



LORAN PERFORMANCE IN A GPS NON-PRECISION APPROACH ENVIRONMENT by David Diggle, Ph.D. Chris G. Bartone, Ph.D., P.E. Avionics Engineering Center--Ohio University

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LORAN (LOng RAnge Navigation) System

- Hyperbolic radio navigation system with precise time/ frequency capability
- Organized by *Chains* as Master/Secondary Stations
- Time difference (TD) measured by a user between the TOA of Master/Secondary transmissions yields the user's position





Current Status of LORAN

- Congressional Funding since 1997--\$160M
 - CONUS and NE Canada have SSX equipment
 - Time and Frequency Equipment upgraded
 - No-break power (UPS) equipment at all sites
- US DOT January 2007 Request for Comment
 - Over 1000 mostly favorable responses received
- LORAN and the modernized eLORAN now designated as the official U.S. Government GPS backup











eLORAN – the latest PNT concept

- Adds a data channel for navigation information
- All LORAN stations are UTC controlled
- New user equipment includes all-in-view receivers
- eLORAN details at www.loran.org





eLORAN Attributes (1/2)

- Accuracy
 - 8-20 meters for harbor approach/entrance
 - 0.3 nmi (307m cross track nse) for non-precision approach (Meets RNP 0.3 requirement)
- Availability 0.999-0.9999
- Integrity 1x10⁻⁷ per hour
- Continuity—0.999-0.9999 (150 sec)





eLORAN Attributes (2/2)

- Timing 50 ns recovery of UTC
- Frequency Stratum 1 (1x10⁻¹¹)





Aviation Applications Overview (1/2)

- Use of locally measured and/or calculated ASF values is key for LORAN and eLORAN to meet accuracy requirements, i.e., RNP (0.3)
- Ohio University has been collecting LORAN C data at six east coast/mid west airport over the past four and one-half years
- Flights are conducted in early spring and late summer seeking to establish patterns for ASF values





Aviation Applications Overview (2/2)

 Goal is to verify if a single set of ASF values can serve an entire airport, including the terminal area, covering all runway approaches





Outline

- ASF* Derivation
- Required Navigation Performance
- GPS Approach Architecture
- Flight Test Results— Measured ASF^{*} Values
- Flight Test Results—Averaged ASF^{*} Values
- Summary and Conclusion





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 synchronized to UTC; any 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





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









GPS RW 25 Approach Ohio University





Typical GPS Approach Structure







FLIGHT TEST RESULTS

• GPS non-precision approaches using measured ASF* values flown at three airports: BLM, ACY, and 5A1

- Detailed results presented for BLM

• GPS non-precision approaches using averaged ASF* values flown at four airports: W29, ACY, PWM, and 5A1

- Detailed results presented for W29





Flight Test Results at Monmouth Executive Airport, NJ (BLM) Using Measured ASF^{*} Values





GPS Approaches Using Measured ASF^{*} Values Monmouth Executive Airport (BLM)







Calculated ASF^{*} Values For BLM

	MONMOUTH EXECUTIVE AIRPORT (BLM) NEW JERSEY (values in microseconds)															
Chain		897	70			9960	7980				5930					
Station	М	W	Х	Y	М	W	Х	Y	Z	М	W	Y	Z	М	Х	Y
3/25/2004	1.97	4.91	0.92	4.82	0.85	1.99	-1.80	1.29	2.26	3.96		-0.78	0.92	2.43	-1.90	-0.89
4/6/2005	1.98	4.90	0.87	4.73	0.79	2.10	-1.75	1.26	2.36	4.03	-3.78	-0.88	0.86	2.55	-1.85	-0.76
4/4/2006	2.13	5.01	0.82	4.59	0.75	1.99	-1.65	1.18		4.05		-0.93	0.80	2.46	-1.76	-0.62
4/10/2007	2.23	5.06	0.93	4.43	0.87	2.21	-1.77	1.27	2.25	4.06	-4.20	-0.82	0.87	2.42	-1.87	-0.79
4/17/2008	2.50	5.17	1.17	5.07	1.10	2.20	-1.87	1.18	2.50	4.07	6.32	-0.96	0.78	2.39	-1.97	-0.86
Mean	2.16	5.01	0.94	4.73	0.87	2.10	-1.77	1.24	2.34	4.03	-0.55	-0.87	0.85	2.45	-1.87	-0.78
Sigma	0.22	0.11	0.14	0.24	0.14	0.11	0.08	0.05	0.12	0.04	5.96	0.07	0.06	0.06	0.08	0.11
8/13/2004	1.92	4.87	0.88		0.80	2.09	-1.68	1.26	2.27	4.00		-0.91	0.82	2.55	-1.79	-0.71
8/24/2005	2.04	4.85	0.86		0.79	2.14	-1.68	1.24	2.41	3.79		-1.15	0.82	2.58	-1.79	-0.62
9/6/2006	2.02	4.77	0.92	4.89	0.84	2.10	-1.70	1.19	2.42	3.99	6.31	-0.89	0.75	2.54	-1.81	-0.64
9/6/2007	2.43	5.11	1.15		1.12	2.26	-1.87	1.31	2.50	3.95		-0.92	0.78	2.44	-1.98	-0.87
Mean	2.10	4.90	0.95	4.89	0.89	2.15	-1.73	1.25	2.40	3.93	6.31	-0.97	0.79	2.53	-1.84	-0.71
Sigma	0.22	0.15	0.13		0.16	0.08	0.09	0.05	0.10	0.10		0.12	0.04	0.06	0.09	0.11
Total Mean	2.13	4.96	0.95	4.81	0.88	2.12	-1.75	1.24	2.37	3.98		-0.92	0.82	2.49	-1.86	-0.75





Runway 14 GPS Approach at BLM







LORAN Performance with Measured ASF*







LORAN Error Performance Using Measured ASF* Values

Date	Airport	Runway	Cro	ss-track Erro	- (ft)	Along-track Error (ft)				
			Mean (ft)	Sigma(ft)	95% (ft)	Mean (ft)	Sigma (ft)	95% (ft)		
4/17/2008	BLM	14	78.8	102.6	284.0	529.4	64.9	659.2		
4/17/2008	BLM	14	80.6	105.8	292.2	534.2	64.0	662.2		
4/17/2008	BLM	14	82.6	107.2	297.0	558.0	67.9	693.8		
Composite	BLM	14	75.5	93.4	262.3	455.6	120.3	696.2		
4/14/2008	5A1	7	94.2	24.3	142.8	471.9	16.0	503.9		
4/17/2008	ACY	13	95.2	93.2	281.6	758.2	251.9	1262.0		





Flight Test Results at Bay Bridge Airport, MD (W29) Using Averaged ASF^{*} Values





GPS Approaches Using Averaged ASF^{*} Values Bay Bridge Airport (W29)







Averaged ASF^{*} Values For W29

	BAY BRIDGE AIRPORT (W29) MARYLAND (values in microseconds)																				
Chain	8970					9960				7980				5930			9610				
Station	М	W	Х	Y	Ζ	М	W	Х	Y	Ζ	М	W	Y	Ζ	М	Х	Y	М	V	Y	Ζ
3/24/2004		3.40	0.37	3.43		0.40	1.93	-1.30	0.12	1.65	2.93	5.23	-0.29	0.10	2.50	-1.61	-0.88	1.75			1.34
4/26/2005	1.35	3.29	0.34	3.55	4.13	0.34	2.52	-1.27	0.11	1.83	2.96	5.12	-0.26	0.09	2.84	-1.49	-0.59	0.15	-0.51	1.33	1.40
4/3/2006	1.46	3.47	0.40	3.55	4.17	0.39	2.52	-1.38	0.10	1.80	2.94		-0.31	0.07	2.77	-1.65	-0.77	0.22		1.38	1.43
4/9/2007	1.53	3.50	0.35	3.05		0.35	2.61	-1.38	0.13	1.63	2.96	5.05	-0.30	0.09	2.68	-1.65	-0.81	0.22	2.59		1.40
Mean	1.45	3.42	0.37	3.40	4.15	0.37	2.40	-1.33	0.12	1.73	2.95	5.13	-0.29	0.09	2.70	-1.60	-0.76	0.59	1.04	1.36	1.39
Sigma	0.09	0.09	0.03	0.24	0.03	0.03	0.31	0.06	0.01	0.10	0.01	0.09	0.02	0.01	0.15	0.08	0.12	0.78	2.19	0.04	0.04
8/12/2004	1.26	3.21	0.38	3.69		0.40	2.59	-1.28	0.10	1.75	2.90		-0.29	0.09	2.09	-1.43	-0.50	0.01	1.59	1.21	1.43
8/31/2005	1.34	3.25	0.37		4.25	0.37	2.62	-1.26	0.08	1.84	2.94	5.33	-0.29	0.06	2.87	-1.41	-0.42			1.28	1.27
9/13/2006	1.27	3.29	0.38	3.60		0.37	2.60	-1.33	0.14	1.76	2.99		-0.20	0.12	2.83	-1.62	-0.73				1.33
9/5/2007	1.70	3.55	0.46	3.65		0.48	2.64	-1.47	0.11	1.80	2.94	5.09	-0.29	0.09	2.67	-1.74	-0.87	0.55			1.46
Mean	1.39	3.33	0.40	3.65	4.25	0.40	2.61	-1.34	0.11	1.79	2.94	5.21	-0.27	0.09	2.62	-1.55	-0.63	0.28	1.59	1.25	1.37
Sigma	0.21	0.15	0.04	0.05		0.05	0.02	0.09	0.03	0.04	0.04	0.17	0.04	0.03	0.36	0.16	0.21	0.38		0.05	0.09
Total Mean	1.42	3.37	0.38	3.52	4.20	0.39	2.50	-1.33	0.11	1.76	2.95	5.17	-0.28	0.09	2.66	-1.58	-0.70	0.43	1.32	1.30	1.38





Runway 29 GPS Approach at W29







LORAN Performance with Averaged ASF*







LORAN Error Performance Using Averaged ASF* Values

Date	Airport	Runway	Cro	ss-track Errol	r (ft)	Along-track Error (ft)					
			Mean (ft)	Sigma(ft)	95% (ft)	Mean (ft)	Sigma (ft)	95% (ft)			
4/17/2008	W29	29	202.1	120.8	443.7	461.1	187.5	836.1			
4/17/2008	W29	29	215.9	127.5	470.9	420.4	180.3	781.0			
Composite	W29	29	207.8	230.2	668.2	411.5	178.3	768.1			
4/14/2008	5A1	7	86.1	86.6	259.3	533.6	176.7	887.0			
4/17/2008	ACY	13	67.5	87.2	241.9	424.6	186.5	797.6			
4/17/2008	PWM	36	148.4	71.2	290.8	415.2	83.7	582.6			





Composite Cross-Track GPS Error Results







Composite Along-Track GPS Error Results







Conclusions(1/2)

- GPS approaches can be flown using LORAN with accuracy results which meet requirements
- 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.





Conclusions (2/2)

- 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 eLORAN, ASFs should prove to be more stable than at present thus yielding even greater accuracy with LORAN.





Questions

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