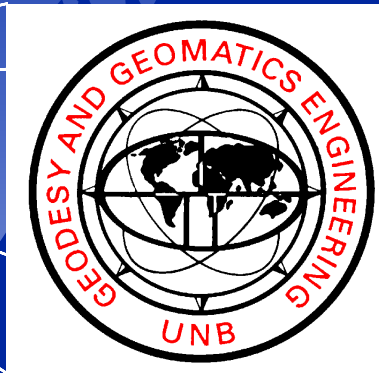


# **A Summary of the Data Analysis for Halifax GPS Precision Approach Trials**

Transport Canada Aviation/Cougar Helicopters Inc.  
University of New Brunswick



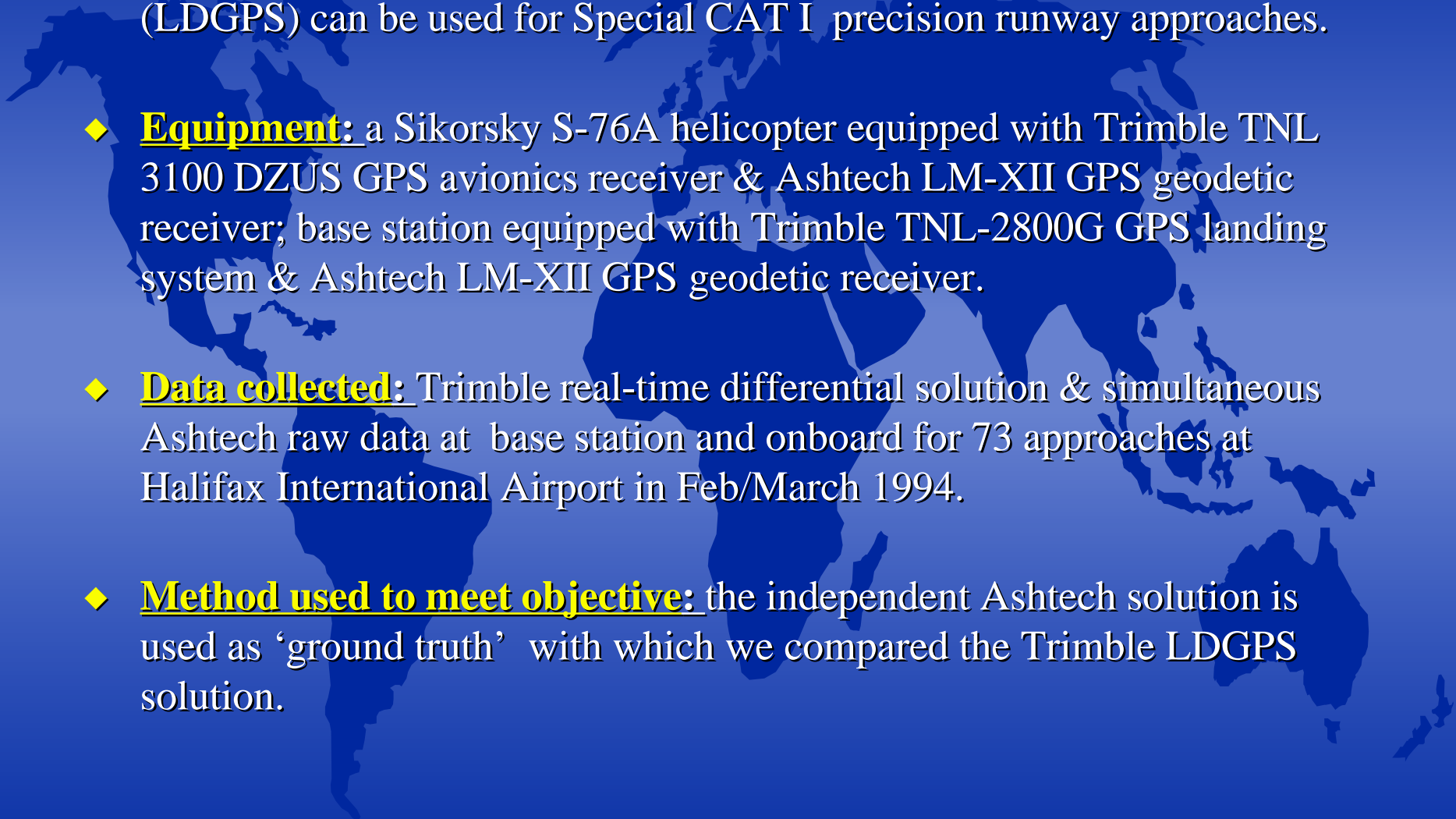
**Attila Komjathy and Richard B. Langley**  
**Geodetic Research Laboratory**  
**University of New Brunswick**  
**Fredericton, NB**  
**E3B 5A3 Canada**  
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Presented at the Technical University of Budapest  
4 March 1996

A dark blue silhouette of a world map is centered in the background of the slide. The title and list are overlaid on this map.

# Outline of the Presentation

- ◆ Introduction
- ◆ Step 1: Evaluating the Ashtech “ground truth” system.
- ◆ Step 2: Software development assessing the Trimble LDGPS solutions based on Ashtech PNAV solutions.
- ◆ Step 3: Development of statistics and analysis of results.
- ◆ Conclusions
- ◆ Recommendations

- 
- ◆ **Objective:** to provide evidence that Trimble local differential GPS (LDGPS) can be used for Special CAT I precision runway approaches.
  - ◆ **Equipment:** a Sikorsky S-76A helicopter equipped with Trimble TNL 3100 DZUS GPS avionics receiver & Ashtech LM-XII GPS geodetic receiver; base station equipped with Trimble TNL-2800G GPS landing system & Ashtech LM-XII GPS geodetic receiver.
  - ◆ **Data collected:** Trimble real-time differential solution & simultaneous Ashtech raw data at base station and onboard for 73 approaches at Halifax International Airport in Feb/March 1994.
  - ◆ **Method used to meet objective:** the independent Ashtech solution is used as ‘ground truth’ with which we compared the Trimble LDGPS solution.

# **Transport Canada Aviation/Cougar Helicopters Inc. GPS Precision Approach Trials**



**Sikorsky S-76A helicopter equipped with Trimble TNL 3100 DZUS GPS avionics receiver  
& Ashtech LM-XII GPS geodetic receiver**



# Airfield of Halifax International Airport



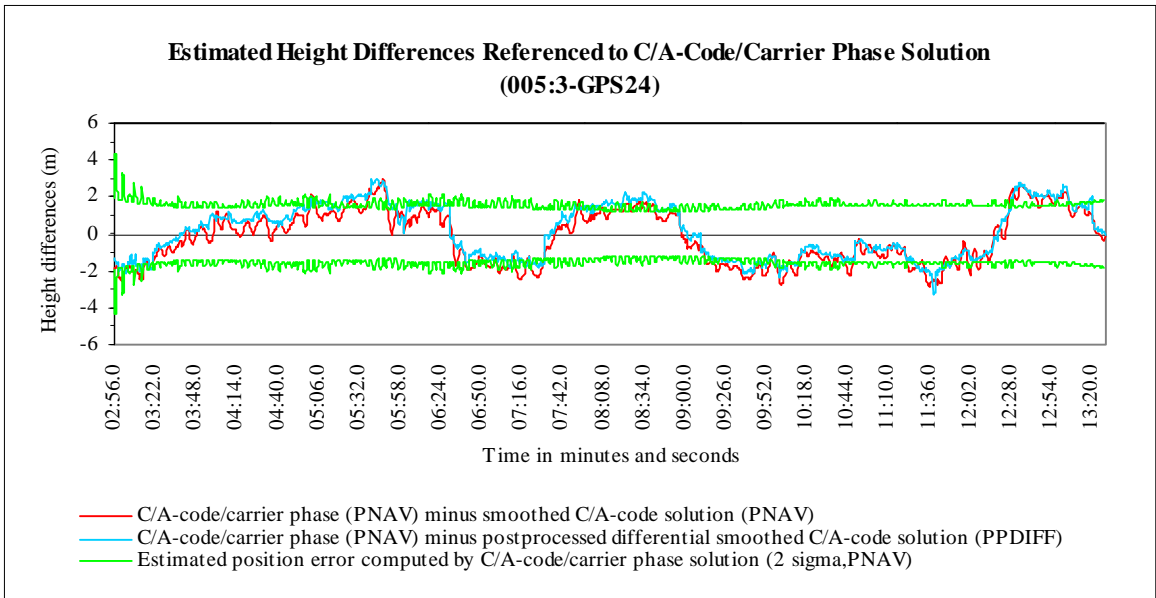
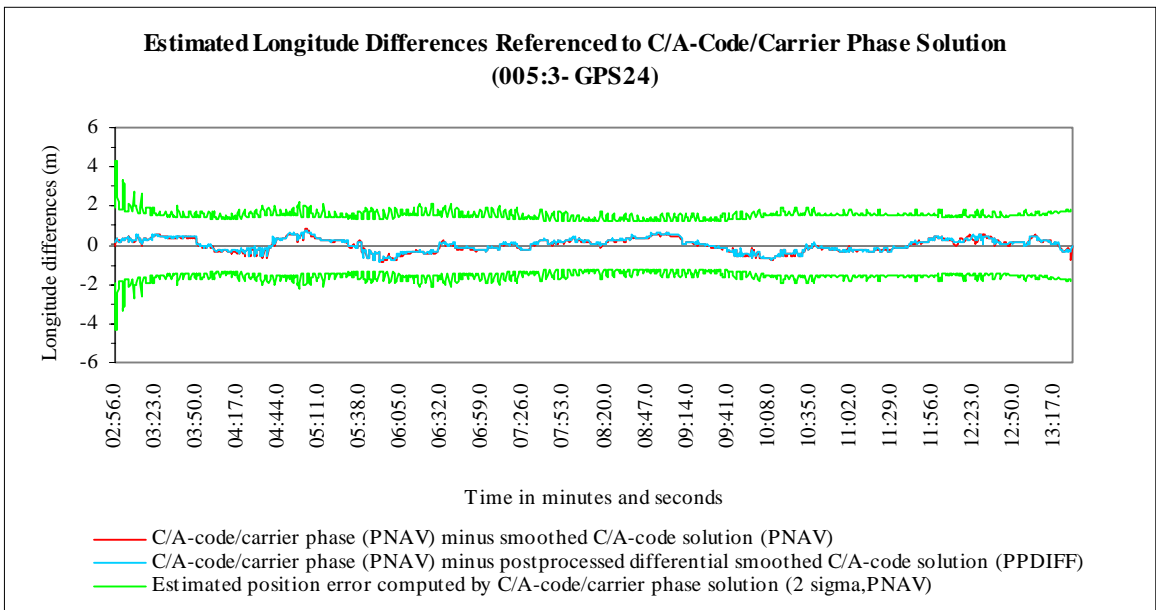
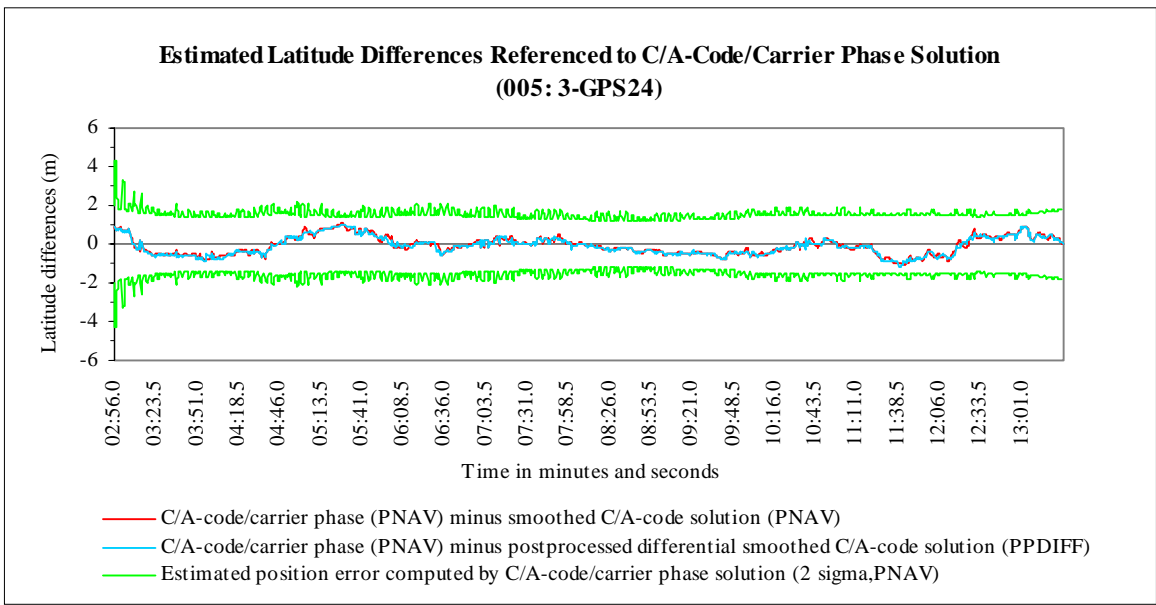
- ◆ **Step 1.** : We used three different solutions to validate the Ashtech solution:
  - C/A-code/carrier phase solution (PNAV),
  - Carrier-phase smoothed C/A-code solution (PNAV),
  - Postprocessed differential smoothed C/A-code solution (PPDIFF).

**Figure 1:** Shows an example of the comparison between the three solutions along with the estimated position accuracy of the Ashtech solution.

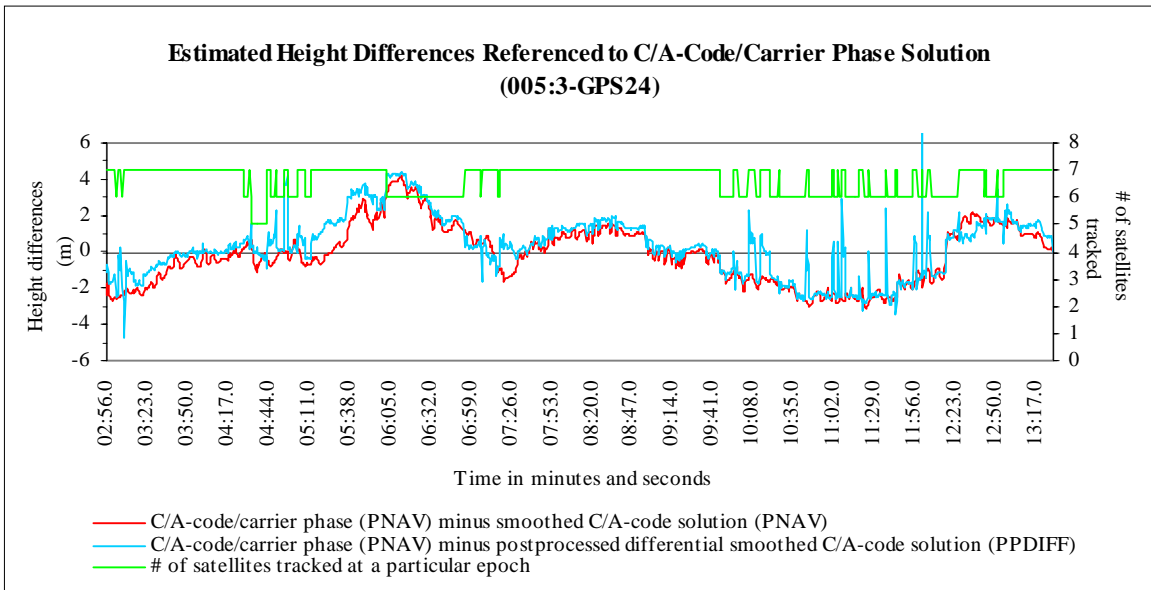
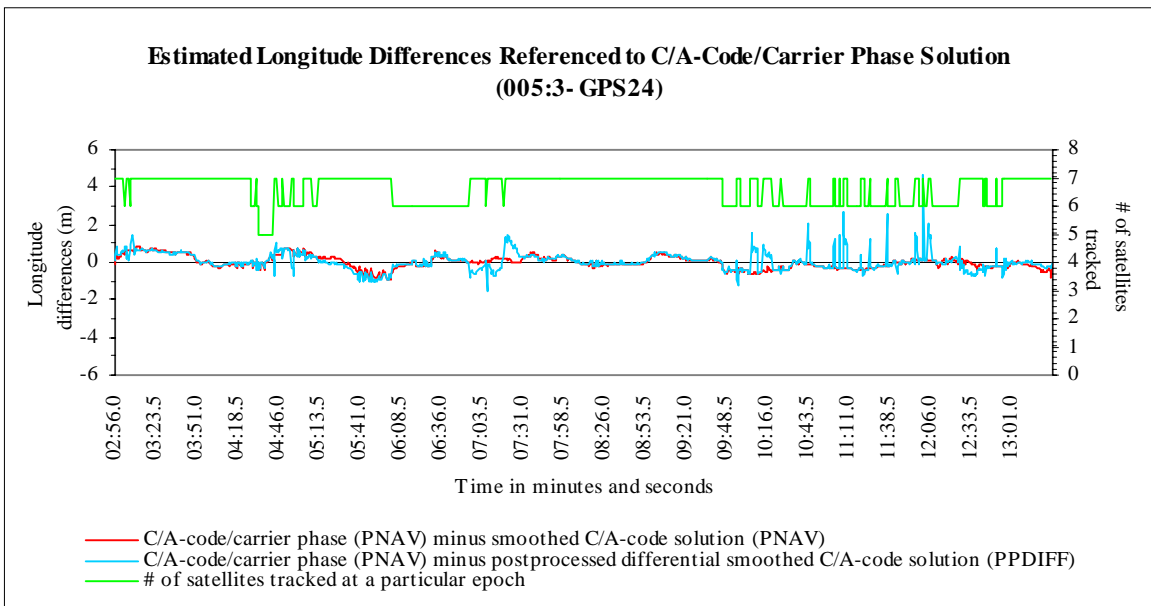
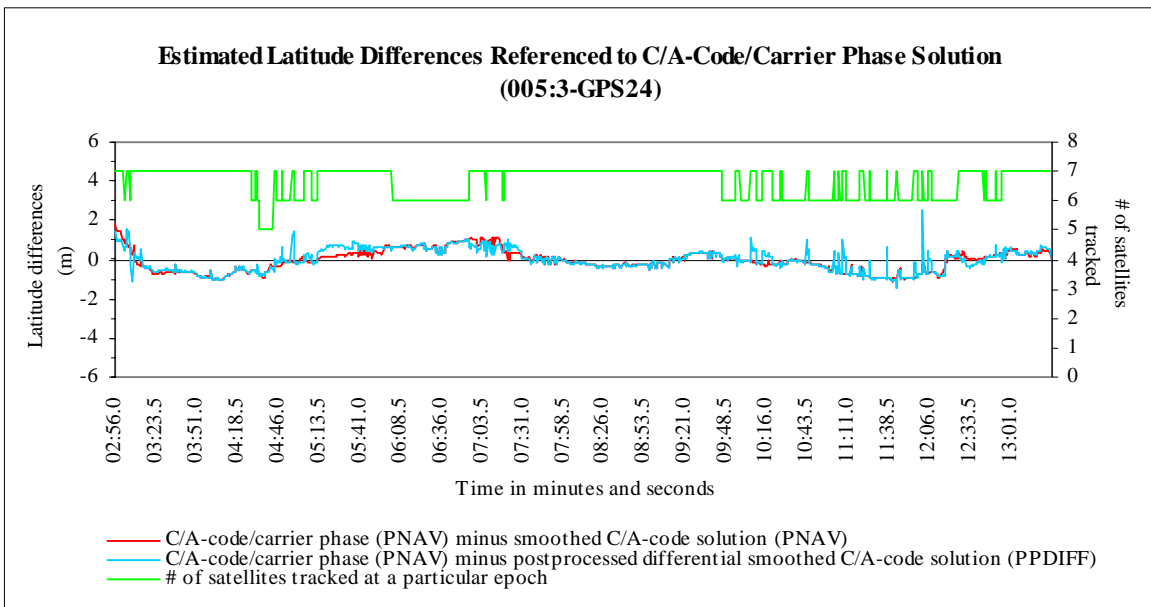
**Figure 2:** Shows an example of the comparison between the three solutions computed from the raw data without cycle slip editing & checking for data quality.

**Figure 3:** Gives an indication about how noisy the solution and data are, and how good PNAV thinks the solution is.

- ◆ **Conclusion from step 1.**: Estimated position accuracy from Ashtech data is lower than expected. Why? Because pseudorange observations are biased by multipath; carrier-phase ambiguities are not resolved; and observation periods are too short.

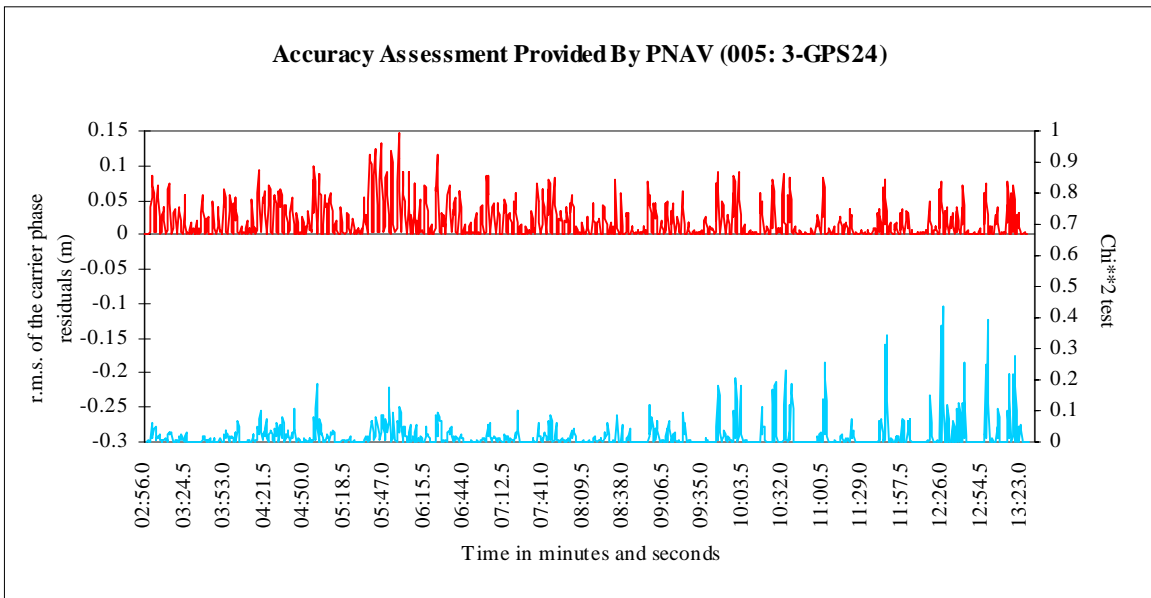
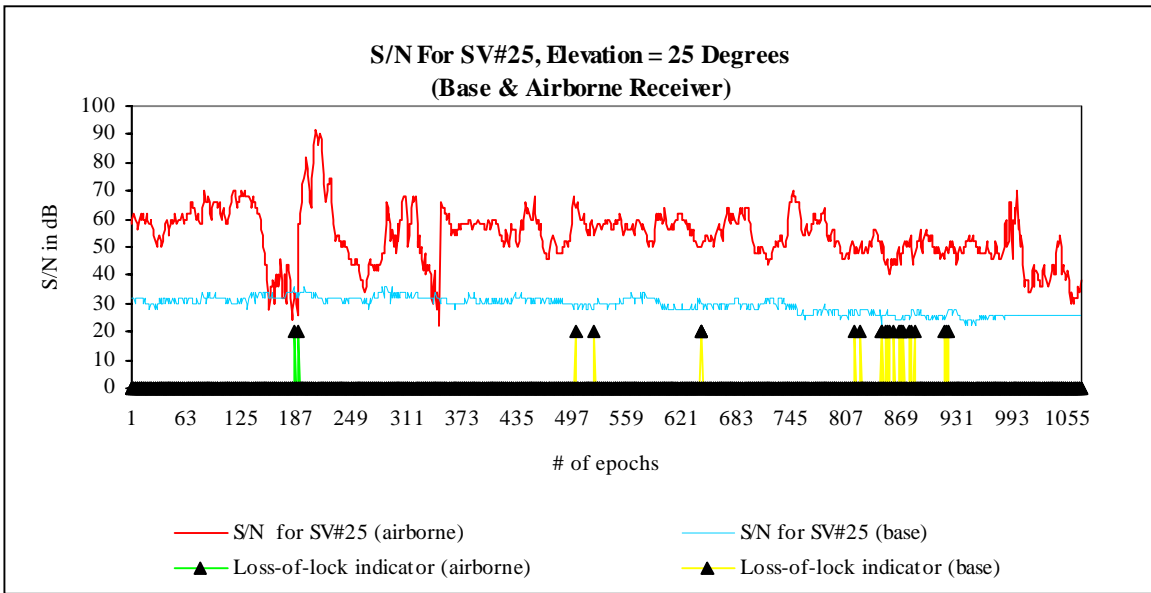
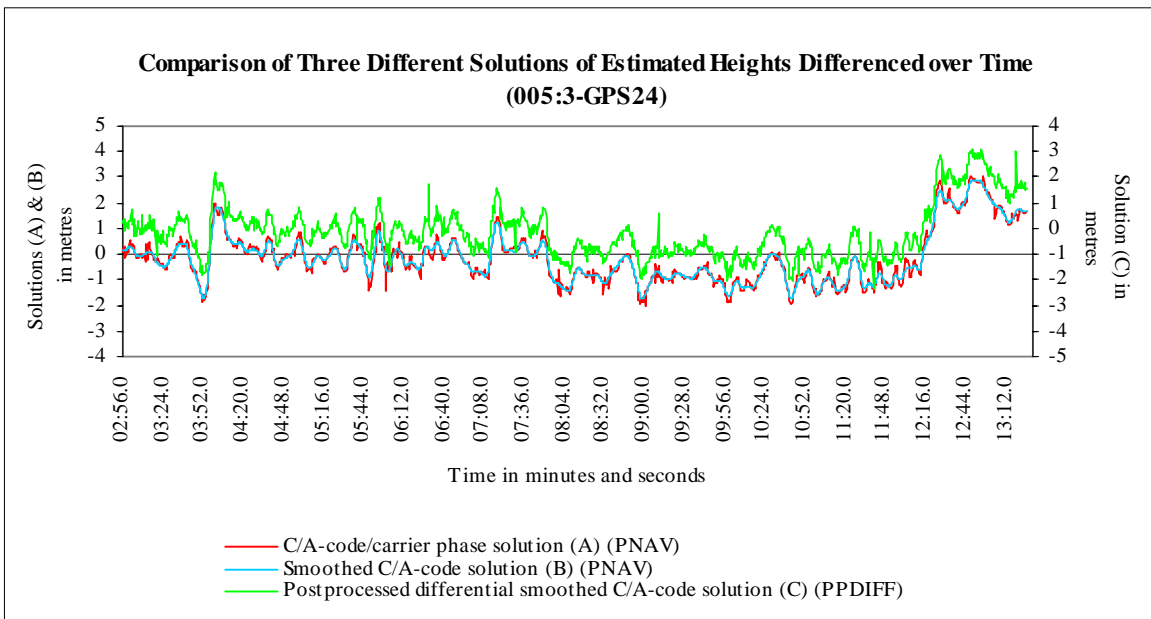


**Figure 1**



**Figure 2**





**Figure 3**

◆ Step 2.:

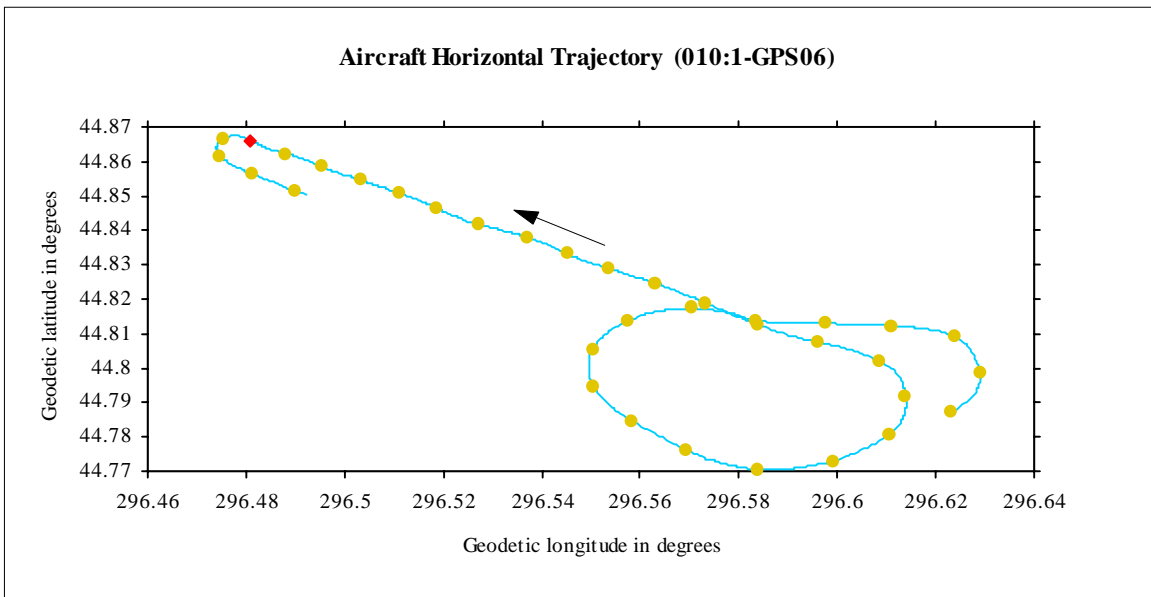
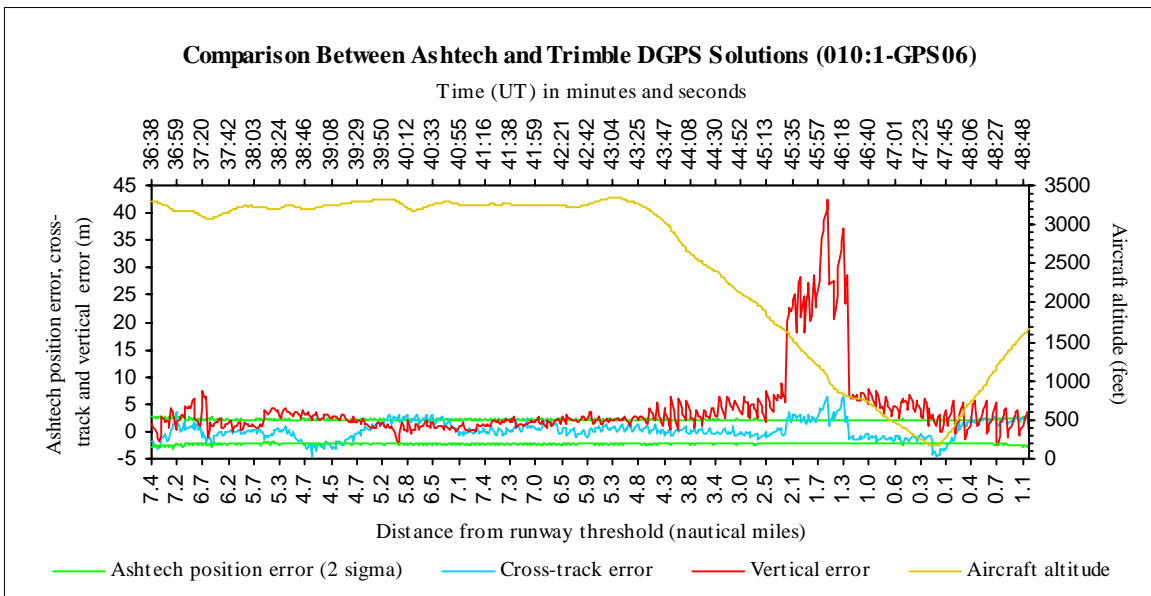
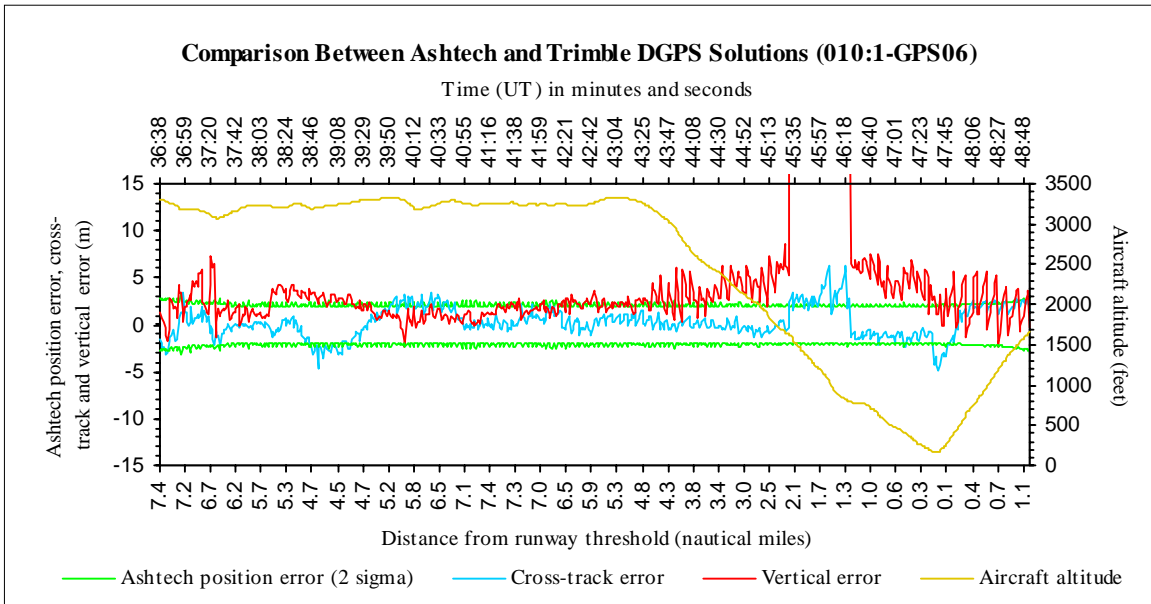
- We used the Ashtech solution as a benchmark against the Trimble DGPS solution.
- Software development that performs the analysis:
  - use aircraft velocity to interpolate aircraft position between epochs,
  - use of geoidal model that accounts for geoidal undulation,
  - use aircraft velocities to compute cross-track error and vertical error.

**Figures 4 & 5 :** Show examples of the comparisons between the two sensors.

◆ Conclusions from step 2.:

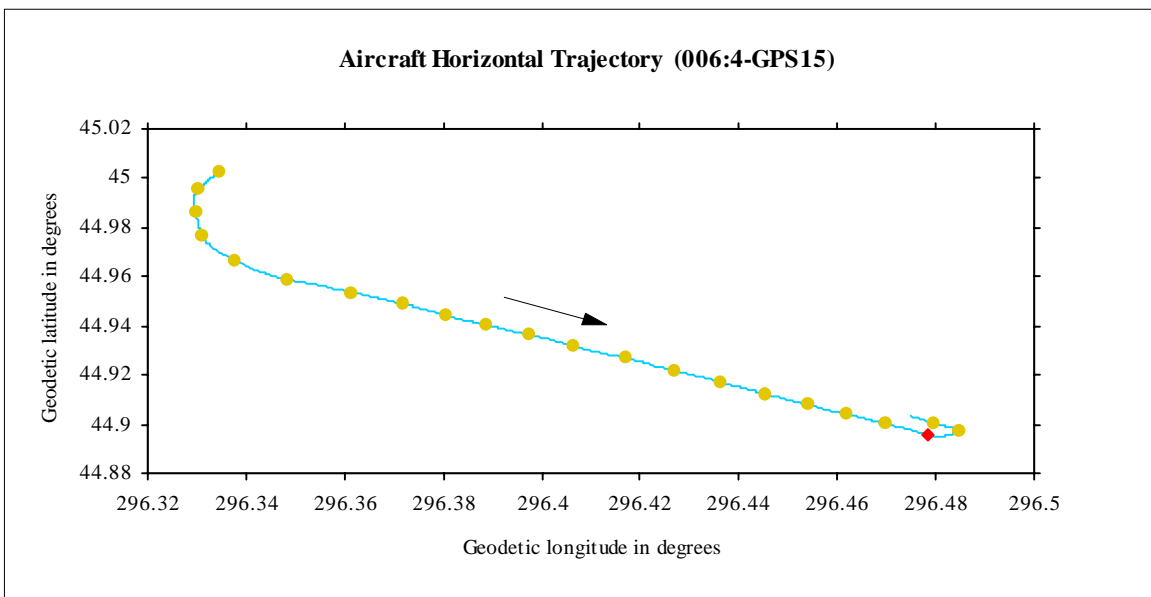
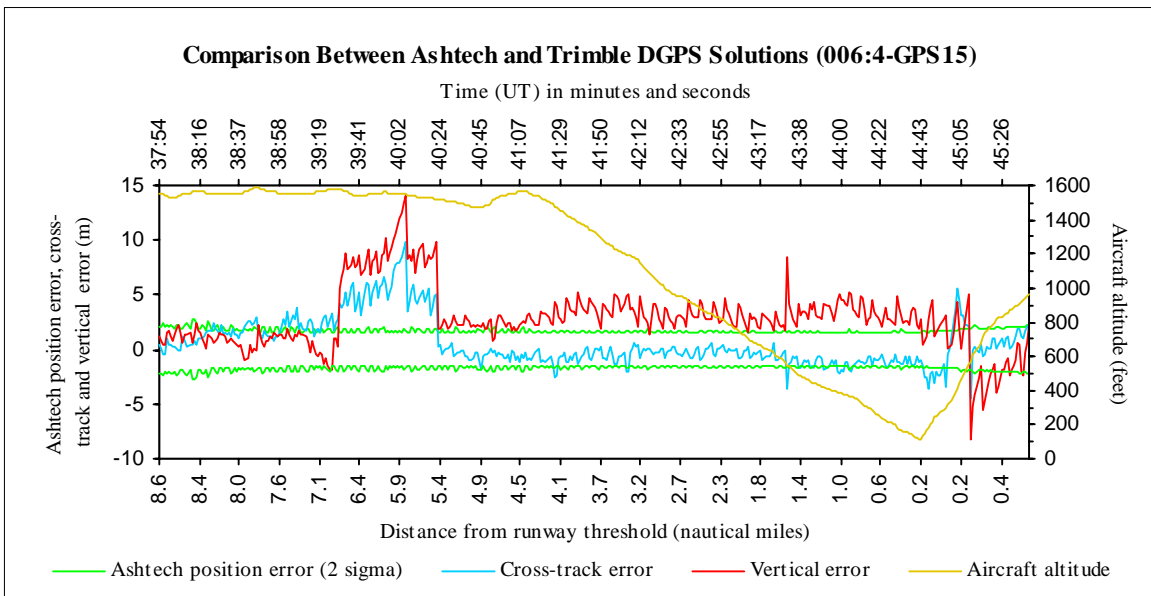
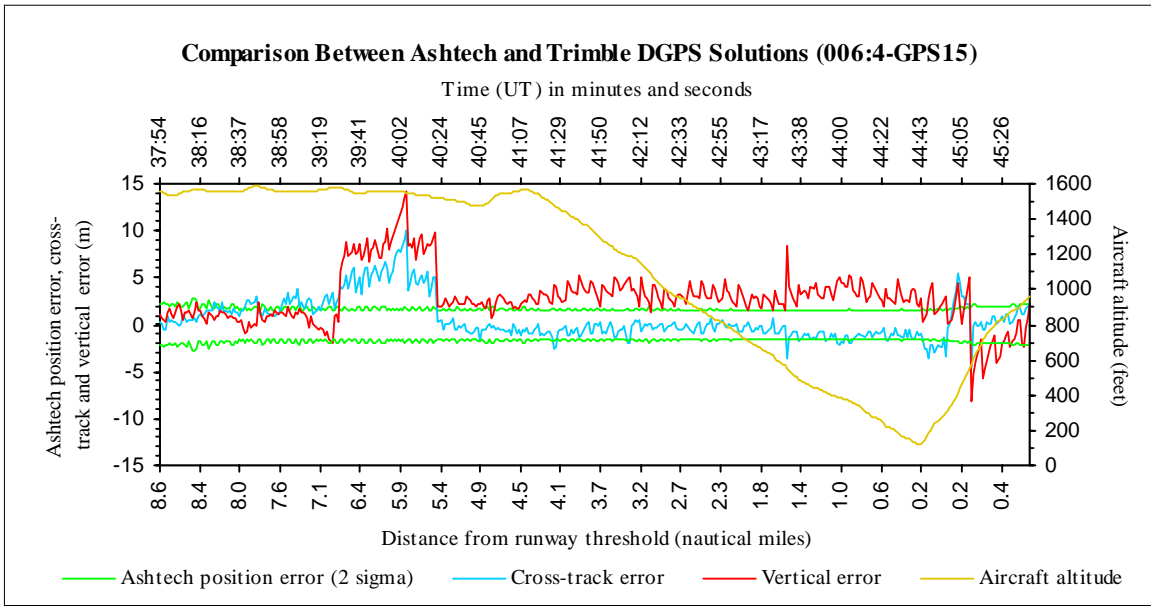
- All 73 approaches were able to be processed.
- Trimble solutions show distinct jumps both in cross-track and vertical sense which could be due to:
  - sudden change in the # of satellites tracked,
  - delay in airborne receiver solution updates.

# Runway Threshold Approach 010:1-GPS06



**Figure 4**

# Runway Threshold Approach 006:4-GPS15



**Figure 5**

◆ **Step 3.:** - A.) Analysis of the whole data set.

- We computed the means & standard deviations of cross-track & vertical errors for all data (**Fig. 6&7**).

- B.) Setting up categories to develop further statistics.

- We also investigated several categories of approaches:

- 3 & 6 degree glidepath approaches,

- 200 & 100 ft decision height approaches,

- missed approaches (landing, left-right, straight),

- 50&70 knot approaches.

- We looked at the data before & after the Trimble airborne receiver firmware modifications.

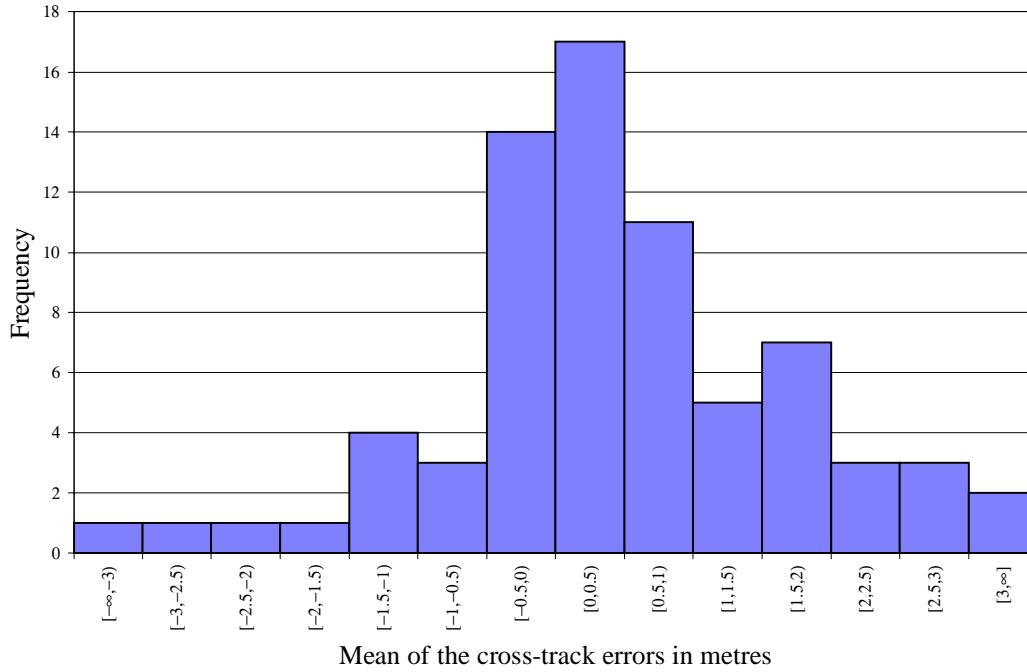
- We treated: 1. all the data collected, 2. all data except 3 approaches which needed to be eliminated due to bad quality of Ashtech “ground truth” solution.

**Figure 8:** as an example shows cross-track error statistics for 3 & 6 degree glidepath approaches.

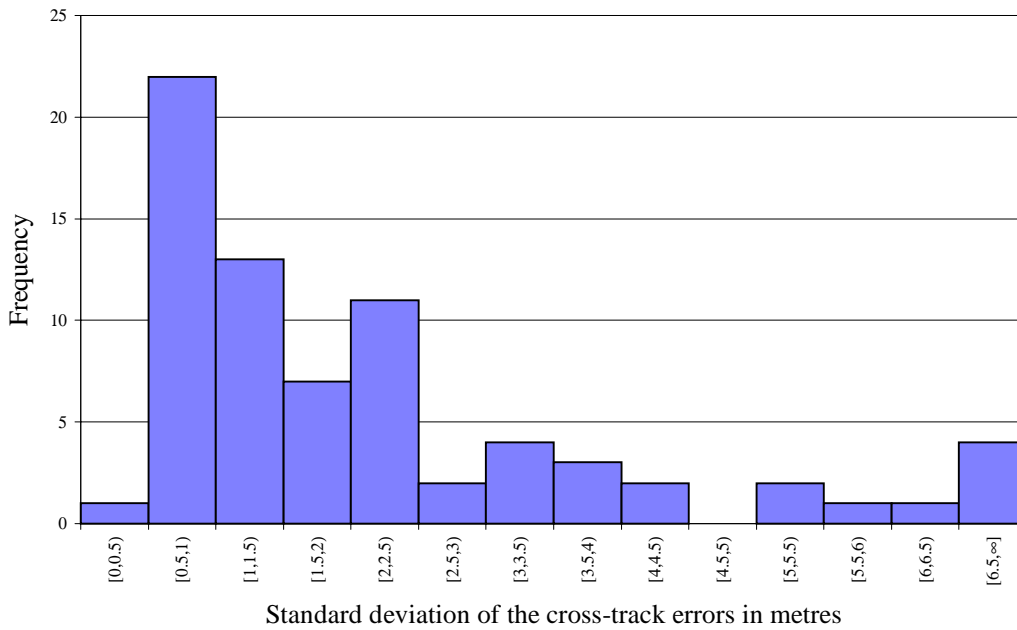
**Figure 9:** shows vertical error statistics for 3 & 6 degree glidepath approaches.



### Mean of the Cross-track Errors for All 73 Approaches

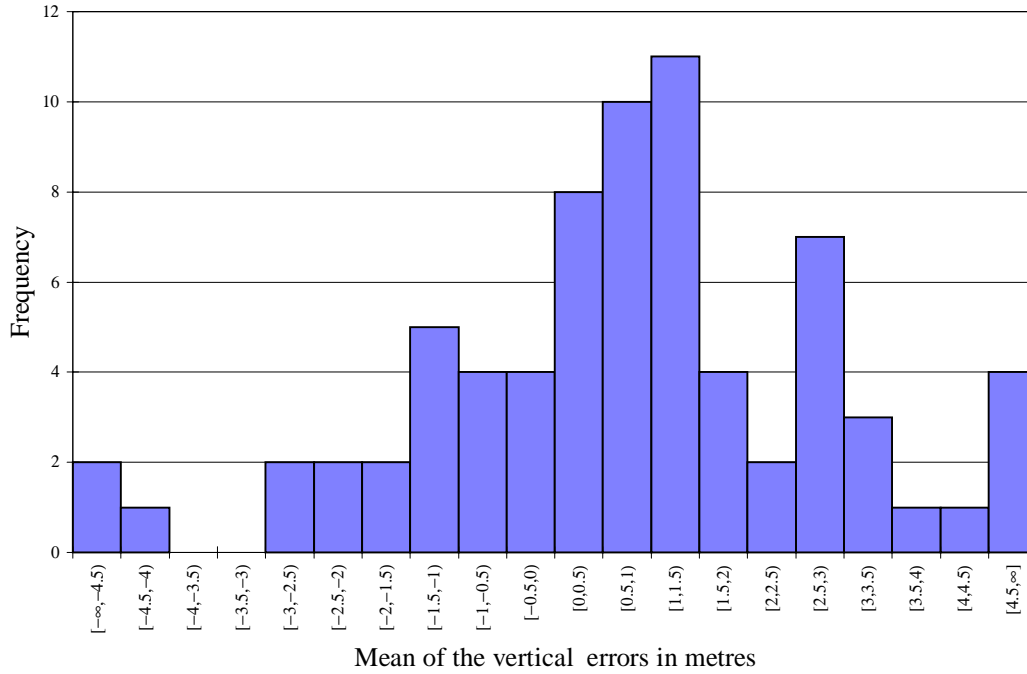


### Standard Deviation of the Cross-track Errors for All 73 Approaches

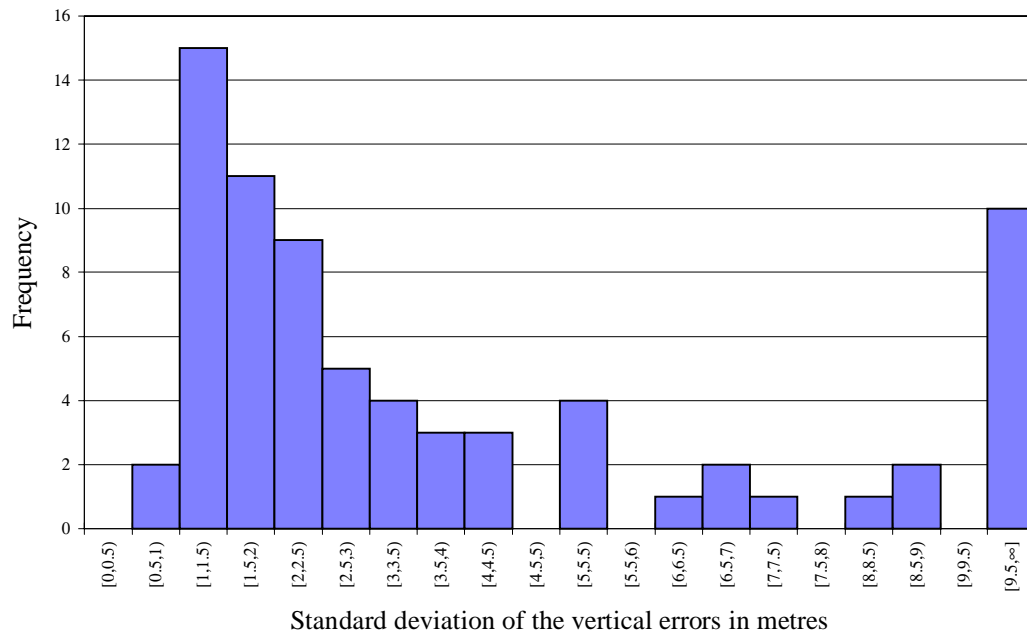


**Figure 6**

### Mean of the Vertical Errors for All 73 Approaches

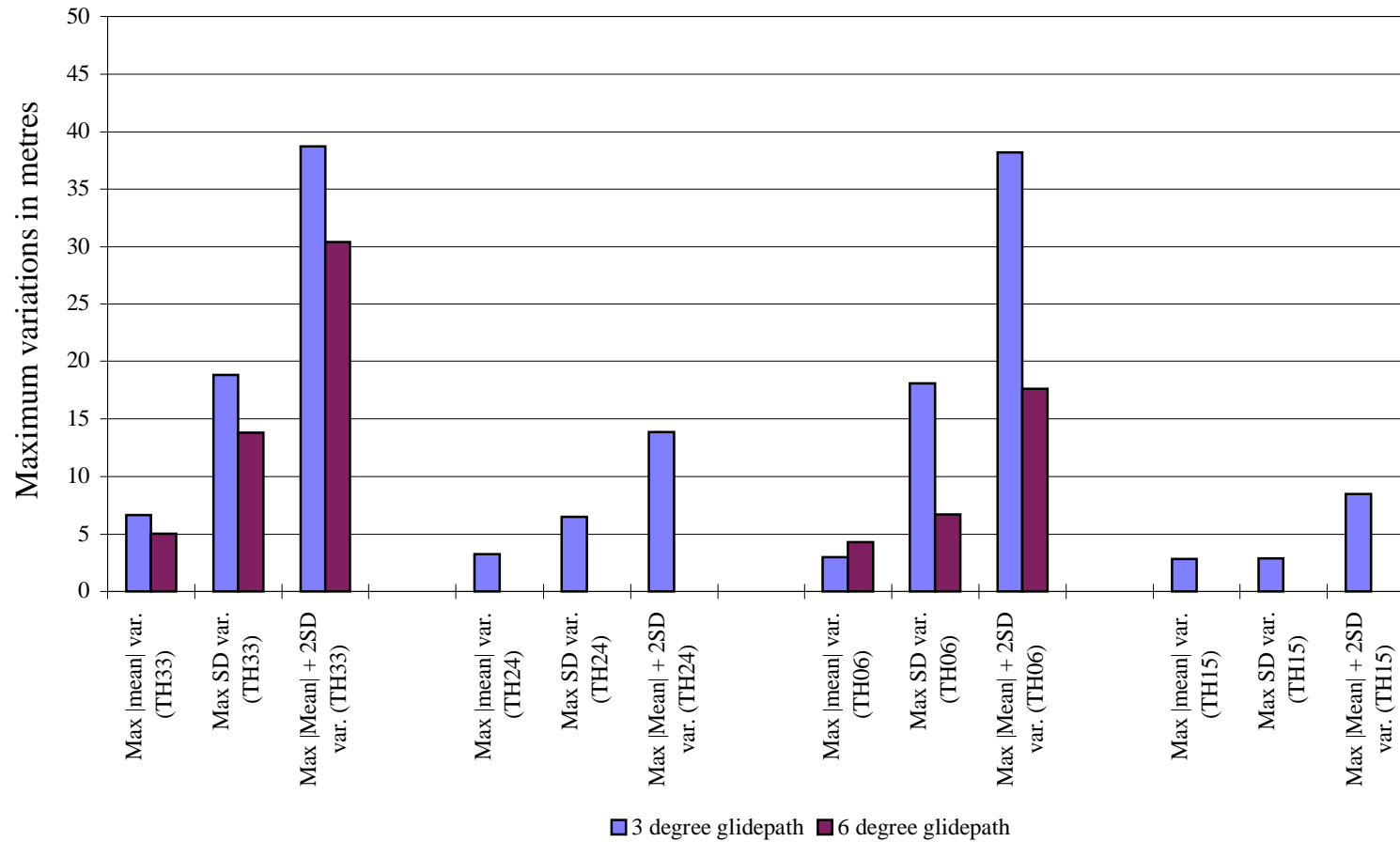


### Standard Deviation of the Vertical Errors for All 73 Approaches



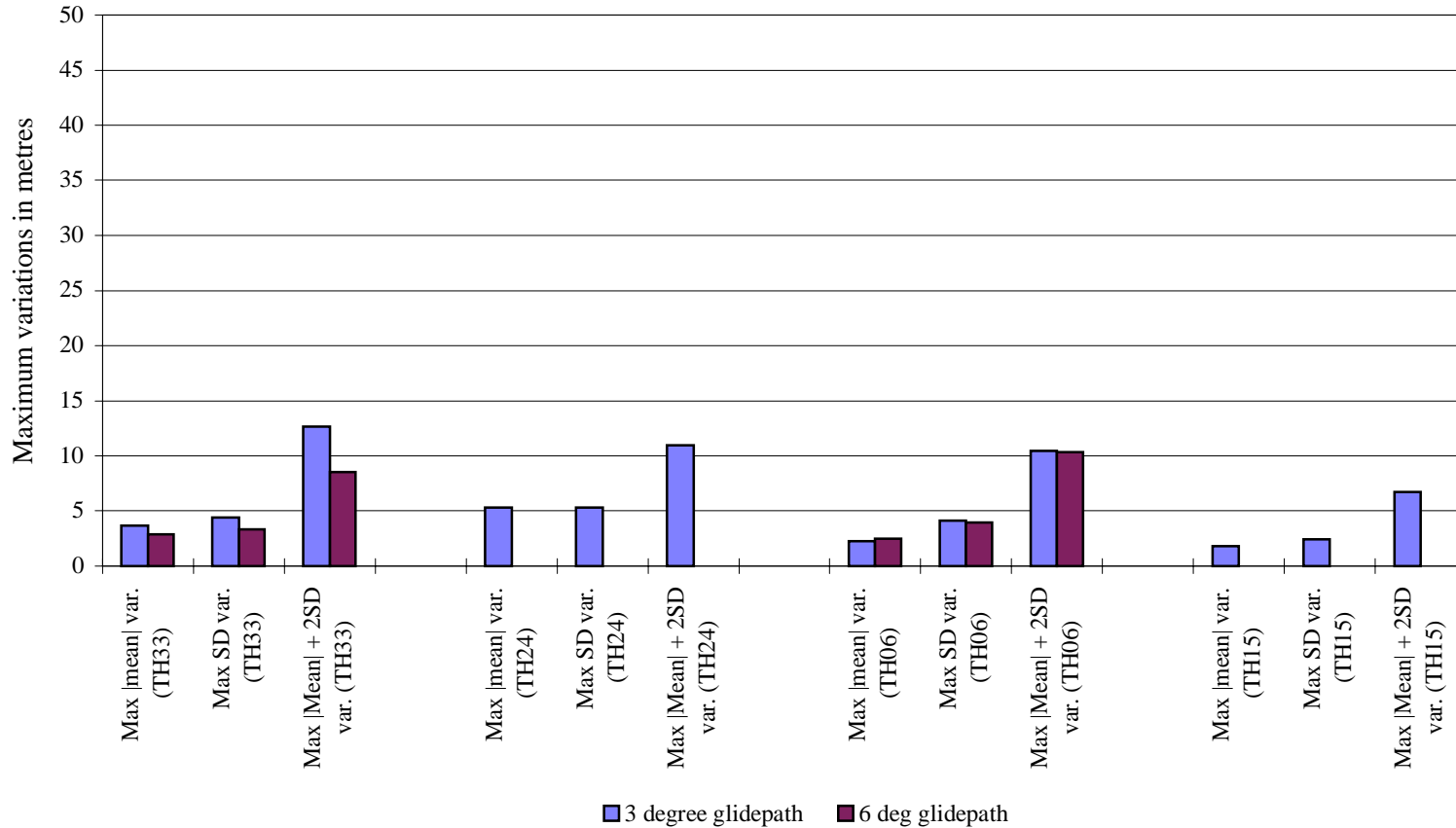
**Figure 7**

## Vertical Errors for 3&6 Degree Glidepath Approaches Prior to the Software Modifications (4 Approaches Eliminated)



**Figure 8**

## Cross-track Errors for 3&6 Degree Glidepath Approaches Prior to Software Modifications (4 Approaches Eliminated)



**Figure 9**

- C.) Investigating categories in 0.1 nm increments from the threshold:
  - 3 & 6 degree glidepath approaches,
  - 200 & 100 ft decision height approaches,
  - 50&70 knot approaches.

**Figure 10:** example of *horizontal* error bars for 3 degree glidepath approaches prior to firmware modifications.

**Figure 11:** example of *vertical* error bars for 3 degree glidepath approaches prior to firmware modifications.

## Analysis of results

- A.) Investigating all data without categorizing them

Mean of the cross-track errors	17 approaches (23%) fall into the bin size ranging from 0.0 to 0.5 metres
	42 approaches (58%) fall into the bin size ranging from -0.5 to 1.0 metres
Standard deviation of the cross-track errors	22 approaches (30%) fall into the bin size ranging from 0.5 to 1.0 metres
	35 approaches (48%) fall into the bin size ranging from 0.5 to 1.5 metres
Mean of the vertical errors	11 approaches (15%) fall into the bin size ranging from 1.0 to 1.5 metres
	29 approaches (40%) fall into the bin size ranging from 0.0 to 1.5 metres
Standard deviation of the vertical errors	15 approaches (21%) fall into the bin size ranging from 1.0 to 1.5 metres
	35 approaches (48%) fall into the bin size ranging from 1.0 to 2.5 metres



### Cross-track Errors (2 Sigma) for 3 Degree Glidepath Approaches Prior to Receiver Software Modifications (TH06)

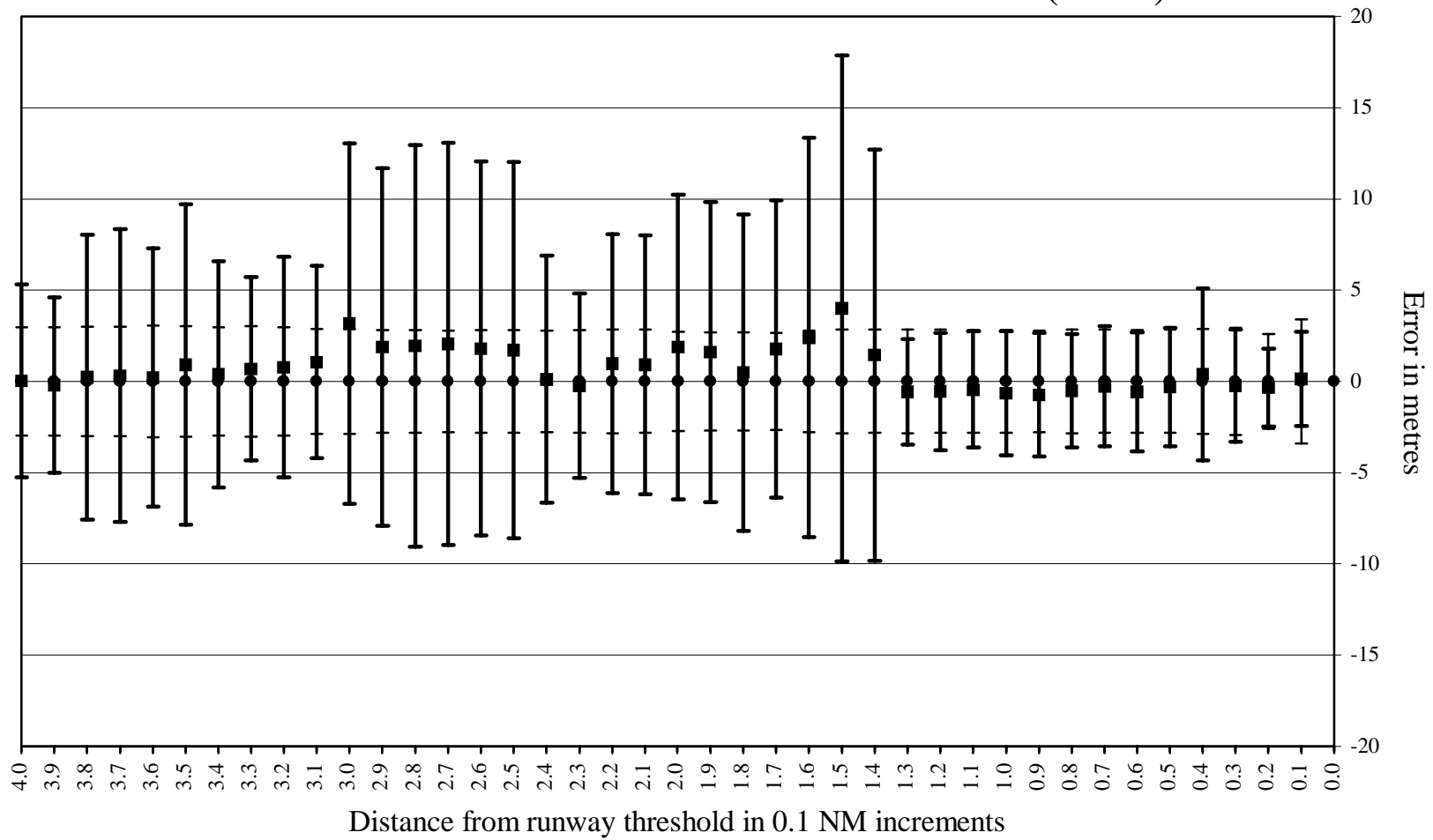
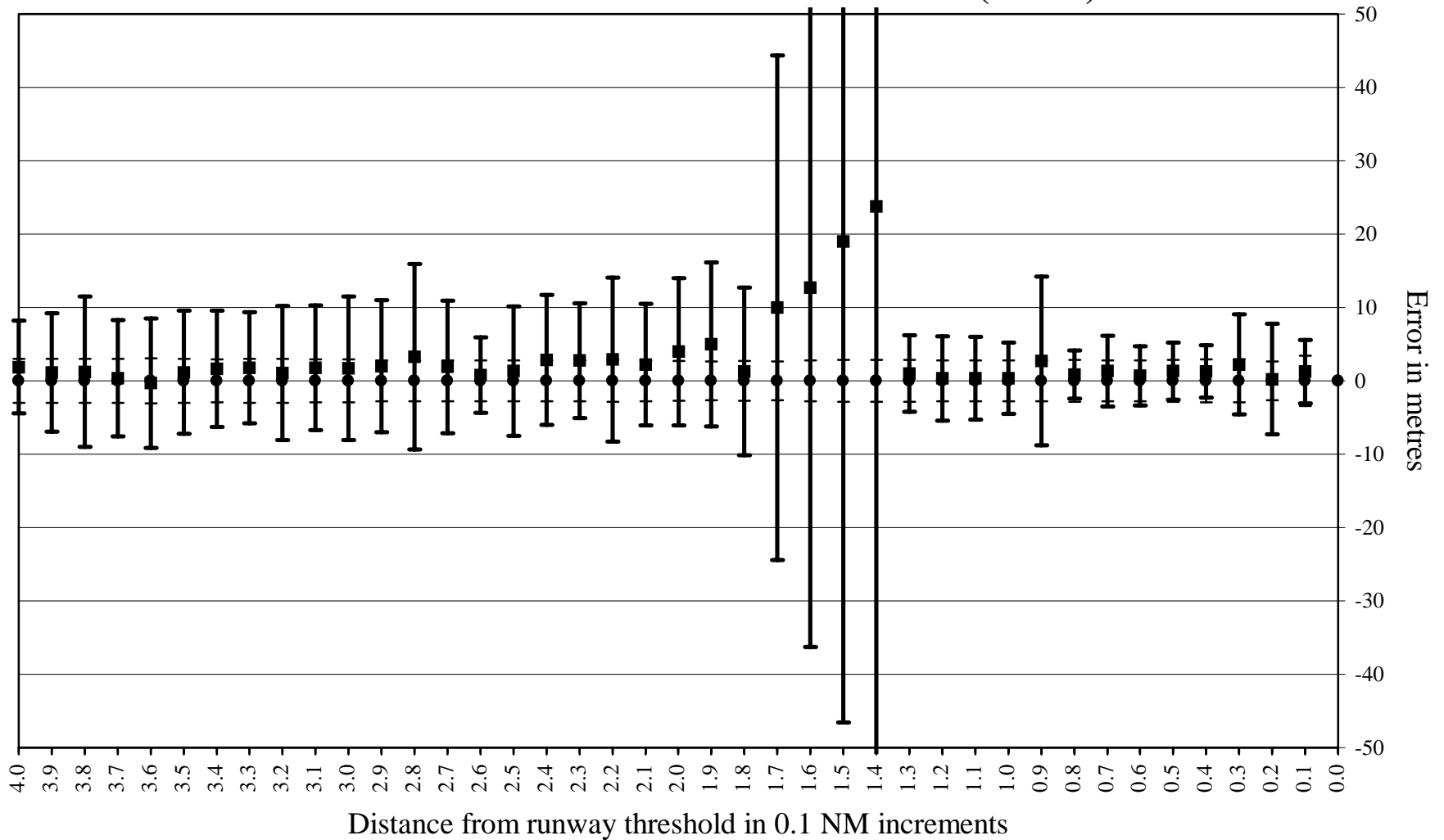


Figure 10

## Vertical Errors (2 sigma) for 3 Degree Glidepath Approaches Prior to Receiver Software Modifications (TH06)



Distance from runway threshold in 0.1 NM increments

Figure 11

- **B.)** Investigating the categories and looking at *maximum mean variation*, *maximum standard deviation variation* and *maximum |mean| + 2sigma variation* (all data, all data minus 4 approaches).

**Figure 12:** shows the three statistics of horizontal errors for the four thresholds, 6 categories, prior to and after the firmware modifications.

**Figure 13:** shows the three statistics of vertical errors for the four thresholds, 6 categories, prior to and after the receiver firmware modifications.

- **C.)** Investigating the categories in 0.1 nm increments from the threshold (all data minus 4 approaches).

**Figure 14:** shows the horizontal error statistics to compare the individual categories, thresholds, prior to and after receiver firmware modification.

**Figure 15:** shows the vertical error statistics to compare the individual categories, thresholds, prior to and after receiver firmware modification.

<b>CROSS-TRACK ERRORS (ALL DATA USED) UNITS IN METRES [MIN,MAX]</b>												
<b>Approaches prior to the receiver software modifications</b>												
<b>Thresholds/ Type of approach</b>	<b>TH33</b>			<b>TH24</b>			<b>TH06</b>			<b>TH15</b>		
	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.
<b>3 deg glidepath</b>	[-0.32,3.65]	[0.47,4.42]	[1.26,12.49]	[-2.69,0.63]	[0.53,15.08]	[1.27,32.85]	[-2.17,2.23]	[0.62,10.34]	[1.75,20.99]	[0.62,1.83]	[2.21,2.46]	[5.04,6.75]
<b>6 deg glidepath</b>	[-0.02,2.86]	[0.97,3.33]	[2.12,8.50]				[-0.86,2.49]	[0.72,3.97]	[1.7,10.43]			
<b>DH 200</b>	[-0.32,3.65]	[0.47,4.42]	[1.26,12.49]	[-2.69,0.63]	[0.53,15.08]	[1.27,32.85]	[-2.17,2.49]	[0.62,10.34]	[2.44,20.99]	[0.62,1.83]	[2.21,2.46]	[5.04,6.75]
<b>DH 100</b>	[1.32,2.86]	[1.9,3.33]	[5.46,8.5]									
<b>Missed approach: landing</b>	[-0.02,2.86]	[1.67,3.34]	[3.77,8.5]	[0.37]	[1.36]	[3.09]	[-1.20,1.62]	[0.62,0.88]	[2.44,3.88]			
<b>Missed approach: left-right</b>	[0.18,0.76]	[0.83,2.28]	[2.42,5.31]	[-0.35,-0.25]	[1.6,5.31]	[3.45,10.97]	[-1.2]	[1.41]	[4.02]			
<b>Missed approach: straight-180 deg</b>	[1.57,1.73]	[1.48,2.07]	[4.69,5.71]	[-0.03]	[1.02]	[2.07]	[-2.17,2.49]	[0.72,10.34]	[1.7,20.99]	[0.62]	[2.21]	[5.04]
<b>50 knots</b>	[-0.02,2.53]	[0.83,3.33]	[2.42,8.5]				[-1.36,2.49]	[0.72,3.55]	[2.8,9.59]			
<b>60 knots</b>							[-2.17,-0.86]	[0.8,0.88]	[2.46,3.18]			
<b>70 knots</b>	[1.32]	[2.08]	[5.48]				[0.26,2.23]	[1.64,10.34]	[3.54,20.99]			
<b>80 knots</b>	[2.86]	[2.51]	[7.88]				[-1.2]	[0.62]	[2.44]			
<b>90 knots</b>				[-0.88]	[0.55]	[1.98]						
<b>120 knots</b>	[1.73]	[1.48]	[4.69]									
<b>Approaches after the receiver software modifications</b>												
<b>Thresholds/ Type of approach</b>	<b>TH33</b>			<b>TH24</b>			<b>TH06</b>			<b>TH15</b>		
	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.
<b>3 deg glidepath</b>	[0.15,1.9]	[0.66,2.42]	[1.47,6.74]	[-0.15,1.32]	[2.23,6.3]	[4.61,13.92]	[-0.39,1.62]	[0.76,15.81]	[3.07,35.61]	[-0.03,2.91]	[1.29,7.56]	[2.61,18.03]
<b>6 deg glidepath</b>	[-0.59,0.66]	[0.58,0.86]	[1.21,2.38]				[-0.19,5.40]	[0.80,5.95]	[2.04,17.3]			
<b>DH 200</b>	[-0.15,0.66]	[0.66,0.86]	[1.47,2.38]				[-0.19,5.4]	[0.91,5.95]	[2.95,17.3]			
<b>DH 100</b>	[-0.59,1.9]	[0.58,2.42]	[1.21,4.9]				[-3.99,0.95]	[0.76,15.81]	[2.36,35.61]			
<b>Missed approach: landing</b>	[-0.05,0.66]	[0.58,0.86]	[1.75,2.38]	[0.19]	[5.16]	[10.51]	[-3.99,0.78]	[0.76,15.81]	[2.39,35.61]			
<b>Missed approach: left-right</b>							[0.40]	[0.98]	[2.36]	[-0.19,-0.03]	[1.29,2.05]	[2.61,4.29]
<b>Missed approach: straight&amp;180 deg</b>	[-0.59,1.9]	[0.66,2.42]	[1.91,4.9]	[-0.15,-0.03]	[2.23,6.3]	[4.61,13.92]	[0.17,1.62]	[0.8,1.78]	[2.04,4.02]			
<b>50 knots</b>	[-0.15]	[0.66]	[1.47]				[0.17,1.49]	[0.8,2.32]	[2.04,4.83]			
<b>60 knots</b>	[-0.59,-0.05]	[0.58,0.80]	[1.21,2.19]				[0.77,0.78]	[1.09,1.88]	[2.95,4.54]			
<b>70 knots</b>	[0.06,1.09]	[0.77,2.42]	[3.44,4.9]	[-0.15,0.19]	[2.23,5.16]	[4.61,10.51]	[[0.07,5.4]	[0.91,5.95]	[2.95,17.3]	[-0.19,2.91]	[1.29,7.56]	[2.61,18.03]
<b>80 knots</b>				[1.32]	[6.3]	[13.92]	[-3.99,0.75]	[1.09,15.81]	[3.25,35.61]			
<b>90 knots</b>							[-1.55]	[0.76]	[3.07]			
<b>DH 50</b>				[0.19,1.32]	[5.16,6.3]	[10.51,13.92]				[-0.19,2.91]	[1.29,7.56]	[2.61,18.03]
<b>DH 150</b>							[1.49]	[0.9]	[3.29]			
<b>65 knots</b>	[0.66]	[0.86]	[2.38]									

Figure 12 .Statistics for cross-track errors of all categories (all data used)

VERTICAL ERRORS (ALL DATA USED) UNITS IN METRES [MIN, MAX]												
Approaches prior to the receiver software modifications												
Thresholds/ Type of approach	TH33			TH24			TH06			TH15		
	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.
<b>3 deg glidepath</b>	[-6.64,2.87]	[1.02,18.8]	[2.55,38.74]	[-0.39,29.86]	[1.11,106.67]	[2.61,243.2]	[-2.93,3.12]	[0.83,18.09]	[4.27,38.22]	[0.98,2.82]	[2.70,2.83]	[6.38,8.48]
<b>6 deg glidepath</b>	[-2.72,5.01]	[1.56,13.84]	[4.34,30.4]				[0.56,7.73]	[1.71,16.03]	[4.12,39.79]			
<b>DH 200</b>	[-6.64,2.87]	[1.02,18.8]	[2.55,38.74]	[-0.94,29.86]	[1.11,106.67]	[2.61,243.2]	[-2.93,7.73]	[0.83,18.09]	[4.27,38.22]	[0.98,2.82]	[2.7,2.83]	[6.38,8.48]
<b>DH 100</b>	[-2.72,5.01]	[4.21,13.84]	[8.6,30.4]									
<b>Missed approach: landing</b>	[-2.72,5.01]	[1.82,18.27]	[4.93,37.92]	[0.94]	[6.48]	[13.9]	[0.56,2.61]	[0.83,1.78]	[4.12,4.27]			
<b>Missed approach: left-right</b>	[-6.64,-1.22]	[1.31,8.88]	[4.39,24.4]	[1.14,3.26]	[1.59,3.23]	[6.44,7.6]	[1.05]	[2.54]	[6.13]			
<b>Missed approach: straight-180 deg</b>	[-4.34,0.18]	[3.5,4.21]	[8.6,11.34]	[1.23]	[1.31]	[3.85]	[0.33,4.29]	[2.06,18.09]	[4.45,38.22]	[2.82]	[2.83]	[8.48]
<b>50 knots</b>	[-2.72,0.18]	[1.38,18.27]	[4.39,37.92]				[0.33,7.73]	[1.78,16.03]	[4.12,39.79]			
<b>60 knots</b>							[2.67,3.07]	[1.71,2.23]	[6.49,7.13]			
<b>70 knots</b>	[0.87]	[8.08]	[17.03]				[2.04,4.29]	[3.43,18.09]	[9.98,38.22]			
<b>80 knots</b>	[5.01]	[10.01]	[25.03]				[2.61]	[0.83]	[4.27]			
<b>90 knots</b>				[0.12]	[1.43]	[2.98]						
<b>120 knots</b>	[-4.34]	[3.5]	[11.34]									
Approaches after the receiver software modifications												
Thresholds/ Type of approach	TH33			TH24			TH06			TH15		
	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.	Max mean var.	Max s.d. var.	Max  mean  + 2s.d. var.
<b>3 deg glidepath</b>	[0.17,0.37]	[1.14,2.48]	[2.55,5.33]	[-0.24,1.43]	[1.77,7.12]	[4.76,8.64]	[-4.56,3.83]	[0.92,11.11]	[2.72,26.78]	[0.75,16.13]	[1.1,29.62]	[2.95,75.37]
<b>6 deg glidepath</b>	[-1.44,1.9]	[1.16,2.1]	[3.07,5.64]				[-2.03,2.79]	[1.15,43.5]	[3.48,89.79]			
<b>DH 200</b>	[-1.44,0.17]	[1.45,2.1]	[3.07,4.37]				[-4.56,2.75]	[1.06,11.11]	[2.46,26.78]			
<b>DH 100</b>	[-0.25,1.9]	[1.14,2.48]	[2.55,5.33]				[-1.91,3.83]	[0.92,43.5]	[2.72,89.79]			
<b>Missed approach: landing</b>	[-1.44,1.9]	[1.16,2.1]	[4.22,5.64]	[1.43]	[7.12]	[15.67]	[-4.5,3.83]	[0.92,43.5]	[2.72,89.79]			
<b>Missed approach: left-right</b>							[1.27]	[2.09]	[5.45]	[0.29,0.75]	[1.1,3.29]	[2.95,6.87]
<b>Missed approach: straight&amp;180 deg</b>	[-0.25,0.27]	[1.14,2.48]	[2.55,5.33]	[-0.24,1.22]	[1.77,4.2]	[4.76,8.64]	[-2.03,1.74]	[1.38,6.61]	[2.46,13.26]			
<b>50 knots</b>	[0.17]	[1.45]	[3.07]				[-1.09,1.72]	[1.15,3.8]	[4.02,8.33]			
<b>60 knots</b>	[-0.25,1.9]	[1.16,1.41]	[3.07,4.22]				[-4.56,0.04]	[6.61,11.11]	[13.26,26.78]			
<b>70 knots</b>	[0.27,0.37]	[1.14,2.48]	[2.55,5.33]	[1.22,1.43]	[1.77,7.12]	[4.76,15.67]	[-2.03,2.79]	[1.29,43.5]	[4.49,89.79]	[0.29,16.13]	[1.1,29.62]	[2.95,75.37]
<b>80 knots</b>				[-0.24]	[4.2]	[8.64]	[-0.34,3.83]	[1.06,1.55]	[2.46,6.93]			
<b>90 knots</b>							[0.88]	[0.92]	[2.72]			
<b>DH 50</b>				[-0.24,1.43]	[4.2,7.12]	[8.64,15.67]				[0.29,16.13]	[1.1,29.62]	[2.95,75.37]
<b>DH 150</b>							[-.72]	[1.38]	[3.48]			
<b>65 knots</b>	[-1.44]	[2.1]	[5.64]									

Figure 13. Statistics for vertical errors of all categories (all data used)



CROSS-TRACK ERROR STATISTICS IN METRES																				
Approaches prior to the receiver software modifications																				
Thresholds/ Type of approach	TH33				TH24				TH06				TH15				All Thresholds			
	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches
<b>3 deg glidepath</b>	1.38	4.17	14.22	10	-0.19	3.43	10.88	10	0.69	6.59	13.86	8	0.54	3.68	7.41	2	0.61	4.47	14.22	30
<b>6 deg glidepath</b>	2.06	3.38	15.67	7					0.92	4.68	18.76	6					1.49	4.03	18.76	13
<b>DH 200</b>	1.27	4.25	15.19	11	-0.14	3.60	12.30	9	0.62	6.29	12.86	15	0.54	3.68	7.41	2	0.57	4.45	15.19	37
<b>DH 100</b>	2.32	3.49	16.45	6													2.32	3.49	16.45	6
<b>50 knots</b>	1.45	2.66	15.87	8					1.57	4.30	18.76	4					1.51	3.48	18.76	12
<b>70 knots</b>	1.80			1					1.89	5.38	18.07	3					1.84	5.38	18.07	4
Approaches after the receiver software modifications																				
Thresholds/ Type of approach	TH33				TH24				TH06				TH15				All Thresholds			
	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches
<b>3 deg glidepath</b>	0.38	2.50	15.20	3	-1.45	6.86	24.50	3	0.66	4.00	11.08	6	-0.05	1.81	6.26	3	<b>-0.11</b>	3.79	24.50	15
<b>6 deg glidepath</b>	0.14	1.76	5.35	3					0.65	2.04	3.57	11					0.40	<b>1.90</b>	<b>5.35</b>	14
<b>DH 200</b>	0.22	1.75	4.08	2					1.00	3.00	8.83	8					0.61	<b>2.38</b>	<b>8.83</b>	10
<b>DH 100</b>	0.22	2.34	14.23	4					0.17	2.45	3.35	8					<b>0.20</b>	2.40	14.23	12
<b>50 knots</b>	-0.37			1					0.52	2.10	3.76	6					<b>0.08</b>	<b>2.10</b>	<b>3.76</b>	7
<b>70 knots</b>	1.36	2.80	4.47	2					1.05	3.08	10.34	6	-0.05	1.81	6.26	3	0.79	2.56	10.34	11

Figure 14. Statistics for cross-track errors of 6 categories using readings sampled at 0.1 NM increments

VERTICAL ERROR STATISTICS IN METRES																				
Approaches prior to the receiver software modifications																				
Thresholds/ Type of approach	TH33				TH24				TH06				TH15				All Thresholds			
	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches
3 deg glidepath	-0.65	13.58	74.16	10	1.11	5.24	27.68	10	3.08	13.07	96.67	8	2.28	3.91	14.11	2	1.46	8.95	96.67	30
6 deg glidepath	0.77	12.73	66.50	7					2.87	10.41	36.66	6					1.82	11.57	66.50	13
DH 200	-0.64	13.79	70.84	11	1.16	5.45	3.91	9	2.32	11.83	66.86	15	2.28	3.91	14.11	2	1.28	8.75	70.84	37
DH 100	0.82	13.97	73.29	6													0.82	13.97	73.29	6
50 knots	-1.13	8.23	87.22	8					0.40	4.02	16.72	4					-0.37	6.13	87.22	12
70 knots	2.25			1					7.98	16.79	113.60	3					5.12	16.79	113.60	4
Approaches after the receiver software modifications																				
Thresholds/ Type of approach	TH33				TH24				TH06				TH15				All Thresholds			
	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches	Average mean	Average 2 s.d.	Max 2 s.d.	Number of approaches
3 deg glidepath	0.39	3.32	15.91	3	0.73	8.51	33.37	3	-0.56	8.16	49.62	6	0.00	2.36	8.18	3	<b>0.14</b>	5.59	49.62	15
6 deg glidepath	-0.67	3.95	10.19	3					0.00	5.85	17.27	11					-0.34	<b>4.90</b>	<b>17.27</b>	14
DH 200	-0.66	4.37	9.64	2					-0.86	9.83	41.78	8					-0.76	7.10	41.78	10
DH 100	0.28	3.12	14.01	4					0.62	3.88	6.66	8					<b>0.45</b>	<b>3.50</b>	<b>14.01</b>	12
50 knots	0.63			1					0.97	3.84	9.32	6					0.80	3.84	<b>9.32</b>	7
70 knots	0.21	1.88	5.56	2					-0.39	5.49	12.99	6	0.00	2.36	8.18	3	<b>-0.06</b>	<b>3.24</b>	12.99	11

Figure 15. Statistics for vertical errors of 6 categories using readings sampled at 0.1 NM increments

## ◆ Conclusions

- Four approaches eliminated (1 for lost VHF link, 3 for inadequate quality of Ashtech “ground truth” data).
- Worse case scenario: in the case of horizontal errors the maximum /mean/+2sigma = 18.0 metres due to jumps in the Trimble positions. Fig.12
- Worse case scenario: in the case of vertical errors the maximum /mean/+2sigma = 89.8 metres due to jumps in the Trimble positions. Fig 13
- There is a marginal improvement in the Trimble positions after the receiver firmware modifications took place (Fig 14 & 15).
- In the case of horizontal errors (Fig 14):
  - 6 degree glidepath app. proved to have performed better than the 3deg,
  - 200 ft decision height app. proved to have performed better than the 100 ft,
  - 50 knot app. proved to have performed better than the 70 knot.
- In the case of vertical errors (Fig 15):
  - comparing 3 and 6 degree app. is inconclusive,
  - 100 ft decision height app. proved to have performed better than the 100 ft,
  - 50 knot app. proved to have performed better than the 70.

- The number of approaches *vary* from category to category. Also, investigation C.) only takes sample every 0.1 nm so it does not contain all data pertaining to a particular approach. Therefore, jumps in positions provided by Trimble are only reflected in investigation A.) and B.) not in C.).

- The accuracy requirements for CAT 1 precision approaches are:

- in horizontal sense 17.0 m at 2 sigma level,
- in vertical sense 7.4 m at 2 sigma level.

- The LDGPS system provided this accuracy for 68 approaches (93%) in horizontal sense but failed to fulfill the vertical requirements for 34 approaches (47%). Why?

- jumps in Trimble solution,
- required vertical accuracy is inherently higher than the horizontal.

◆ **Recommendations:**

- More accurate “ground truth” system is required such as by using Ashtech Z-12s.
- More repeated approaches of the same kind and careful design of approaches are needed.