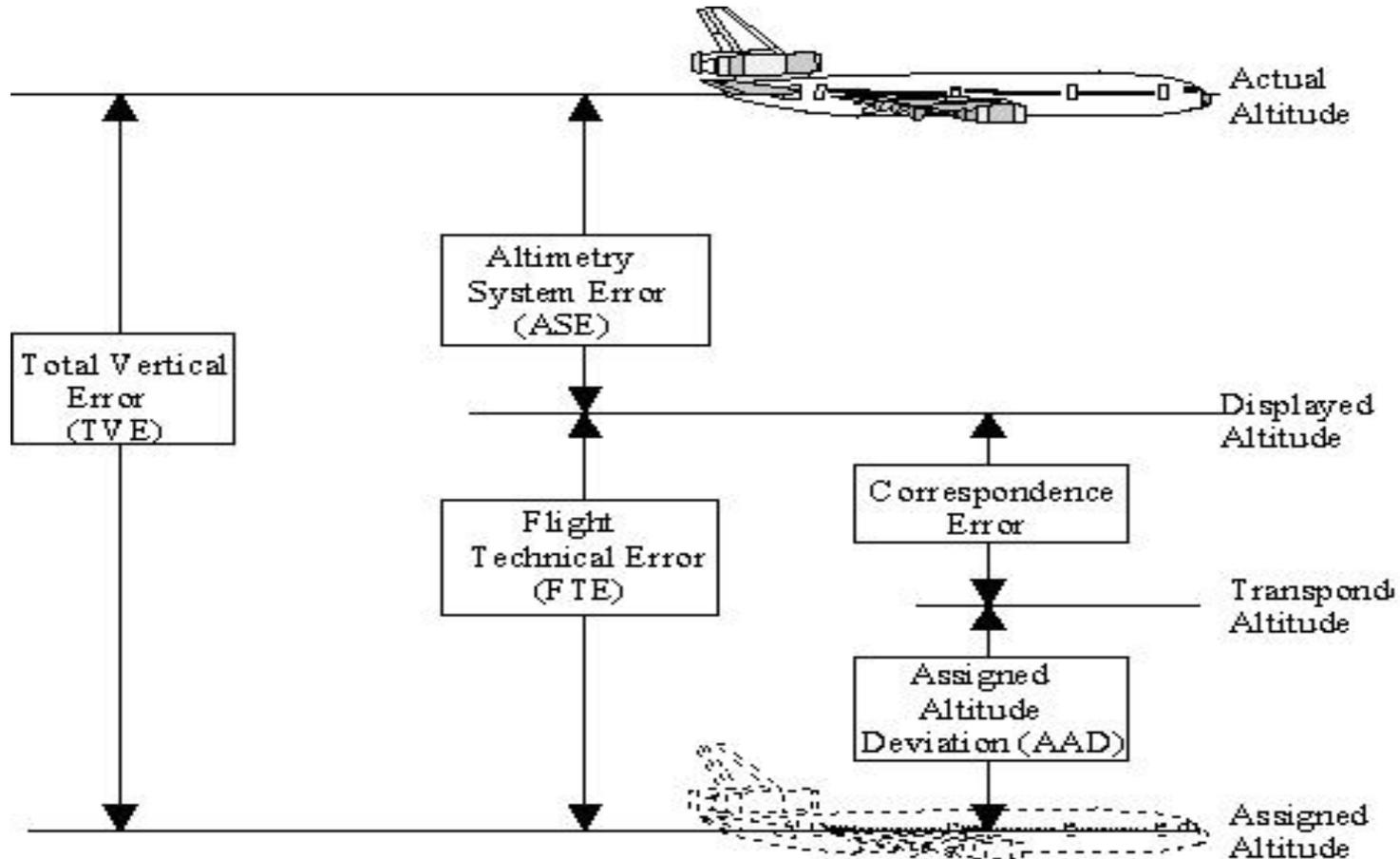


# Introduction - ASE

- **ASE is a measure of the height-keeping performance of an aircraft**
  - Defined as the difference between the altitude indicated by the altimeter display and the pressure altitude
- **ASE is not detectable in routine operations**
  - These types of errors are hidden from both the pilot and ATC
  - There is no instrument to gauge when the pressure sensed by the static probe is the actual ambient pressure
  - As a result it is necessary to assure that the aircraft systems are designed and maintained to control the magnitude of ASEs
  - Currently, specialized measurement equipment is necessary to independently measure the errors



# Total Vertical Error (TVE) and ASE



# Introduction

- **Why is Aircraft ASE Important ?**
  - Reduced Vertical Separation Minimum (RVSM)
    - Reduced the vertical separation between aircraft from 2000 ft to 1000 ft
    - Magnified the importance of aircraft height keeping capabilities
    - ICAO requirements for monitoring ASE



# Introduction – ADS-B

- **ADS-B equipped aircraft use a GPS receiver to determine their position**
- **Aircraft position information is broadcast to other ADS-B equipped aircraft and to air traffic controllers**
- **FAA is currently increasing the ADS-B ground network infrastructure**
- **Other countries are initiating programs to include ADS-B in their air traffic control systems**



# Background

- **In the US most ASE estimates are computed using data collected by an enhanced GPS based monitoring unit (EGMU) on board the aircraft.**
  - EGMU must be installed on each aircraft that is being monitored at a cost to the airline/operator
- **RVSM approval is required for aircraft between FL290 and FL410**
- **ICAO has set monitoring requirements for obtaining/maintaining RVSM approval**
  - Initial monitoring to obtain RVSM approval
  - Periodic monitoring to maintain RVSM approval



# Data Sources and Description

- **Test Flights**

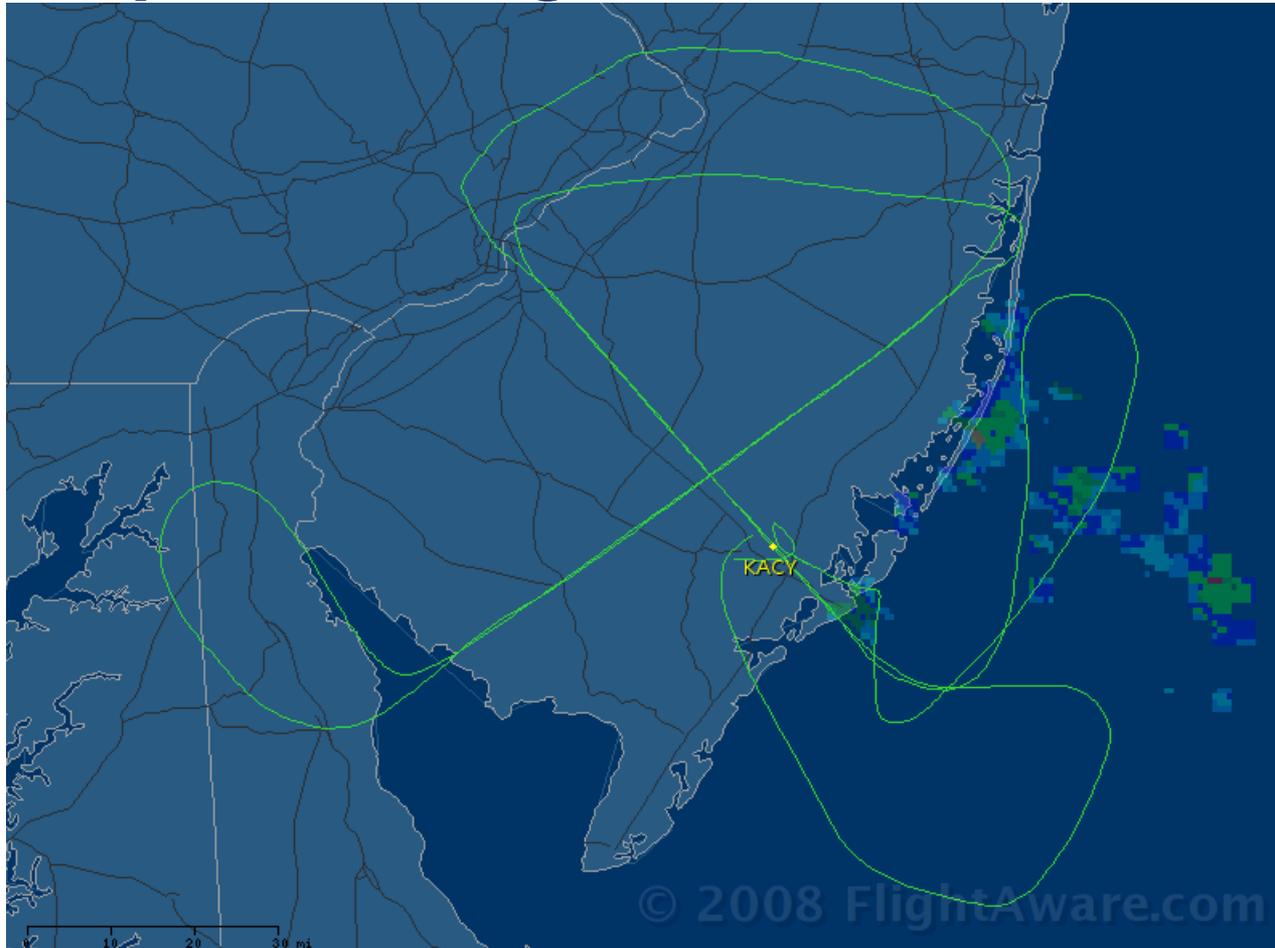
- FAA Technical Center has a fleet of research aircraft that are used for conducting tests and evaluations of avionics systems
- N47 – a Bombardier BD-700-1A11 aircraft was used for this study



- Test flights were conducted on June 26, 27 and July 2 at FL280 and FL410
- All departed from and returned to the Atlantic City International Airport

# Data Sources and Description

## *Sample Test Flight Path*



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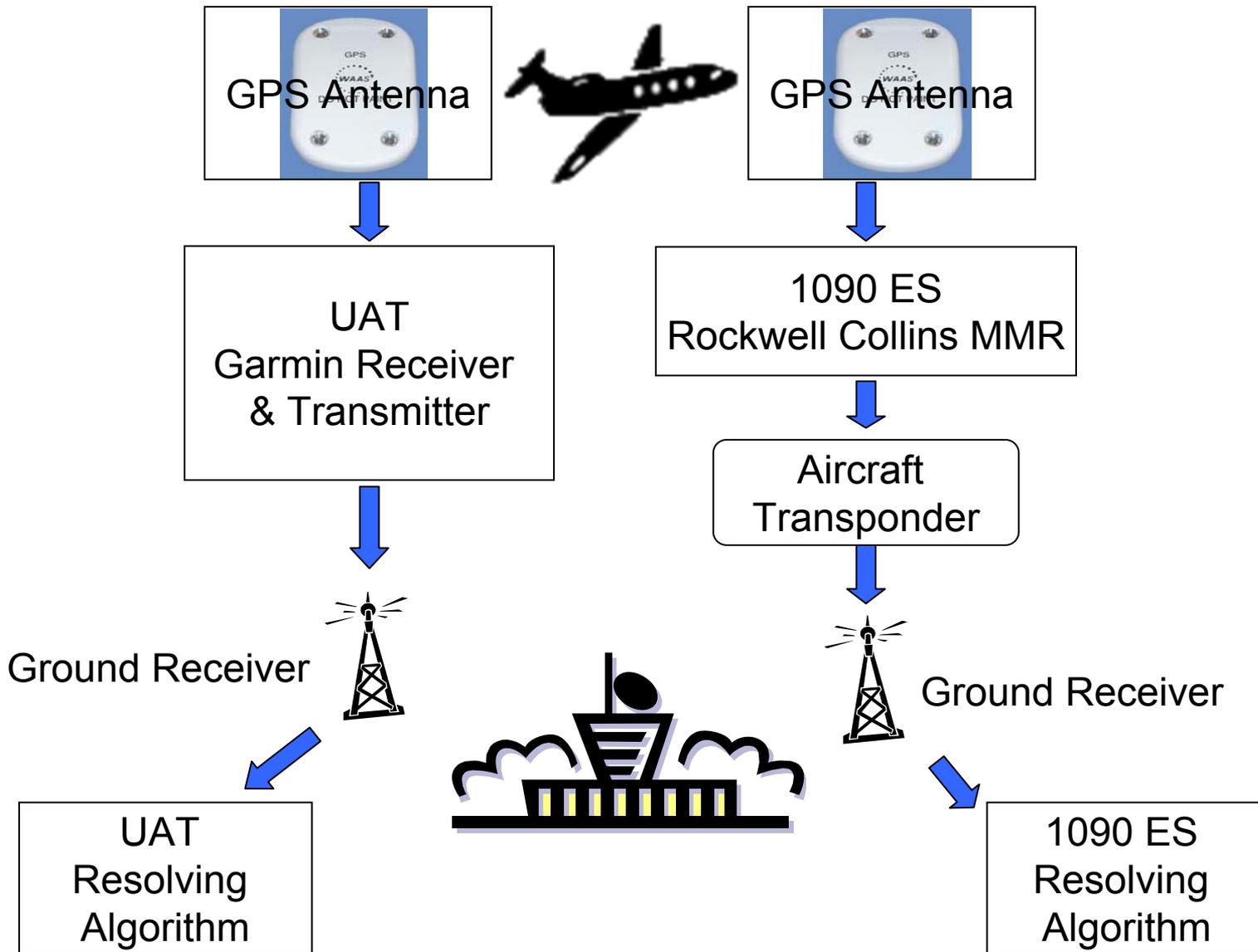


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# Data Sources and Description

## *ADS-B Data*

- **Two different collection methods of ADS-B data in use in the US – both were installed on N47**
  - Universal Access Transceiver (UAT) Data Link – General Aviation Aircraft
  - 1090 Extended Squitter (ES) – Commercial Airlines
- **Both systems installed on the test aircraft were using wide area augmentation system (WAAS) – which allows GPS receivers to remove errors in the GPS signal**
  - UAT systems always use WAAS corrections
  - 1090 ES systems may or may not use WAAS corrections



# Data Sources and Description

## *Truth and EGMU Data*

- **Truth Data**

- The geometric heights in the truth data are obtained from an independent Ashtech Inc. GPS receiver. The truth data are post processed using Novatel's software called GrafNav/GrafNet version 6.03. This post processing procedure improves the accuracy of the data by using information collected at various ground stations.

- **EGMU Data**

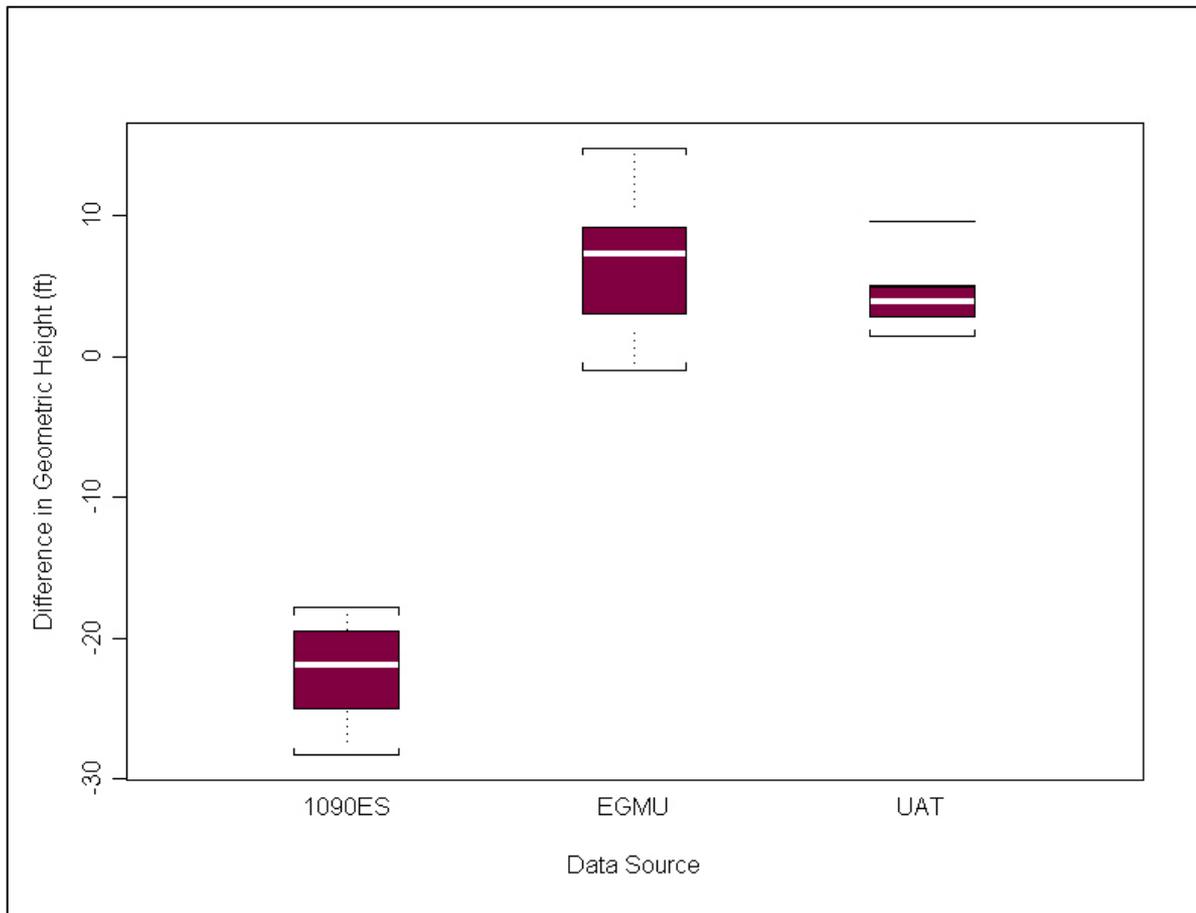
- The aircraft geometric height data obtained from the EGMU is differentially corrected through post-processing. Meteorological data, needed to determine the geometric height of the assigned flight level, are obtained from the National Weather Service.

# Methodology

- **Aircraft geometric heights obtained from both ADS-B data sources and EGMU data were compared with aircraft geometric heights contained in the truth data**
- **Comparison of ADS-B data with EGMU data is important because EGMU has been proven as reliable data source for estimating ASE**
- **Aircraft geometric height is a direct input to the process that computes ASE**
- **Data sources are time matched to the truth data and the geometric altitudes are compared**



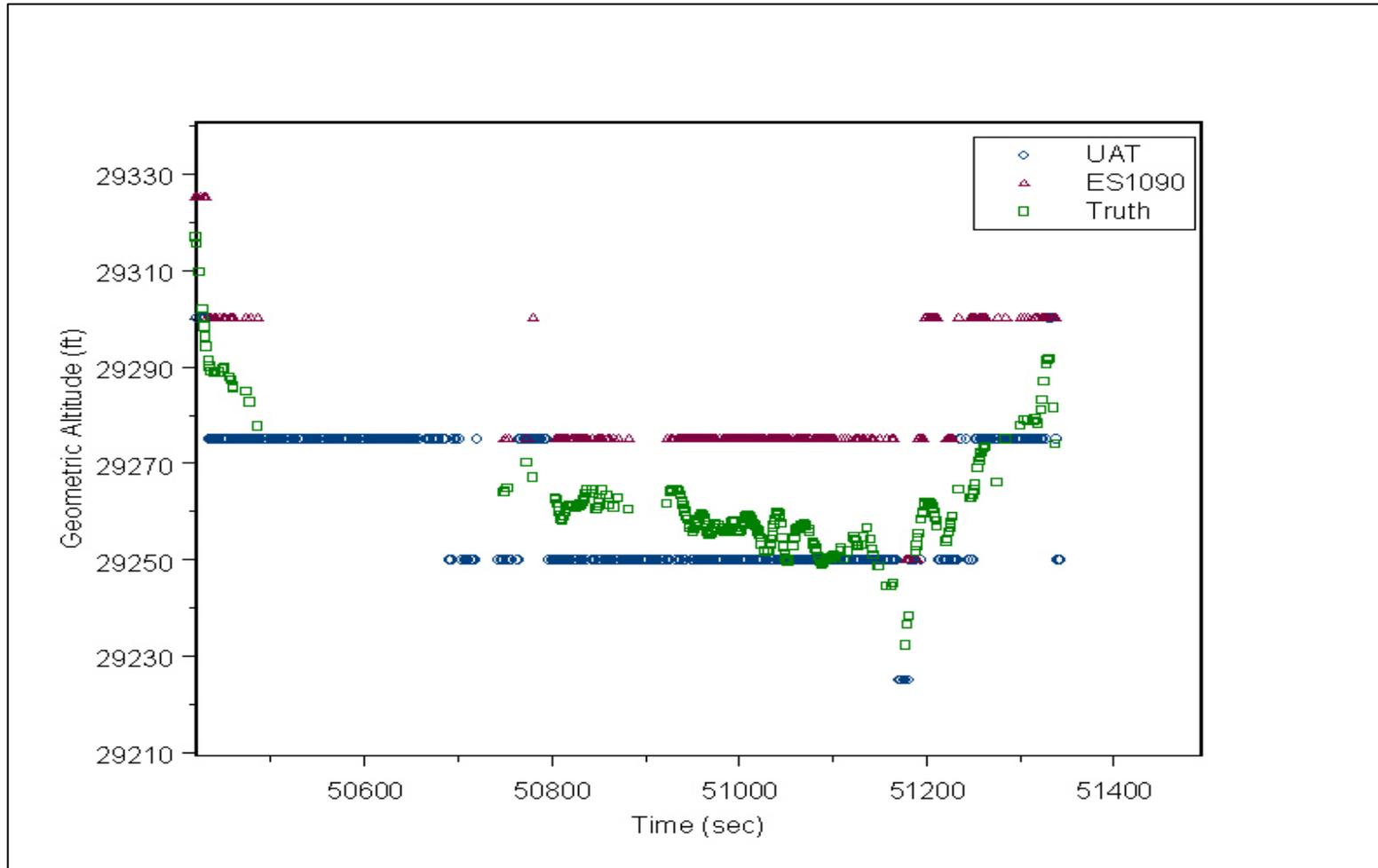
# Methodology



Data Source	Avg. Diff in Geometric Height (ft)
1090 ES	-22.419
EGMU	6.623
UAT	4.303

# Methodology

## Comparison of UAT, 1090 ES and Truth Data



# Methodology

- **Prior to analysis of ADS-B data it was expected that both sources of ADS-B data would produce similar results when the aircraft geometric heights were compared to truth data**
- **Each ADS-B data source treats the data differently**
  - UAT: rounds geometric height to nearest 25 ft increment then send the estimate to the ground receiver
  - 1090 ES: determines difference between geometric altitude and pressure altitude, rounds this value to the nearest 25 ft increment. Also rounds the pressure altitude to nearest 25 ft increment. Both of these values are sent to the ground receiver. Geometric height is computed during post processing.



# Methodology

- **Expected Value and Variance for UAT and 1090 ES data**
  - UAT:  $h_u$  = rounded GPS aircraft height  
 $h_t$  = true geometric height of the aircraft  
 $e_n$  = random error  $N(0, \sigma)$ 
    - $E(h_u) = E(h_t) + 12.5$  (ft)
    - $\text{Var}(h_u) = \text{Var}(h_t) + \text{Var}(e_n) + 625/12$  (ft)
  - 1090 ES:  $d_r$  = the rounded difference between the GPS aircraft height and pressure altitude height  
 $h_{es}$  = geometric height from 1090 ES  
 $h_t$  = true geometric height of the aircraft  
 $e_n$  = random error  $N(0, \sigma)$ 
    - $E(h_{es}) = E(h_t) + 25$  (ft)
    - $\text{Var}(h_{es}) \sim \text{Var}(h_t) + \text{Var}(e_n) + 104$ (ft)

# Analysis and Results

## ANOVA Table

- ANOVA test is used to test for differences among two or more independent samples

Groups	Count	Sum (ft)	Average (ft)	Variance (ft)		
EGMU	8	52.987	6.623	25.812		
1090 ES	8	-179.359	-22.419	13.272		
UAT	8	34.428	4.303	5.979		
<b>ANOVA</b>						
<b>Source of Variation</b>	<b>SS</b>	<b>df</b>	<b>MS</b>	<b>F</b>	<b>P-value</b>	<b>F crit</b>
Between Groups	4168.122	2	2084.061	138.738	7.88E-13	3.466
Within Groups	315.451	21	15.021			
Total	4483.573	23				

- Test shows that the mean difference between the three independent sources of aircraft geometric height and the aircraft geometric height obtained from the truth data are significantly different

# Analysis and Results

## T-test

- A T-test can be used to test the means of two samples

<b>Null Hypothesis</b>	<b>T statistic</b>	<b>P(T&lt;=t)</b>	<b>t Critical</b>	<b>Results</b>
$\mu_{\text{EGMU}} = \mu_{1090\text{ES}}$	13.388	0.000	2.365	reject null hypothesis
$\mu_{\text{EGMU}} = \mu_{\text{UAT}}$	1.890	0.101	2.365	null hypothesis can not be rejected

- The mean difference between the geometric heights obtained from 1090 ES data and the truth data and the mean difference between the EGMU data and the truth data are significantly different
- The mean difference between the geometric heights obtained from UAT data and the truth data and the mean difference between the EGMU data and the truth data are not significantly different

# Analysis and Results

- **The expected value of the 1090 ES data contains a 25 ft bias in the estimate of the aircraft geometric height caused by the two rounding errors**
- **This leads to the mean of the geometric heights obtained from the data being statistically different from the other two sources of data.**
- **If this bias is removed and the ANOVA test is recomputed the results indicate that the three sample means are not significantly different**



# Analysis and Results

## ASE Estimates for Test Flights

Segment and Flight Level	Data Source	ASE	Number of Observations
June 27 FL 410	EGMU	73	188
	1090 ES	95	176
	1090 ES – 25 ft bias	70	176
	UAT	73	310
June 27 FL 410	EGMU	111	137
	1090 ES	149	65
	1090 ES – 25 ft bias	124	65
	UAT	118	173
June 27 FL 410	EGMU	78	155
	1090 ES	Insufficient Data	5
	UAT	76	155
July 2 FL 410	EGMU	57	647
	UAT	58	58
July 2 FL 410	EGMU	55	468
	UAT	50	46



# Conclusions

- **Focus of study was mainly on the comparison of the aircraft geometric heights obtained from two sources of ADS-B data**
- **Discovered differences in the way the UAT and the 1090 ES collect and treat the data which lead to differences in the geometric heights collected with each system**
- **The main focus of both ADS-B systems is on the pressure altitude not geometric altitude**
- **UAT system will be used by mainly general aviation aircraft while the 1090 ES will be used by commercial operations**
  - ASE is calculated only for aircraft within RVSM flight levels, which is mainly commercial aircraft



# Conclusions

- **The aircraft geometric height data obtained from the UAT system was not significantly different from the aircraft geometric height data obtained from the EGMU, which is a proven source of geometric height for ASE calculation**
- **When adjusted for the 25 ft bias, the aircraft geometric height data obtained from the 1090 ES was not significantly different from the EGMU**
- **Future test flights are planned to continue the analysis to determine if both sources of ADS-B data can be used for ASE estimation**
- **These tests will also examine the effect of WAAS on the geometric heights**



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