



Loran C Additional Secondary Factors: Implications for Meeting Required Navigation Performance (RNP) 0.3—An Update

by

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Overview

- Use of locally measured and/or calculated ASF values is key for Loran C to meet accuracy requirements of RNP (0.3)
- Ohio University has been collecting Loran C data at six east coast/mid west airports over the past two years
- Flights are conducted in early spring and late summer seeking to establish patterns for ASF values
- Goal is to verify if a single set of ASF values can serve an entire airport covering all runway approaches



Outline

- Loran-C Signal Propagation
- ASF Measurement System
- ASF* Derivation
- Required Navigation Performance
- Flight Test Results
- Summary and Conclusion



Loran C Signal Propagation

- “Primary” factor (PF) is signal delay through the atmosphere as compared to a vacuum
- “Secondary” factor (SF) is signal delay over seawater
- “Additional” secondary factor (ASF) accounts for additional delays over terrain due to ground conductivity (moisture/temperature dependent)
- ASFs contribute largest positional errors for Loran and their incorporation is essential for local accuracy

ASF Measurement System



- 2 SatMates (E and H-field)
- 12 channel GPS/WAAS
- Notebook PC with ASF software utility for rapid on-site ASF calculation
- Flashcard for easy data storage and transfer to the aircraft receiver
- UPS/ruggedized unit for field use

ASF* Derivation

- Collect ~ 1 hour Loran and GPS data at airport site
- ASF software utility generates local ASF* values
 - TOAs are measured using Loran C receiver clock locked to a composite frequency derived from all stations being tracked
 - Measured TOAs are differenced from TOAs calculated using GPS-derived position and the PF and SF yielding AFS*
 - ASF* contains UTC offset, receiver delays
 - Common receivers (ground/air) are used to account for the receiver delays
 - Loran C system is well managed and UTC offsets within the system remain reasonably constant over time
- Second utility reads ASF* values and burns flashcard
- Flashcard is used to initialize aircraft Loran C receiver

ASF System in Operation

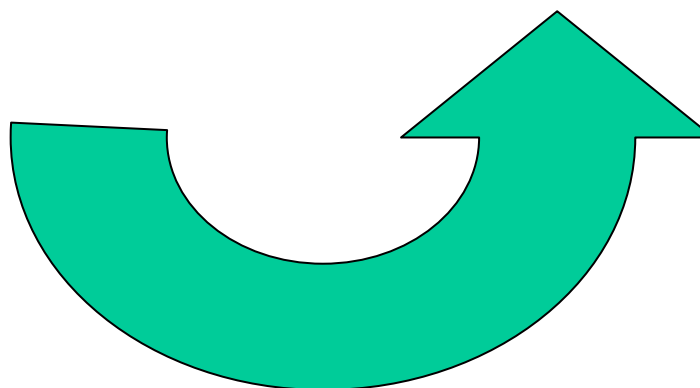


- ASF Measurement System
- Tripod holds GPS, E-field and H-field Loran antennas
- Shown here in operation at Jacksonville, Florida
 - Craig Municipal Airport

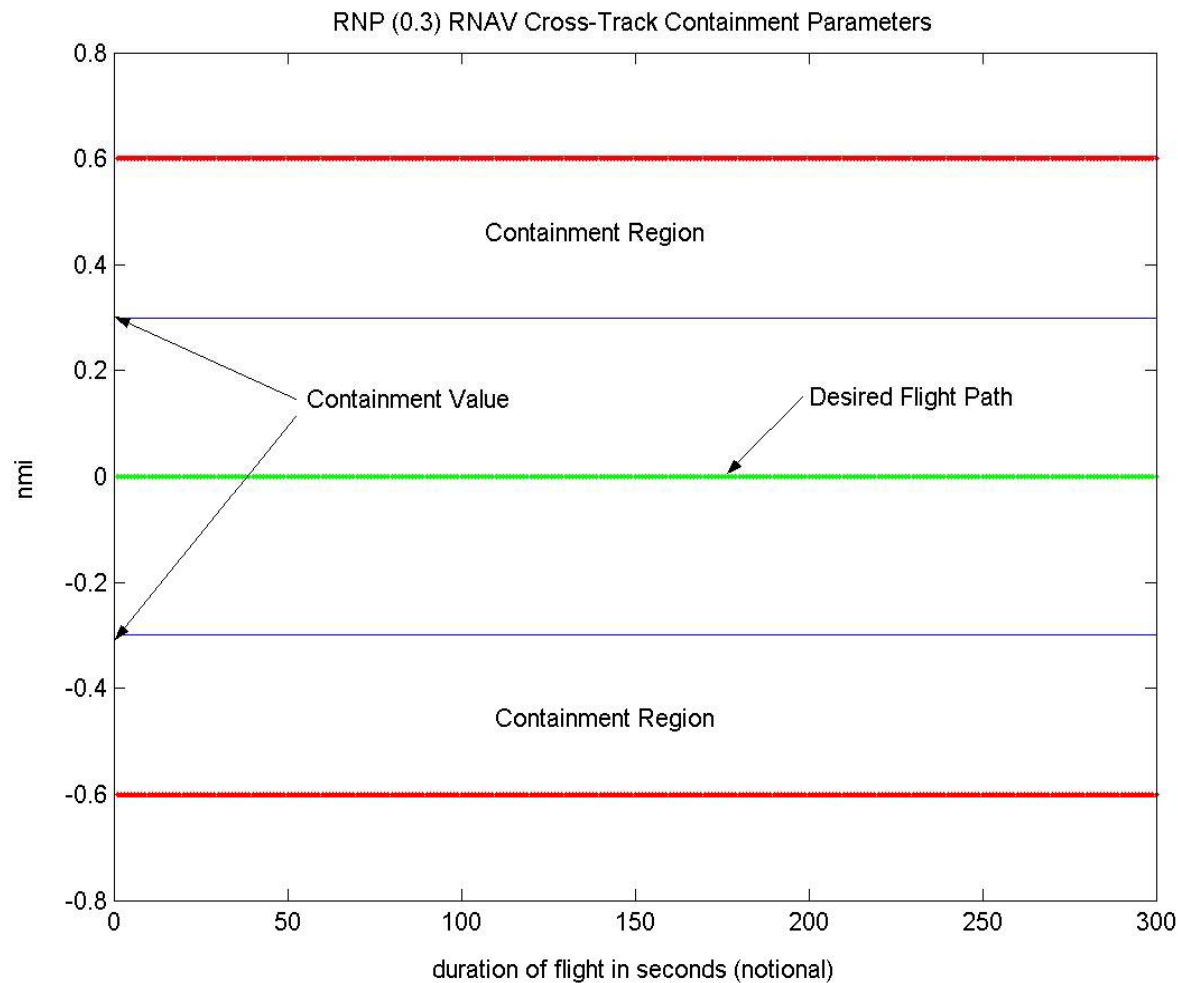
Example ASF* File for an Airport

Typical ASF* values:

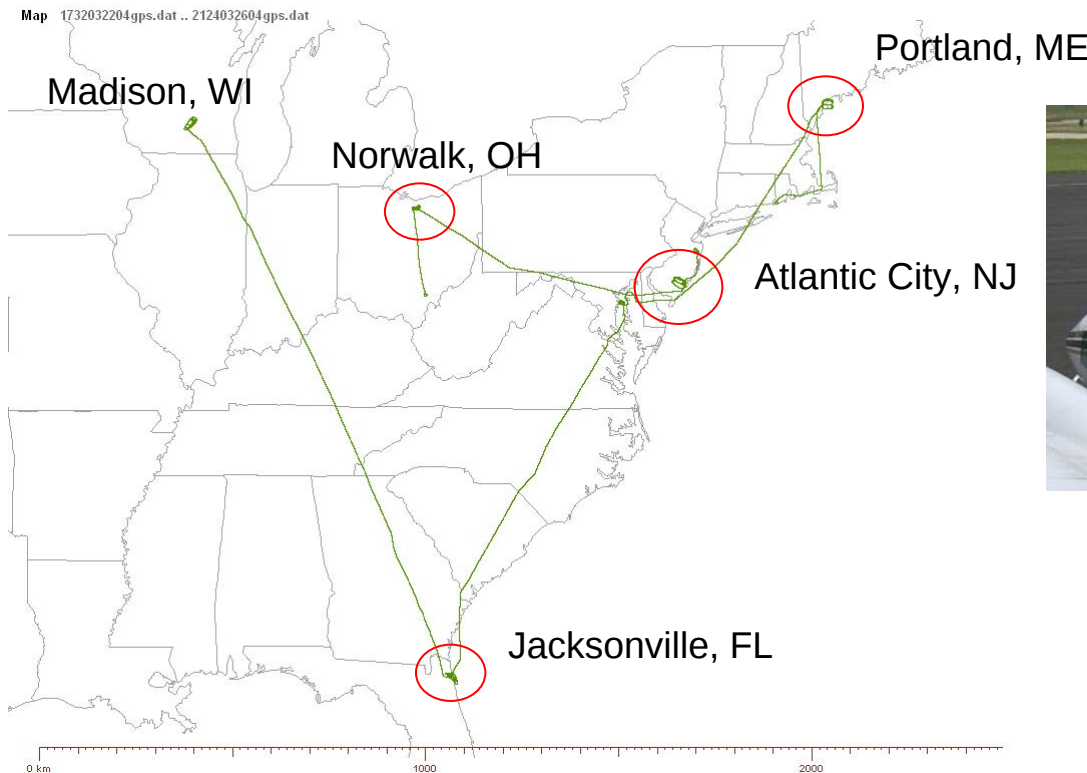
#ASF 8970M -0.906us [13500]
#ASF 8970X 0.429us [13498]
#ASF 8970Y 0.685us [13500]
#ASF 9960M 0.39us [13500]
#ASF 9960W 27.5us [8]
#ASF 9960Z -0.83us [13500]
#ASF 9960X 2.18us [13314]
#ASF 8970W 2.88us [13486]
#ASF 7980M -0.589us [13456]
#ASF 7980W -1.4us [13470]
#ASF 8970Z 0.118us [13468]
#ASF 7980Z -0.271us [13444]
#ASF 8290M 0.324us [13450]
#ASF 8290W 0.665us [13456]
#ASF 8290X 0.24us [13364]
#ASF 9610X 0.495us [12358]
#ASF 9610Y 0.523us [11932]
#ASF 9960Y 2.56us [13220]
#ASF 9610M -1.49us [13064]
#ASF 9610V -0.846us [13064]
#ASF 9610Z 0.261us [13064]
#ASF 7980X -0.544us [11690]
#ASF 7980Y 0.799us [6610]



Required Navigation Performance (RNP) 0.3 (From RTCA DO-236B)



Flight Tests From March 2004



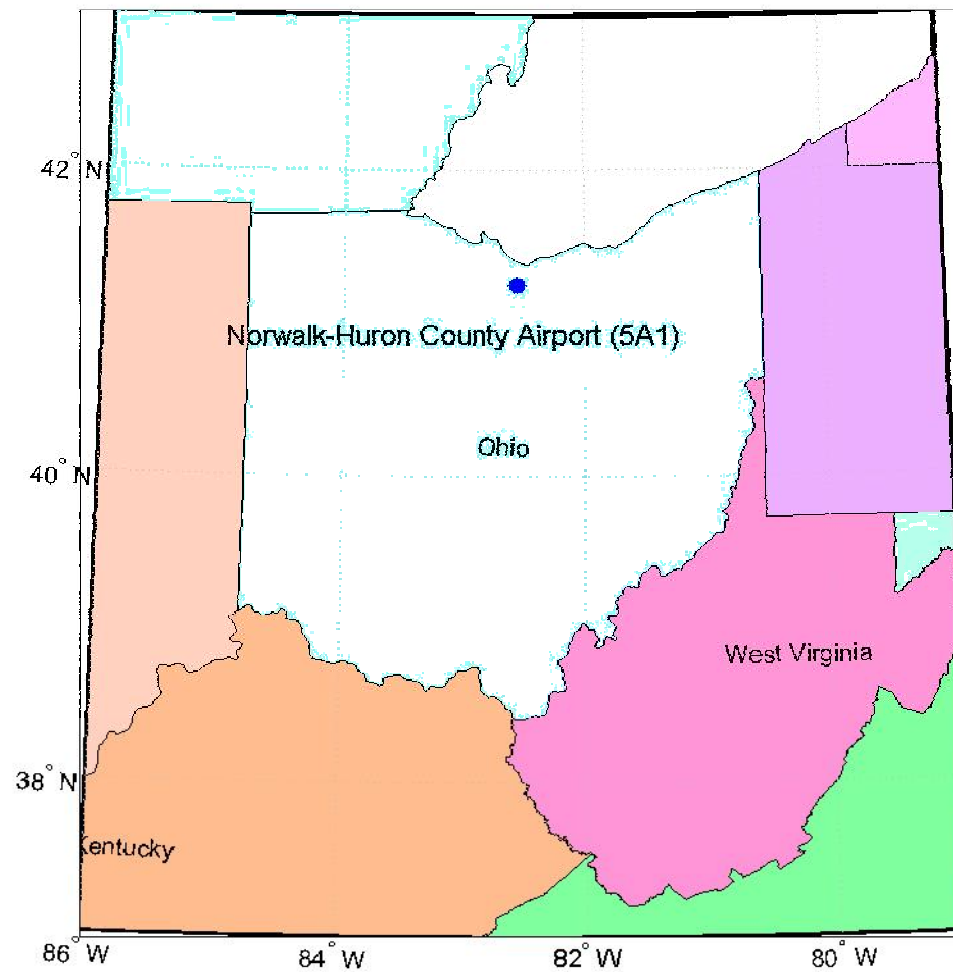
Ongoing flight tests performed by Ohio University's Avionics Engineering Center (AEC) using King Air, C-90SE twin turboprop



Flight Test Results from Four Locations

- Norwalk-Huron County Airport (5A1) Ohio
- Atlantic City International Airport (ACY)
- Portland International Jetport (PWM)
- Craig Municipal/Jacksonville Airport(CRG)

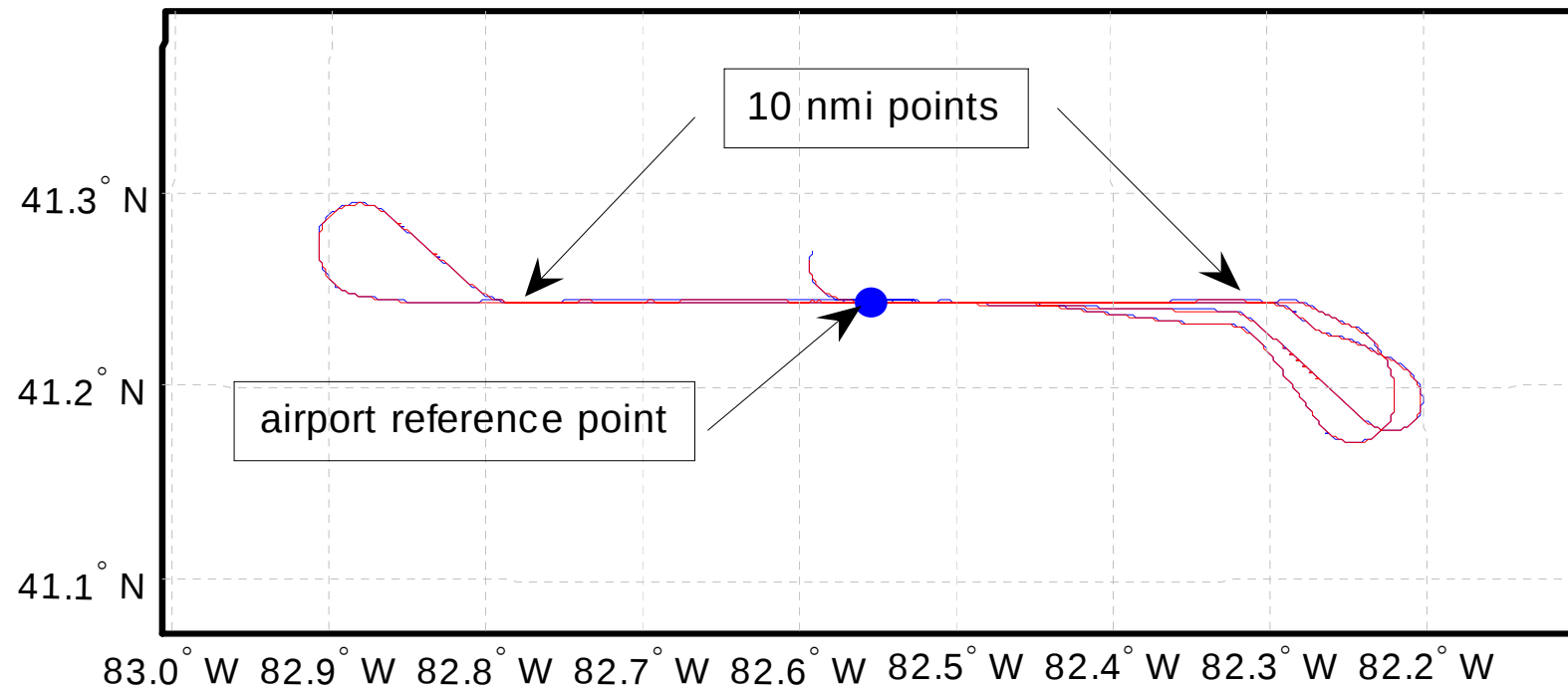




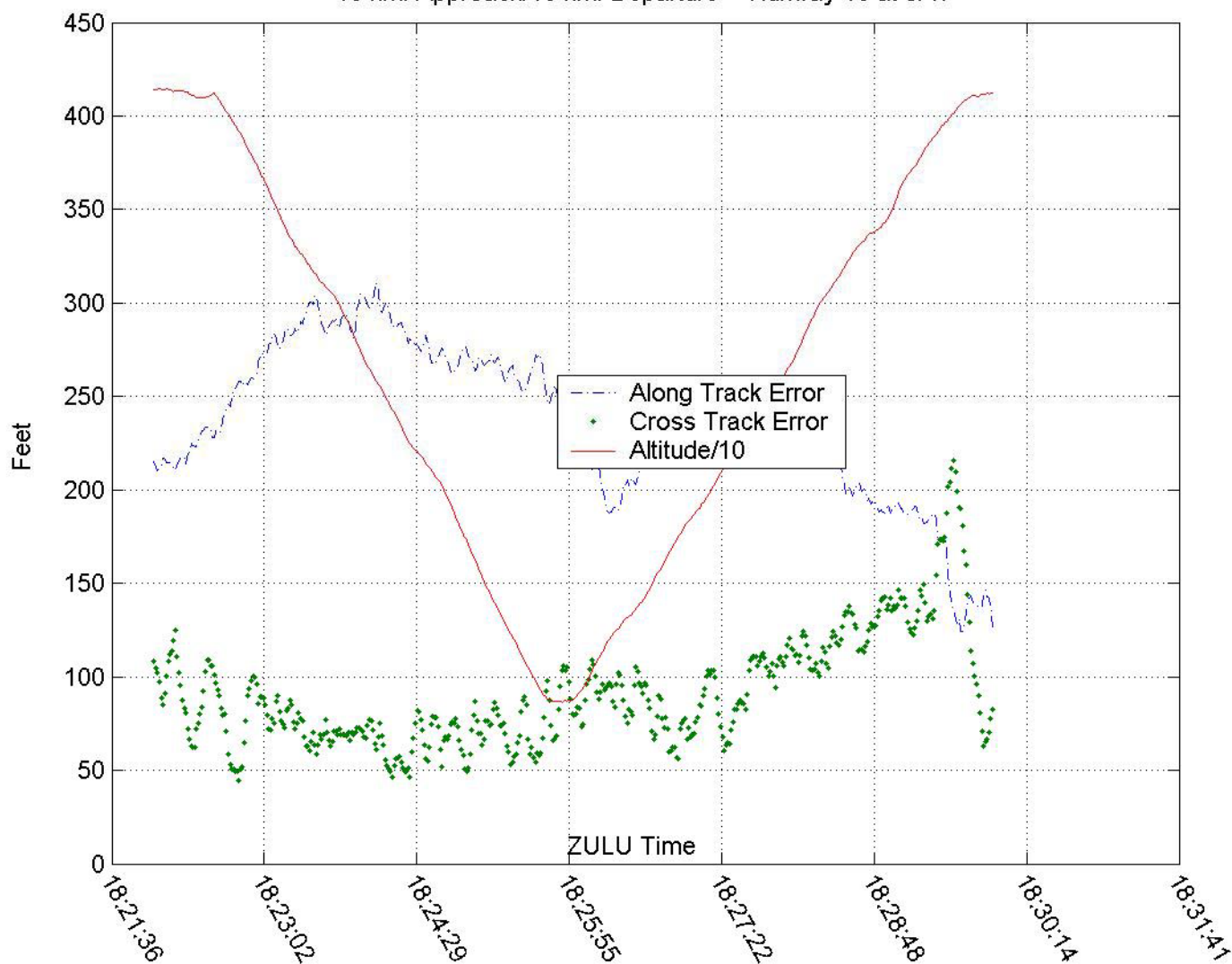
ASF* Values for 5A1

	NORWALK-HURON COUNTY AIRPORT (5A1) OHIO (values in microseconds)																						
Chain	8970					9960					7980					8290			9610				
Station	M	W	X	Y	Z	M	W	X	Y	Z	M	W	X	Y	Z	M	W	X	M	V	X	Y	Z
3/26/2004	-0.88	4.42	0.56	1.75	0.86	0.44	2.02	2.52	2.27	-0.60	3.10	2.61	2.25	1.89	1.54	-1.92	-2.20	-2.64	-2.05	-1.15	0.29	0.00	0.89
4/5/2005	-0.84	4.41	0.59	1.84	0.82	0.45	1.93	2.49	2.31	-0.61	3.07	2.56	2.12	1.89	1.54	-1.98	-2.20	-2.75	-2.06	-1.20	0.18	-0.07	0.87
Mean	-0.86	4.42	0.58	1.80	0.84	0.44	1.98	2.51	2.29	-0.60	3.09	2.59	2.19	1.89	1.54	-1.95	-2.20	-2.70	-2.06	-1.18	0.23	-0.03	0.88
Sigma	0.026	0.007	0.023	0.064	0.027	0.005	0.064	0.021	0.028	0.007	0.021	0.035	0.092	0	0	0.042	0	0.078	0.007	0.035	0.078	0.049	0.017
8/20/2004	-0.93	4.27	0.651	1.72	0.89	0.478		2.7	2.29	-0.63	3.04	2.63	2.28	1.85	1.51	-1.87	-2.21	-2.64	-2.04	-1.23		-0.04	0.822
8/24/2005	-0.93	4.25	0.655	1.89	0.924	0.487	1.88	2.68	2.31	-0.65	3.02	2.63		1.89	1.51	-1.92	-2.19	-2.66	-2.03	-1.18	0.296	-0.12	0.802
Mean	-0.93	4.26	0.653	1.805	0.907	0.483	1.88	2.69	2.3	-0.64	3.03	2.63	2.28	1.87	1.51	-1.9	-2.2	-2.65	-2.04	-1.21	0.296	-0.08	0.812
Sigma	0.001	0.014	0.003	0.12	0.024	0.006		0.014	0.014	0.011	0.014	0		0.028	0	0.035	0.014	0.014	0.007	0.035		0.052	0.014

10 nmi Approach/10 nmi Departure--Runway 10/28 at 5A1--8/24/05

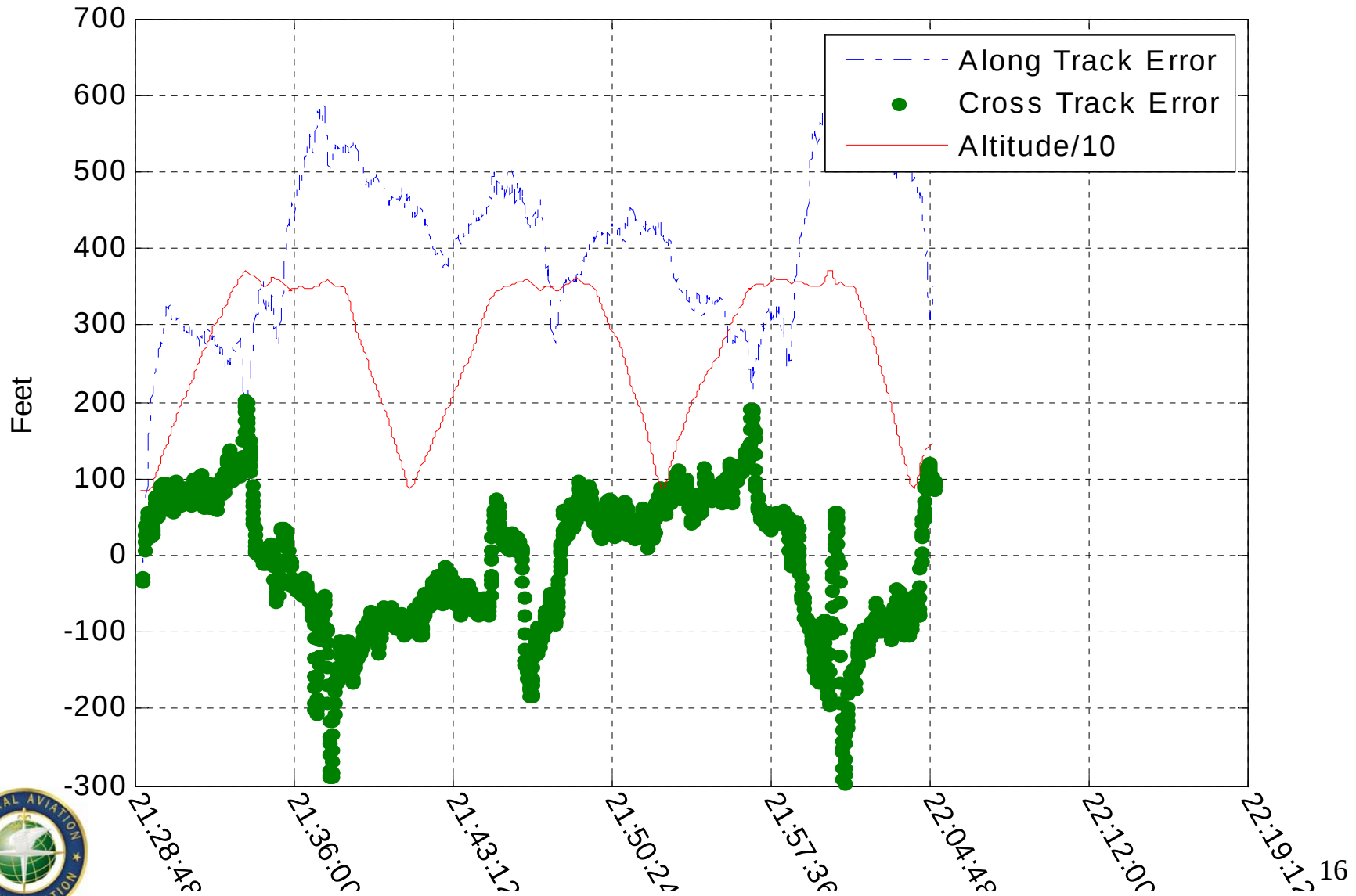


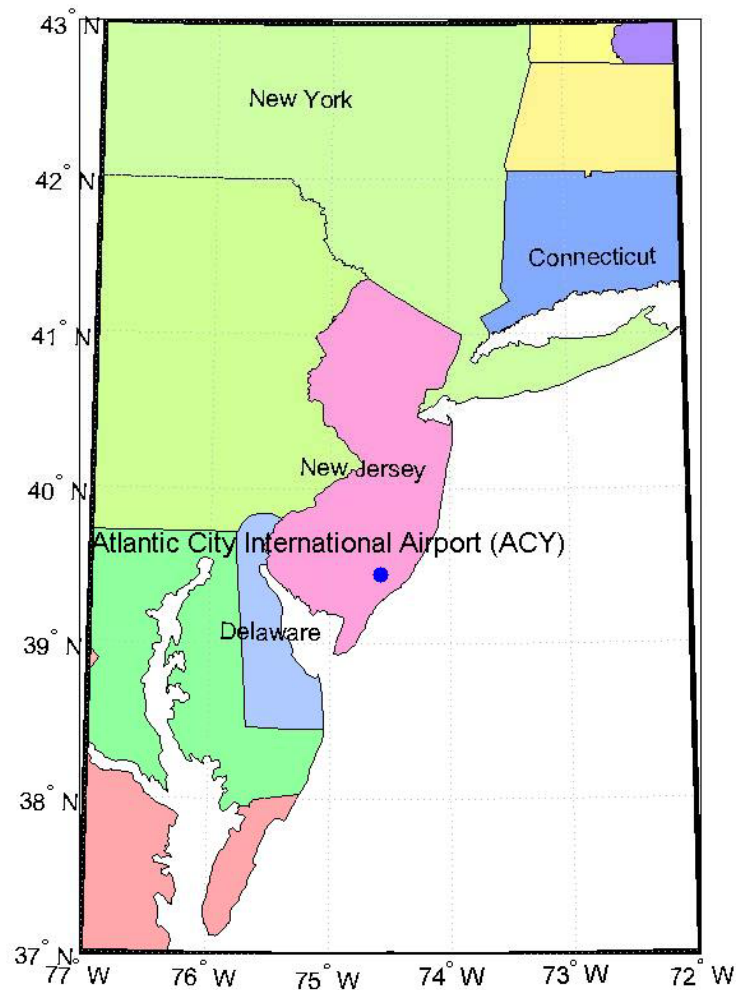
10 nmi Approach/10 nmi Departure -- Runway 10 at 5A1





10 nmi Approach/10 nmi Departure--Runway 10/28 at 5A1--8/24/05

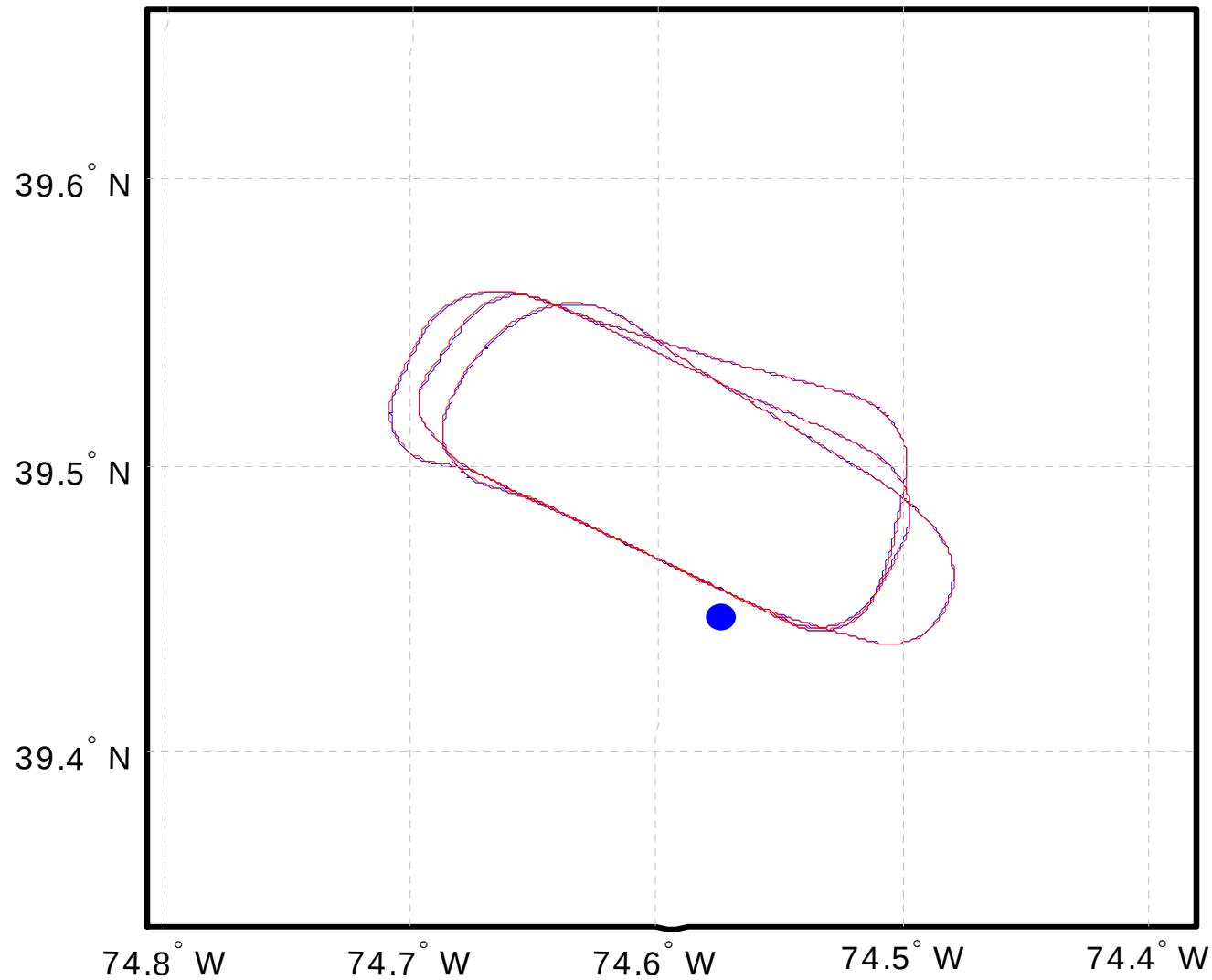




ASF* Values for ACY

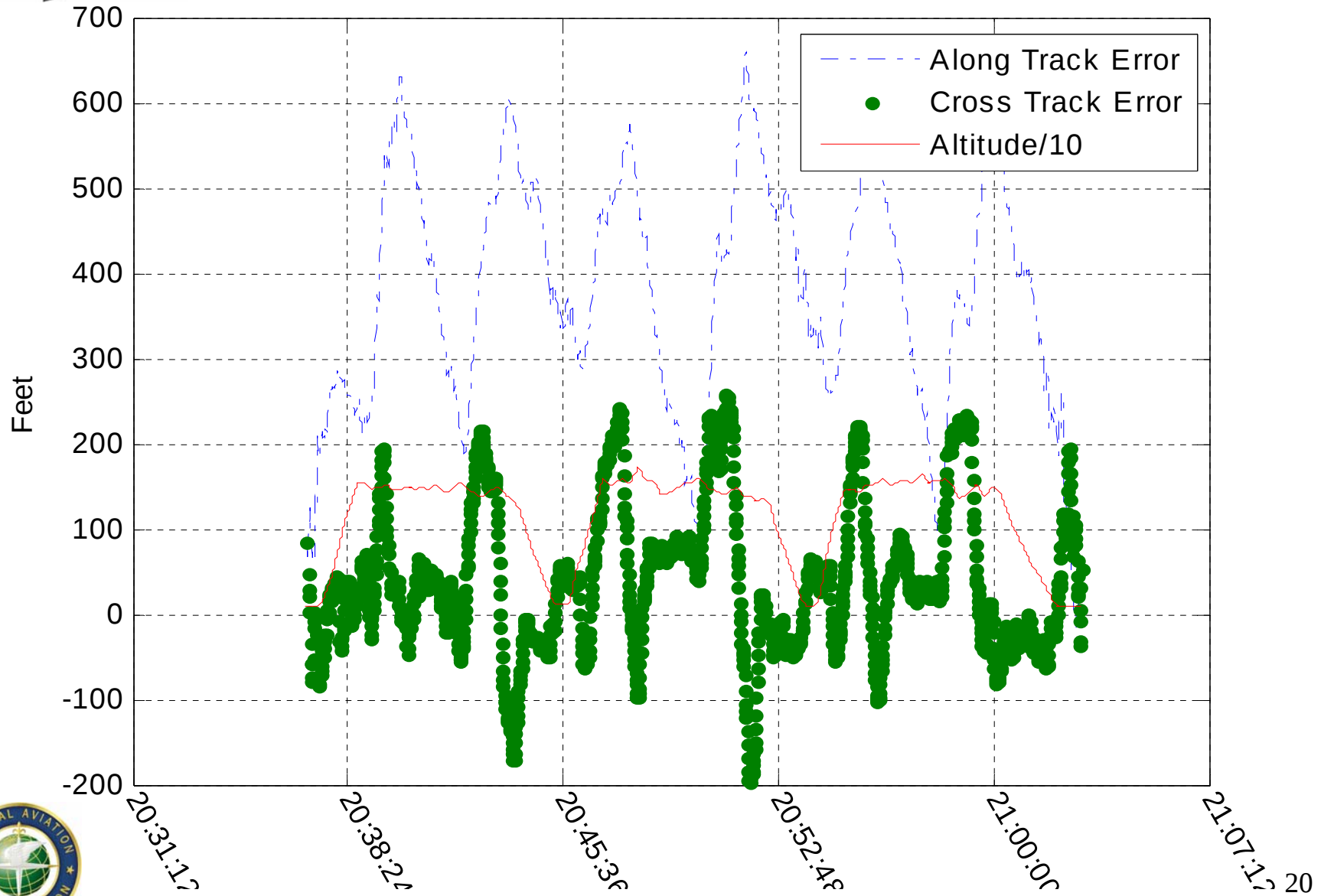
	ATLANTIC CITY INTERNATIONAL AIRPORT (ACY) NEW JERSEY (values in microseconds)																					
Chain	8970					9960					7980					8290			5930			
Station	M	W	X	Y	Z	M	W	X	Y	Z	M	W	X	Y	Z	M	W	X	M	X	Y	Z
3/26/2004	2.39	4.11	1.16	5.11		1.12	2.42	-1.63	0.61	2.69	3.54	6.15		-1.05	0.52		-1.42	8.58	2.80	-1.76	-1.41	
4/5/2005	2.41		1.27	5.28		1.19	2.48	-1.60	0.62	2.81	3.51			-1.11	0.46				2.89	-1.72	-1.31	3.50
Mean	2.40	.	1.22	5.20		1.16	2.45	-1.62	0.61	2.75	3.53			-1.08	0.49				2.85	-1.74	-1.36	
Sigma	0.014		0.078	0.12		0.049	0.042	0.021	0.006	0.085	0.021			0.042	0.046				0.064	0.028	0.071	
8/12/2004	2.51	4.21	1.51	5.19		1.20	2.48	-1.73	0.52	2.61	3.42	6.10		-1.13	0.44				2.94	-1.86	-1.35	
8/23/2005	2.33	4.03	1.2			1.15	2.54	-1.61	0.59	2.74	3.59			-1.02	0.525				2.95	-1.74	-1.28	
Mean	2.42	4.12	1.36	5.19		1.18	2.51	-1.67	0.56	2.68	3.51	6.10		-1.08	0.48				2.95	-1.80	-1.32	
Sigma	0.127	0.127	0.219			0.035	0.042	0.085	0.048	0.092	0.12			0.078	0.057				0.007	0.085	0.049	

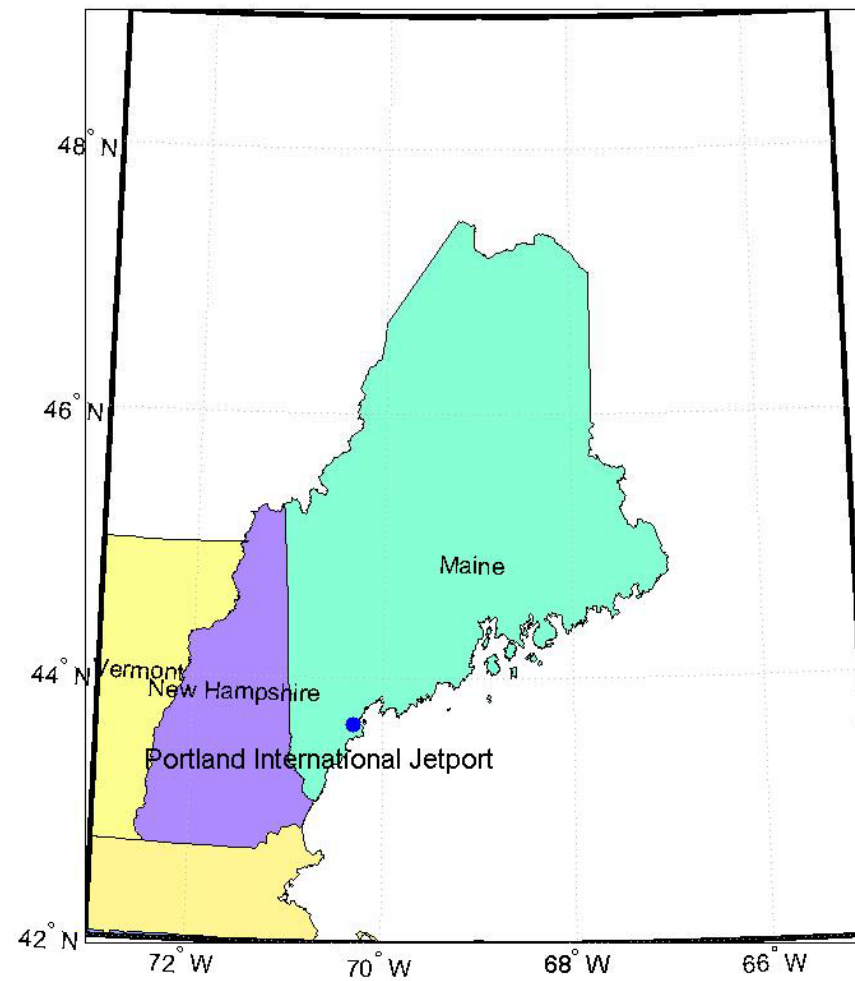
5 nmi Approachess to Runways 31/13/13 at ACY





5 nmi Approaches to Runway 13 at ACY

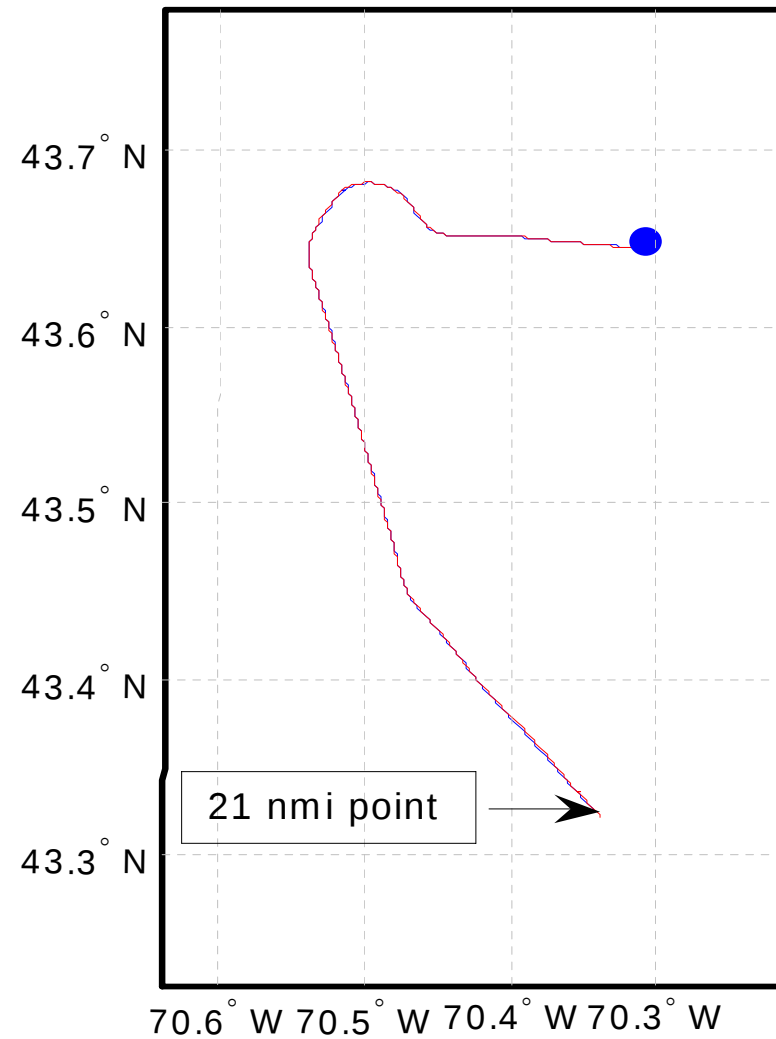




ASF* Values for PWM

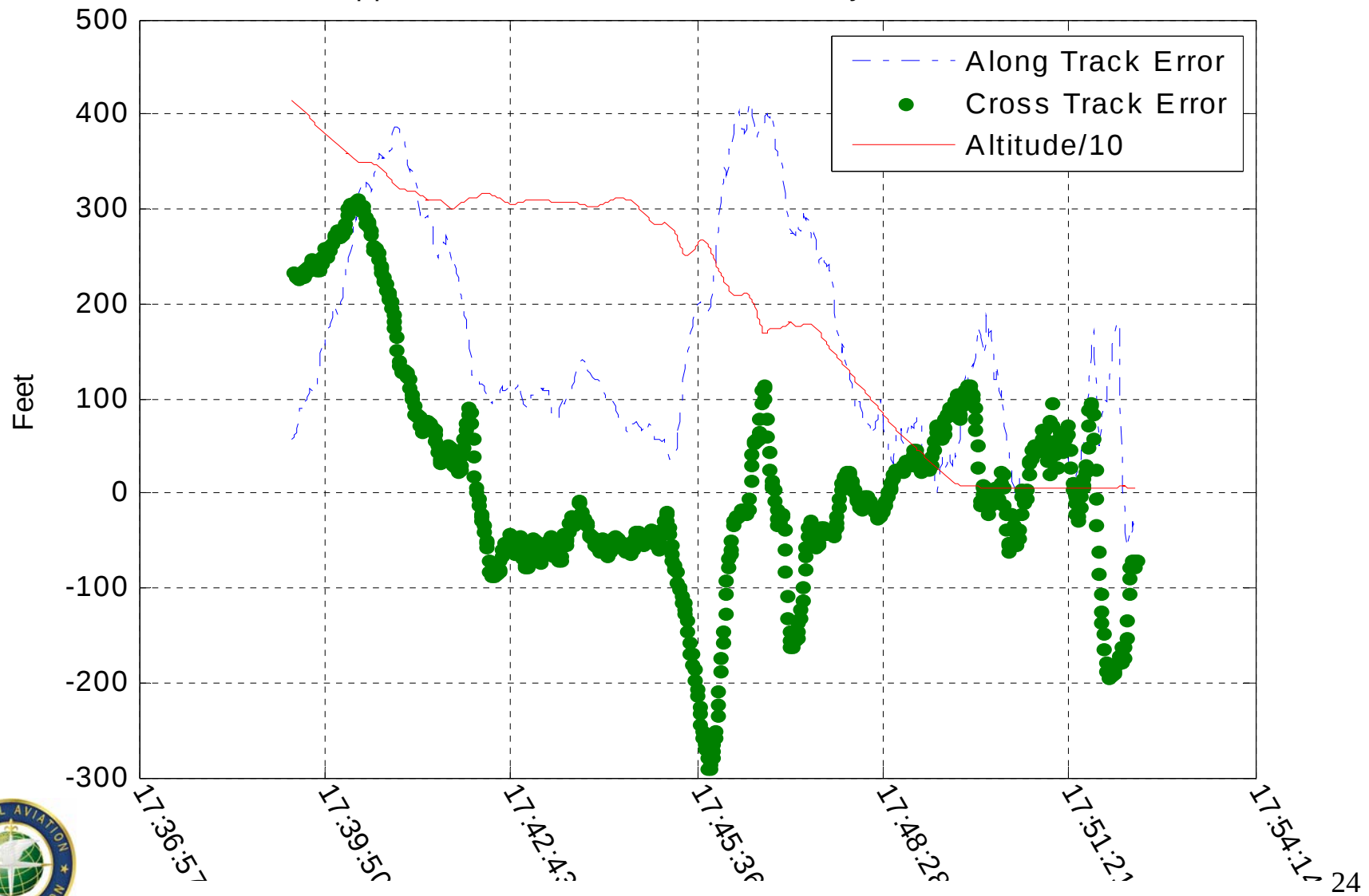
	PORTLAND INTERNATIONAL JETPORT (PWM) MAINE (values in microseconds)																							
Chain	8970					9960					7980				5930				9610					
Station	M	W	X	Y	Z	M	W	X	Y	Z	M	W	Y	Z	M	X	Y	Z	M	V	X	Y	Z	
3/25/2004	3.39	1.89	1.60	0.67		1.62	0.46	-1.84	1.16	3.65					0.82	-1.98	-0.07							
4/25/2005	3.15		1.48			1.46	0.53	-1.83	1.21	3.53			-1.90	-0.40	0.93	-1.99	0.06							
Mean	3.27	1.89	1.54	0.67		1.54	0.49	-1.84	1.19	3.59			-1.90	-0.40	0.87	-1.99	-0.01							
Sigma	0.17		0.08			0.11	0.05	0.01	0.04	0.08					0.08	0.01	0.09							
8/11/2004	3.20	-2.40	1.46	5.33		1.45	0.57	-1.88	1.25	3.68			-1.96	-0.45	0.96	-2.05	0.10	2.71					0.58	
8/30/2005	3.22		1.46			1.44	0.59	-1.74	1.21	3.64						-1.74	0.30							
Mean	3.21	-2.40	1.46	5.33		1.45	0.58	-1.81	1.23	3.66			-1.96	-0.45	0.96	-1.90	0.20	2.71					0.58	
Sigma	0.014		0			0.007	0.018	0.099	0.028	0.028						0.219	0.143							

10 nmi Approach with Old ASFs to Runway 11 at PWM--8/30/05

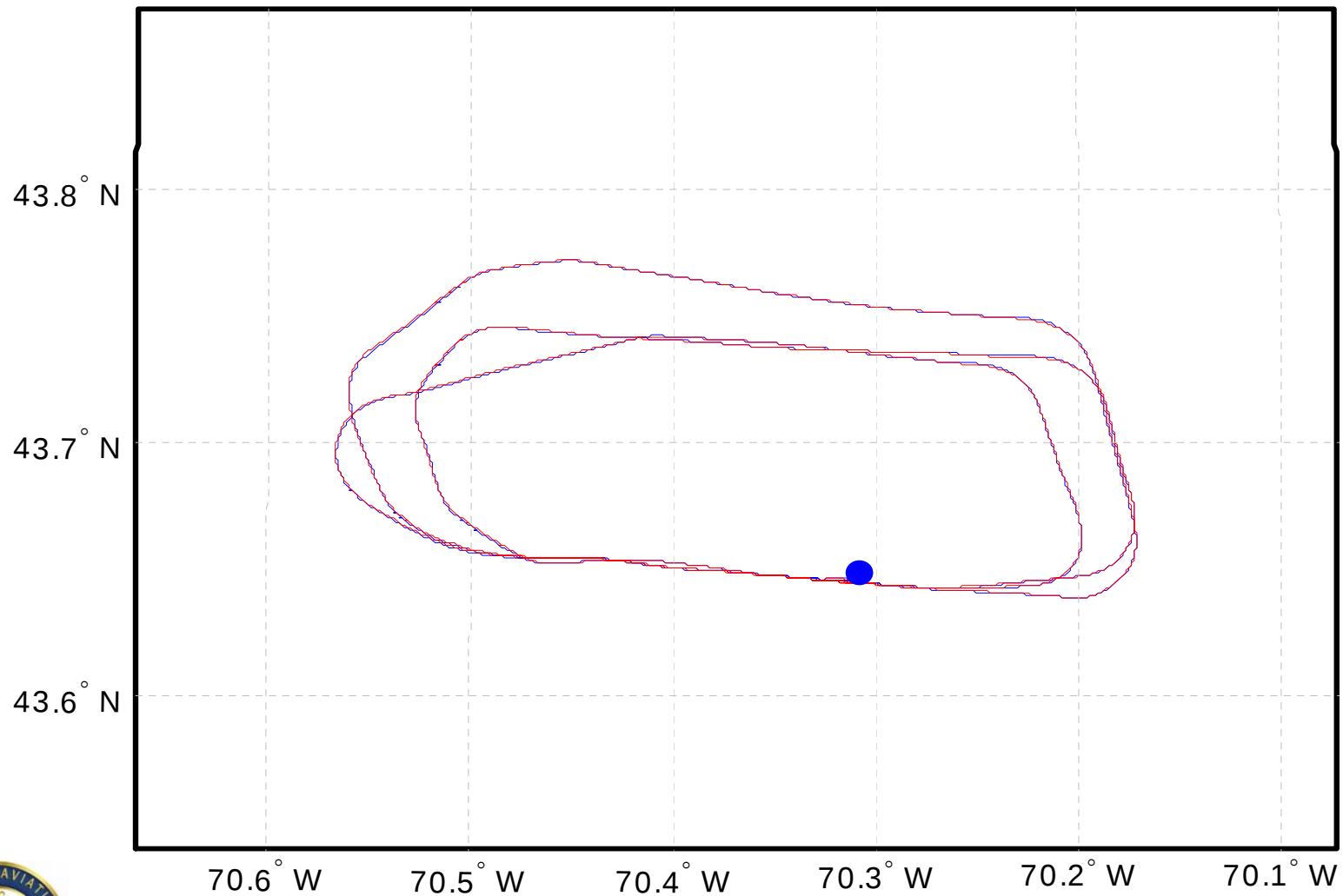




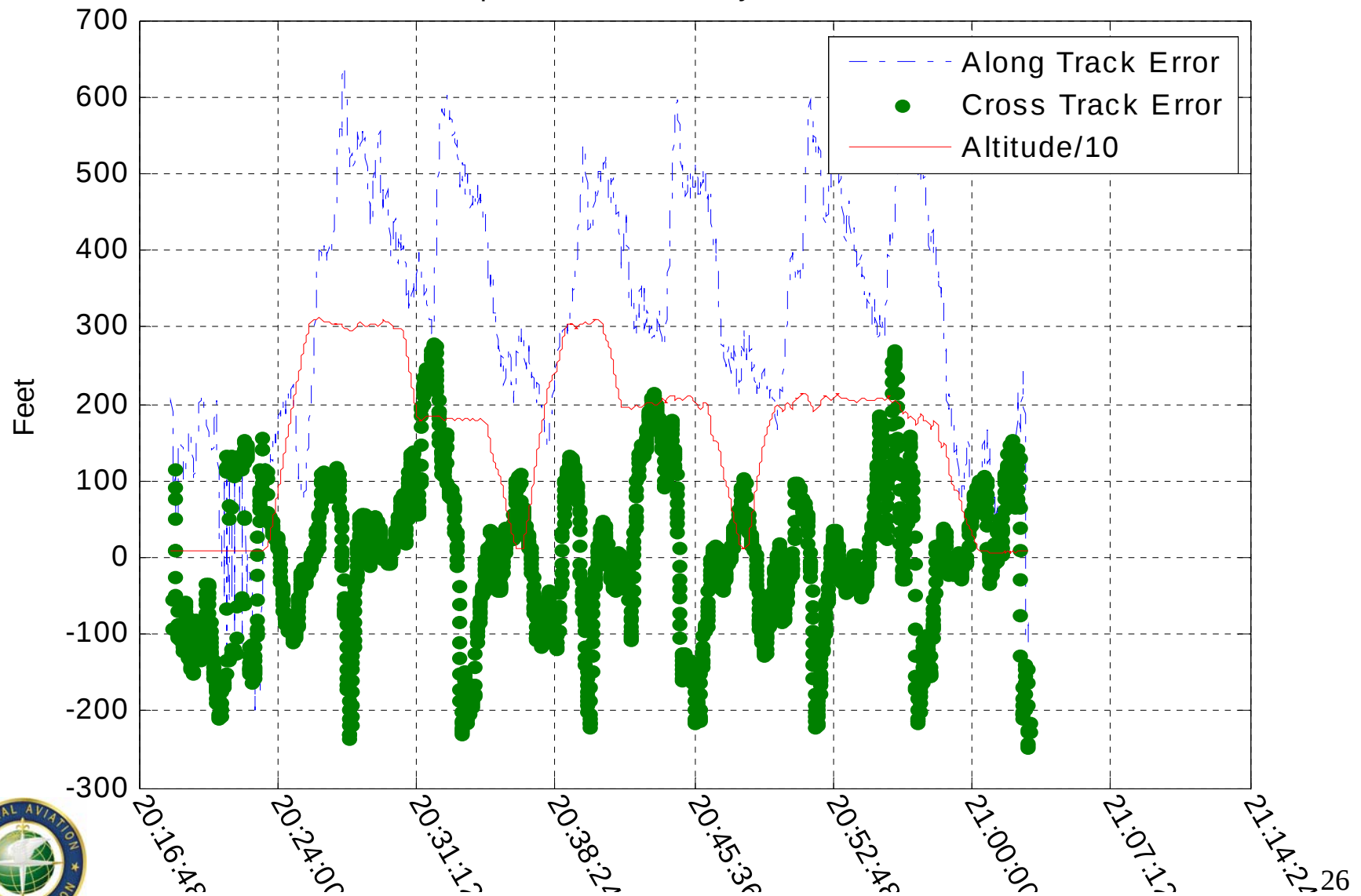
10 nmi Approach with Old ASFs to Runway 11 at PWM--8/30/05



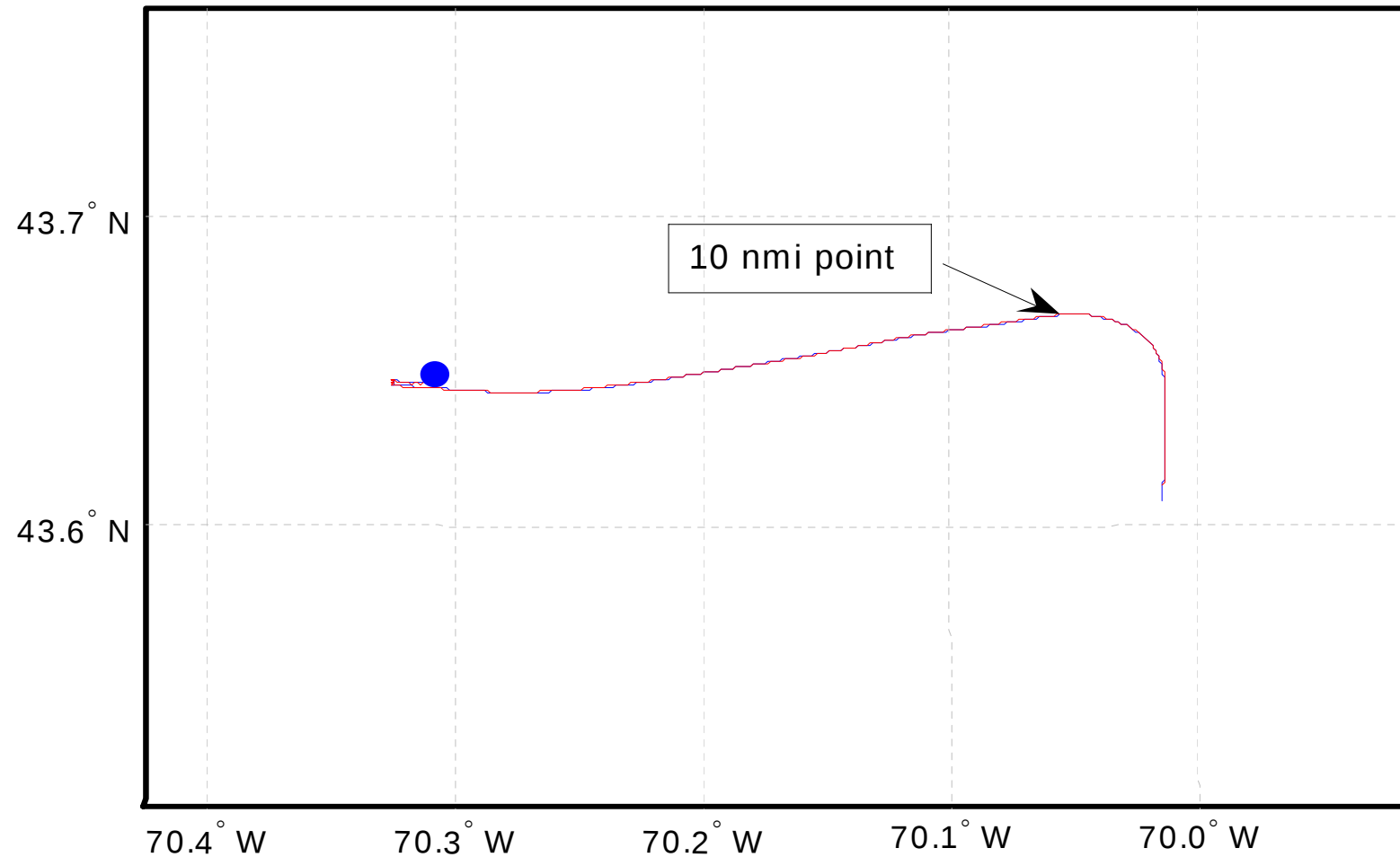
10 nmi Departure on Runway 11 at PWM--8/30/05



10 nmi Departure on Runway 11 at PWM--8/30/05

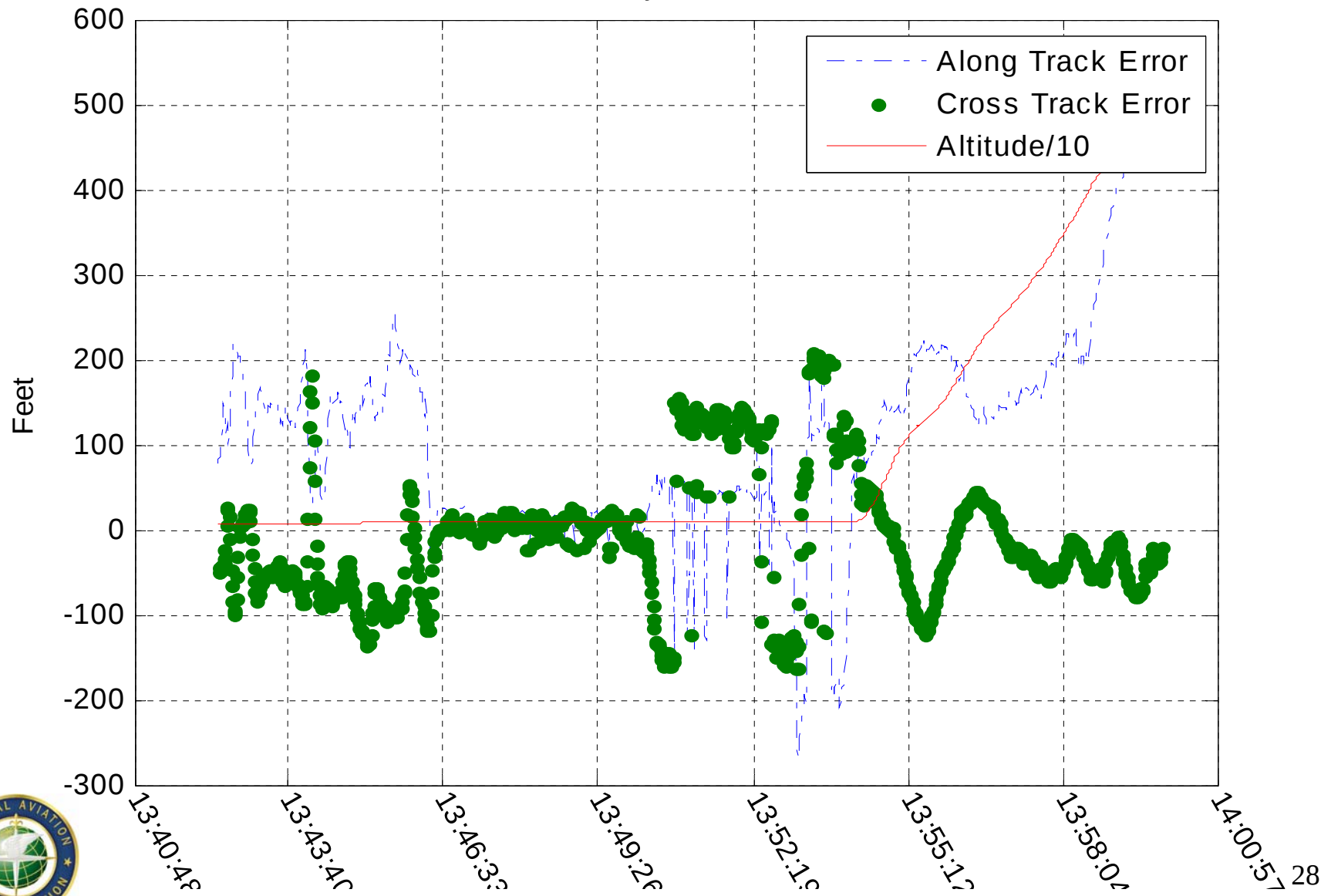


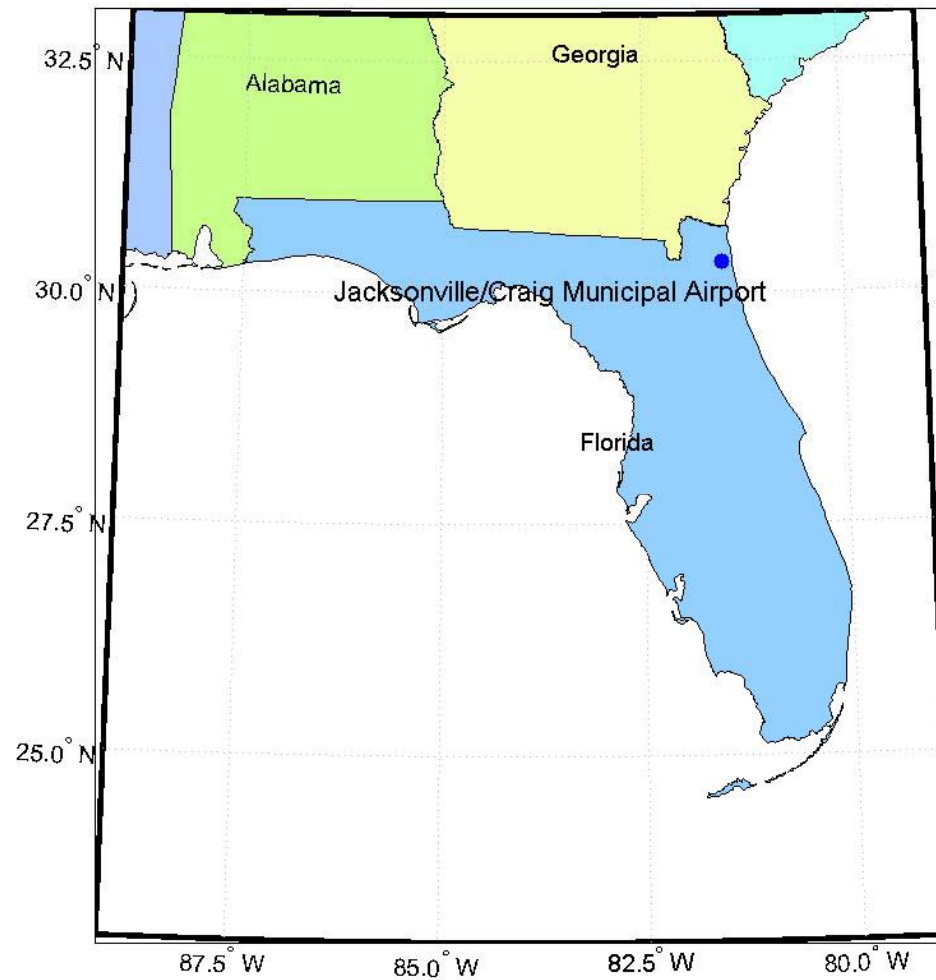
10 nmi Departure on Runway 11 at PWM--8/30/05





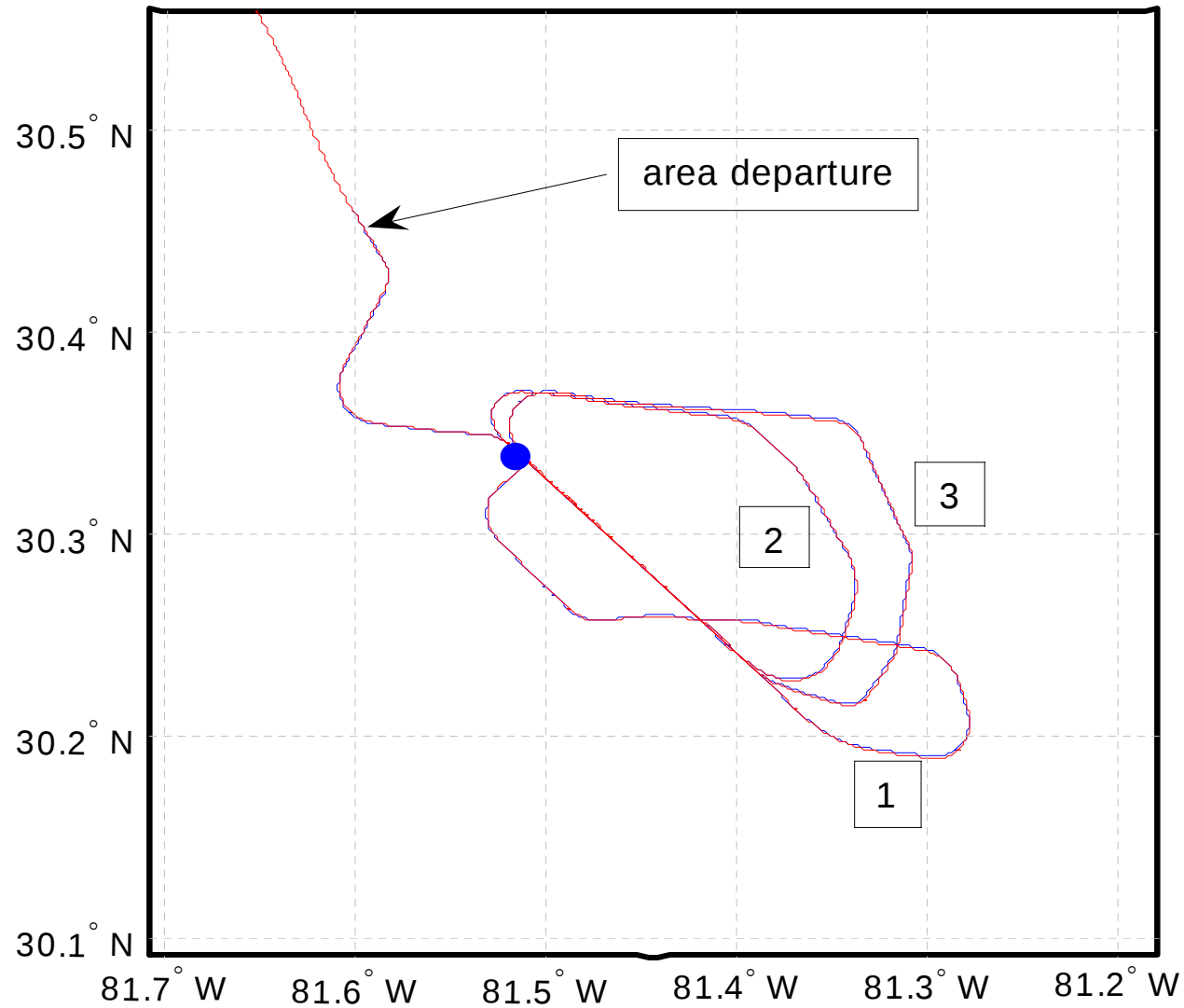
10 nmi on Runway 11 at PWM--8/31/05



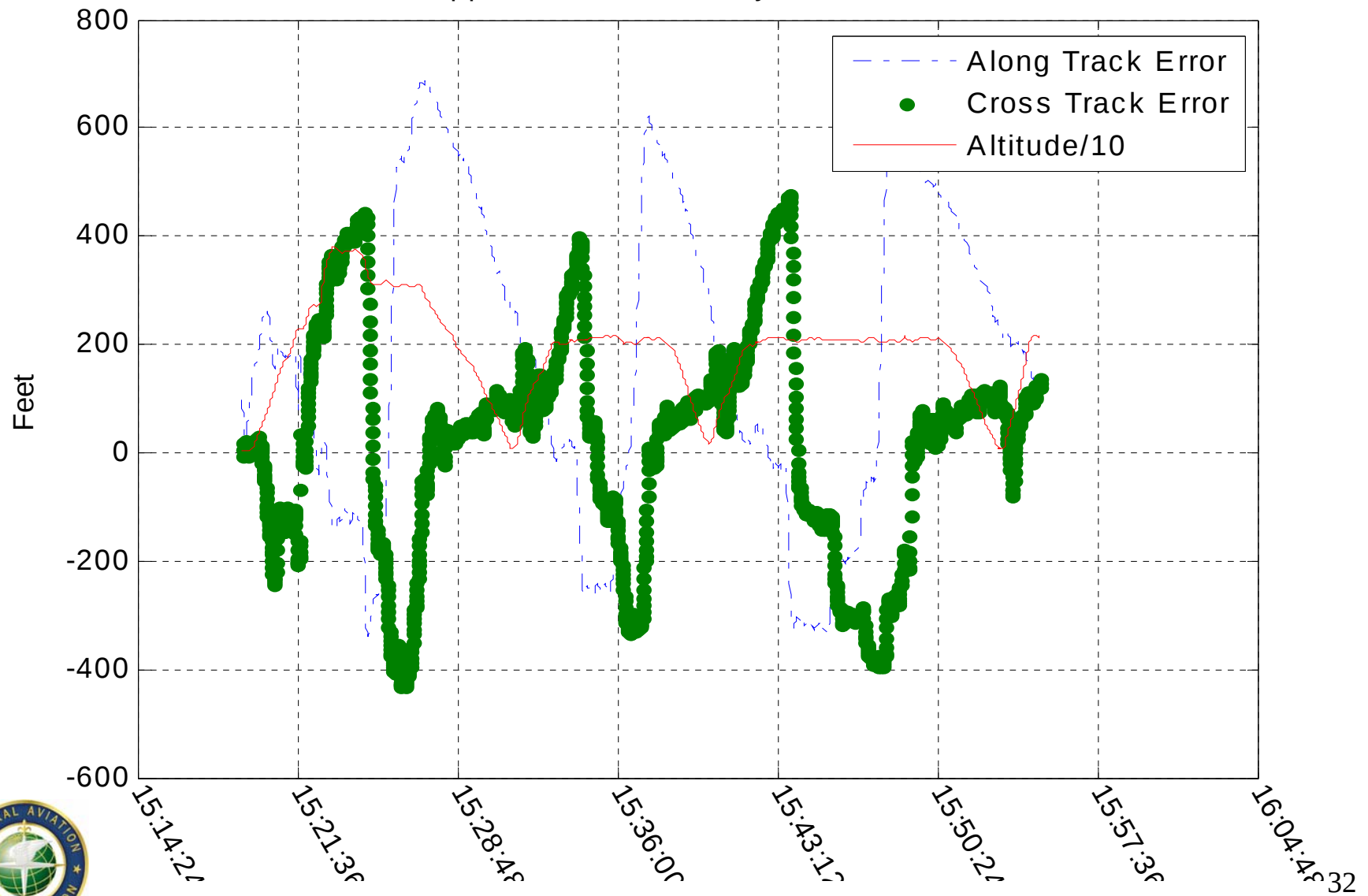


ASF* Values for CRG

JACKSONVILLE/CRAIG MUNICIPAL AIRPORT (CRG) FLORIDA (values in microseconds)																				
Chain	8970					9960					7980					9610				
Station	M	W	X	Y	Z	M	W	X	Y	Z	M	W	X	Y	Z	M	V	X	Y	Z
3/23/2004	2.93	1.07	3.66	5.59	3.92	3.98	-5.69	-1.13	-1.24	3.41	1.00	3.49	-0.08	-0.06	-1.11	1.77	3.15	3.35	-2.82	1.29
4/27/2005	2.98	1.08	3.98		3.96	4.20		-0.98	-1.24	3.60	1.00	3.49	-0.13	-0.06	-1.11	1.80	3.15	3.28	-2.92	1.30
Mean	2.96	1.08	3.82	5.59	3.94	4.09	-5.69	-1.06	-1.24	3.51	1.00	3.49	-0.10	-0.06	-1.11	1.79	3.15	3.32	-2.87	1.30
Sigma	0.035	0.007	0.226		0.028	0.156		0.106	0.000	0.134	0.003	0.000	0.035	0.000	0.000	0.021	0.000	0.049	0.071	0.007
8/20/2004	3.14	1.10	4.20		4.22	4.32		-0.93	-1.23	3.73	1.02	3.58	-0.08	-0.03	-1.11	2.01		3.78	-2.84	1.32
9/1/2005	3.06	1.09	4.06		4.10	4.22		-0.96	-1.26	3.63	1.00	3.53	-0.09	-0.04	-1.11	2.06			-2.78	1.30
Mean	3.10	1.10	4.13		4.16	4.27		-0.95	-1.25	3.68	1.01	3.56	-0.08	-0.03	-1.11	2.04		3.78	-2.81	1.31
Sigma	0.057	0.007	0.099		0.085	0.071		0.022	0.021	0.071	0.014	0.035	0.005	0.003	0.000	0.035			0.042	0.014



5-nmi Approaches to Runway 32 at CRG--9/1/05



Summary

- Locally generated ASF* measurements demonstrate year-to-year (temporal) consistency but trials to date are limited.
- Flight measurements demonstrate that cross-track error is well behaved for stabilized approach procedures typical of those published by FAA for non-precision approach
- Numerous flight tests (these and others previously reported) have demonstrated RNP 0.3 performance over a wide area surrounding the point where ASF* values were generated.
 - with ASF corrections derived the same day
 - with ASF corrections several months old

Conclusions

- It appears that a single set of ASF* values per airport will be sufficient to meet RNP 0.3 accuracy requirements for all runway ends.
- Twice annual updates may be needed for some airports where all-in-view geometry is limited.
- Airports surveyed to date are representative of those east of the Rocky Mountains. The inter-mountain and west coast areas need to be studied since ASF gradients can be steep.
- With new TFE equipment in place and a move to time-of-transmission control, ASFs should prove to be more stable than at present thus yielding even greater Loran C accuracy.