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Implementation of RNAV Flight Inspection by the Federal Aviation Administration March, 2002

ABSTRACT

Over the past five years the FAA has been actively involved in the development of policies, methods and procedures for the implementation of GPS and alternate technologies being introduced into the National Airway System (NAS). This paper will describe the methods and procedures implemented by the FAA to support current and future policies pertaining to one aspect of this NEW NAS, Area Navigation (RNAV) procedures.

The policies put in place by the FAA required that new technologies and technologies that have existed in the NAS for decades be merged and implemented into the Flight Inspection capability of the FAA Fleet, these included, GPS Non-precision, DME/DME LNAV and Wide Area Augmentation System (WAAS). This paper will describe the methods and systems being employed by the FAA to meet these requirements. System level descriptions of the equipment involved in the commissioning and periodic inspection of RNAV procedures will be covered. The current Automatic Flight Inspection

Systems (AFIS) in use aboard FAA aircraft will be defined.

PURPOSE

To provide an overview of the preliminary and ongoing work conducted by AVN and other FAA organizations in pursuit of broadening the available navigational and procedural resources to the flying public.

BACKGROUND

The acronym RNAV (area Navigation) has been in the aviation industry for decades. Early RNAV systems integrated the available ground based navigational resources along with on aircraft sensors to produce a best-known position. These systems were generally limited to large transport class aircraft being used in the intercontinental segment of the aviation business. Several factors, availability of ground navigational resources, air traffic control limitations, and cost of aircraft equipment limited early utilization of these integrated systems. With the advent of GPS, reduced aircraft systems costs, significant

improvements in the air traffic and navigation aid infrastructures RNAV capabilities can now become a major component in the world airspace system. Providing increased air traffic flexibility, positional accuracy, and safety.

With the implementation of Required Navigation Performance (RNP) route widths (i.e., RNP 1.0 or less), the DME ground infrastructure will require additional attention to insure that facilities are adequate to support the required accuracy and integrity. ICAO Annex 10 and FAA Order 8200.1A have established the DME facility tolerances; however, many other issues are involved. Some of the issues raised are DME facility survey accuracy, survey requirements in conjunction with the relocation of a DME facility, the ability of an FMS to a facility which does not meet signal requirements, interference encountered when operating outside a facilities frequency protected service volume, NOTAMS, and tools for assessing the DME infrastructure used to support a procedure.

SUBJECT

1.-RNAV Procedures Development

The development of RNAV procedures involves many FAA organizations, this paper will provide an overview of the process starting with orders covering criteria produced by FAA Flight Standard Services AFS-400, implantation of these criteria into approach and Departure procedures by AVN-100 using the IAPA development system and flight inspection procedures for commissioning prior to publication.

a.- RNAV Approach Criteria The FAA order 8260.48 establishes the guidance and provides the approach construction criteria for the development of RNAV procedures using GPS SBAS augmented systems (WAAS), Lateral Navigation (LNAV) with Barometric Vertical Navigation (VNAV).

b.- RNAV DME/DME Design The design of both RNAV Approach and Departure procedures are supported by

multiple DME facilities providing a computed position for operation in a Required Navigational Performance (RNP) environment. The procedure is developed under FAA Order 8260.44A to either Level 1, 2 or Level 3 criteria. Each of these levels corresponds to an RNP value: 1.0, 2.0, and 0.3 respectively.

The viability of an intended procedure is initially determined through the use of modelling software where the approach or departure route is used to derive the available DME ground facilities that will support the procedure. The model uses geometric, service volume, and geodetic qualifiers. The model also excludes DME facilities associated with ILS and TACAN facilities. The ILS exclusion is due to the potential alteration of ranging data to provide correlation with runway threshold distances. The TACAN exclusion is due to the status of these facilities as it relates to the US National Airspace System (NAS). The DME facilities identified by the model are provided to flight inspection operations as part of the commissioning procedure package.

e. - Sample Procedures

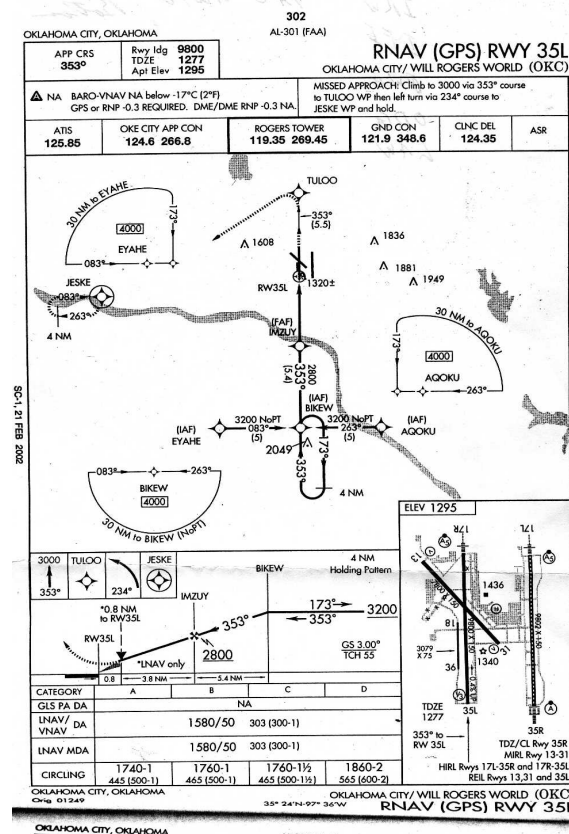


Figure 1 RNAV Approach Plate

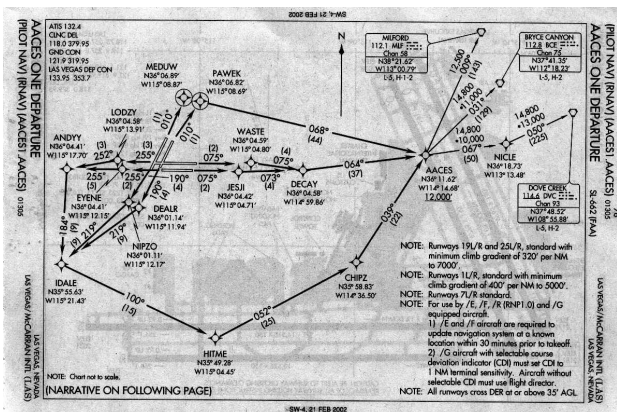


Figure 2 RNAV Departure Procedure

2.-Flight Inspection System. The FAA Flight Inspection fleet contains several different aircraft types (B300 King Air, Lear 60, Bae 800-125, Challenger C1601) these aircraft perform the AVN flight inspection mission both domestically and internationally. Although these aircraft have diverse performance and flight endurance capabilities, the flight inspection system configuration and capability are consistent. The flight inspection system uses a combination of real-time Global Positioning System (GPS)/Inertial Reference Unit (IRU) hybrid position, DME/DME and pseudo-time IRU velocity measurement as the truth system during flight inspection. The RNAV inspection mode is comprised of a WAAS precision approach mode and a DME/DME sub-mode.

a. RNAV DME/DME The Flight Inspection System (FIS) configuration for DME/DME RNAV inspection utilizes the real-time IRU hybrid position as the truth system, the flight inspection systems digital TACAN and the multiple facility capability of a transport grade DME-900 transponder. In the DME/DME mode the flight inspection system is restricted to GPS/IRU hybrid positioning due to the extensive use of the single flight inspection DME unit and the accuracy provided by the IRU hybrid position.

The flight inspection systems digital TACAN is used to measure the multiple DME facilities signal strength. The system supports both departure and approach procedures conducting analysis of up to five DME facilities simultaneously. The

flight inspection system receives flight plan waypoint positions and identifiers from the Flight Management System (FMS), after designation by the system operator of the Final Approach Fix (FAF) a search of the flight inspection system database is initiated based on the geodetic position of the FAF waypoint. This search mirrors the function performed by the AFS-420 DME/DME screening model. The operator can edit the provided list of DME facilities if required to insure that the facilities under inspection match those selected for the procedure.

The FIS computer configures the FI DME for directed frequency mode tuning each of the five available slots to one of the selected DME's. While in the directed frequency mode the DME will continually acquire and track each station for a period of 100ms. This provides updated distance data at a minimum rate of 2 Hz when 5 facilities are tuned. The FIS digital TACAN is also tuned to each facility under inspection reporting the facilities signal strength for a 5 second period then re-tuning each facility in a round robin routine.

NAU DATA				DME/DME NAU TEST CTRL DATA				PAGE 1 OF 3			
P-RNG	004.2			DME ID	RNG/BRG	ERR/SS	ERR/DIST	SS/DIST	MAX	MIN	
P-BRG	107.3										
P-HDG	195.2										
P-ANG	00.04										
ALT-B	03099										
F/W	03119										
GND SP	233										
VARIAS	00057X										
IRU S/D	00/000										
D/T	032502/2019										
UTC	***:***:***										
HPL (W)	0068.0										
UPL (W)	0085.1										

CMD STRT	STOP	WAAS LAT	*****:***:***	IPR	***:***:***						
EXEC CMD		WAAS LON	*****:***:***	IPR ER	***:***:***						
		WAAS ALT	*****:***FT	ICS BG	***:***:***						
AUTO THFIX	REFIX			ICS ER	L***:***:***						
ATK U***:***:***											
XTK R***:***:***											
FXHT ***:***:***											
EXEC FIX											

								FLIGHT PLAN		HOLD FLG 00	
TYPE	APPROACH									HEALTHY	7
DRS/PT	#103/000001A/C									USED	122
DME/DME	YES	IEYAE	IAF							APRCH	NP
TO WPT	IEYAE	IBKEW	IF								
R/B	11.4/184.8										
		IRW3SL	RDP								

ANNOUATE:											
DATLS FAIL											

EXEC SETUP ?											

Figure 3 DME/DME Inspection page

The system provides a station "HOLD" functions allowing constant monitoring of an individual facility interrupting the signal strength scan. The system also decodes and verifies that the tuned stations are transmitting the proper Ident. code. The DME/DME inspection page provides the operator with real-time range/bearing to the facility, current error and signal strength.

The maximum distance error and minimum signal strength are recorded at the distance from the selected runway.

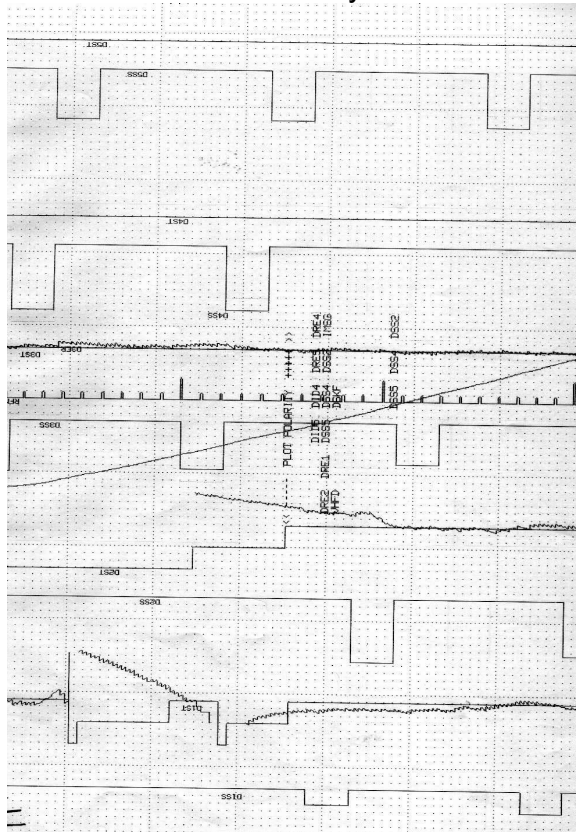


Figure 4 DME/DME Plot

The five facilities under inspection have corresponding plots for Distance Error, Signal Strength, and Status. The plot also contains a FI range mark representing the distance from the selected runway threshold in .1nm increments, with 1nm-enhanced marks. Upon any waypoint crossing a plot annotation of waypoint identifier, current altitude, range/bearing to selected runway is produced. A barometric altimeter trace is also provided. The DME status trace for each of the five DME facilities provides an indication of the flight inspection DME receivers state during the entire scan cycle. Reported states indicate normal operation, Coast, or No Computed Data (NCD). The Status trace when reporting normal operation underlies the DME error trace providing an easily recognizable zero error baselines.

The AFIS monitors the parameters and applies the following tolerances and will generate an operator alert when tolerances are exceeded.

DME Parameter	Alert Level
Distance Error	> 0.1 nm

Signal Strength	< -80 dbm
Facility Ident.	No Ident. > 45 sec.

Table 1 DME/DME Tolerances

Operation of the system during Approach or departure modes are identical with the exception of an operator selection of either approach or departure profile. This provides the system with correct orientation of runway end reference and alignment of FI mark traces on the plotter recording.

The system digitally records all position and inspection information to a removable media for post mission analysis when required.

b. WAAS Approach

The WAAS approach inspection mode has been developed to comply with the performance and data requirements as defined in the FAA Order 8200.WAAS. Additional capabilities have been included to provide support for FAA and AVN WAAS testing during the WAAS ORE and initial aircraft integration.

The inspection mode utilizes runway data from the AFIS database for comparison of Final Approach Segment course alignment, Reference Datum Point (RDP) to threshold position comparison, and Threshold Crossing Height (TCH) calculations. The procedure data (waypoint Lat/Lon and Altitude) is digitally transferred from the FMS.

NAU DATA				WAAS	NAU TEST CTRL DATA	PAGE 1 OF 3
P-RNG	000.4	I	WAAS	PRST	AVE	WDRST/RNG/UTC
P-BRG	1093.5	I	IXTK	-9999	0003	0019/01.7/17:10:58
P-HDG	184.5	I	IXTKR	0075	0001	0007/04.4/17:09:56
P-RNG	99.99	I	IATKR	0012	0007	0155/04.6/17:09:51
ALT-B	03203	I	IHPL	0036	0036	0037/00.1/17:11:35
F/W	03202/03104	I	IUPL	0063	0064	0066/02.5/17:10:41
GND SP	238	I	ISNR-W	036	034	032/00.9/17:11:16
UABIAS	00090X	I	IHDOP	00.97	01.00	01.00/04.6/17:09:51
IRU S/D	00/002	I	IHFDM	0017.8	0012.2	0017.8/00.0/17:11:36
D/T	032002/1715	I	IUDOP	01.44	01.44	01.44/04.6/17:09:51
UTC	17:14:133	I	IUFDM	0016.4	0016.7	0017.2/02.5/17:10:41
HPL(W)	0037.1	I				
UPL(W)	0063.5	I				

CMD	STRT	STOP	I	WAAS	LAT	N035^23^11.25
EXEC	CMD		I	WAAS	LOH	W097^44^13.40
			I	WAAS	ALT	03104.50FT
PLT	THFIX	REFIX	I			
ATK	U000.0	U000.0	I			
XTK	R000.0	R000.0	I			
FXHT	044.0	051.9	I			
EXEC	FIX		I			

TYPE ON				FLIGHT PLAN		IULD FLG 00
DRS/PT	#012/00846	I	A/C	165.31^M/010.54/0.00^		IHEALTHY 8
DME/DME	NO	I	EYAKE	002.90^M/005.00/0.42^		IUSED 122
TO WPT	JESKE	I	BIKEW	352.97^M/005.40/0.65^		IAPRCH NP
R/B	06.0/254.0^	I	IMZUY	352.96^M/004.59/3.00^		
		I	IRW3SL	353.12^M/005.54/2.20^		
ANNOTATE						
DATLG	RUN					
						EXEC SETUP ?

Figure 5 WAAS Inspection Page

The WAAS inspection profile is flown as designed (see RNAV procedure Figure 1). The AFIS system can be placed in a run condition at any point in the initial segment. The AFIS will automatically begin data collection for Path and Course Alignment at the FAF waypoint. All results data presented on page 1 are from the Final Approach Segment (FAS) (FAF to RDP). The FAS Course alignment is based on the last mile to threshold. The measured Path Alignment is based on the entire Final Approach Segment. WAAS related parameters displayed at the top of the inspection page represent "Present" or real-time values, "AVE" is the average value from the FAS, and "WORST/RNGE/UTC" is the worst value for each parameter recorded during the FAS, the range to threshold and the time of occurrence. All values except the present data are refreshed during the back correction process.

3. – Flight Inspection Policy

DME/DME RNAV

The FAA draft policy on DME evaluation in support of RNAV approach and departure procedures have been implemented to insure that the DME environment provides accuracy, coverage, and geometry adequate to support the navigation solution required for the RNAV procedure. The geometry of the DME facilities used by the procedure is verified by the DME screening model during the initial procedural design.

The aircraft used for RNAV inspections are required to be equipped with an FMS, Scanning DME sensor, and Inertial providing coupled guidance to the aircraft flight control system. The crew will fly the procedure with the DME and IRU selected as the primary sensors, requiring that the GPS sensor be disabled. The other FMS is configured to use the GPS sensor as its primary navigation source and is used during the inspection for comparison of course guidance.

a. – DME/DME Departure

The operator verifies that the retrieved facilities match those defined in the procedure package. The DME facilities shall be evaluated from takeoff rollout to a point 30nm from the airport. The aircraft shall use the minimum climb gradient and altitudes specified in the procedure. The course alignment of the procedure is verified and monitored during the departure.

The AFIS system in DME/DME mode is use to monitor and collect data on the facilities called out in the procedure package (previously determined via modelling during procedure development). The criteria directing the inspector at what point of the departure the DME facilities must become valid has not been finalized. It has been discussed that the distance shall correspond to the ability of an IRU sensor to maintain position accuracy within the RNP .3 criteria. DME error less than .2 nm is verified along with continuous lock-on. Signal Strength is monitored by the system but no inspection tolerance is applied.

b. - DME/DME Approach

The operator verifies that the retrieved facilities match those defined in the procedure package. The DME facilities shall be evaluated from the Intermediate Waypoint (IWP) through the Final Approach Fix (FAF) to the procedure Decision Altitude (DA). It is anticipated that DME availability will be lost during the Final Approach Segment (FAS) prior to the DA, the IRU shall provide guidance during the remainder of the FAS and through the Missed Approach Segment if a missed approached is executed. The Approach is evaluated at 100' below procedural altitude.

The criteria for procedural denial is when insufficient or poor geometry prevents operations at an RNP .3 level. DME facility tolerances in the Approach mode are as depicted in Table 1.

WAAS Policy

The FAA has developed a draft WAAS inspection policy order, 8200.WAAS. This order details the flight inspection procedures, requirements for the evaluation of WAAS precision and non-precision approach procedures. The FAA has taken a comprehensive attitude concerning the policy covering the initial stages of WAAS precision approach. This will provide significant insight into all aspects of the WAAS environment as it relates to the available signal in space and the accuracy attainable during approach operations. There are five major sections called out for flight inspection analysis.

4.1 Procedural Design and Data base integrity.

4.2 Horizontal Alignment and Glidepath Angle

4.3 Missed Approach Segment

4.4 Satellite Parameters

4.5 Electronic Spectrum

The following table represents the tolerances applied and the section referenced for measured parameters.

Parameter	Ref.	Tolerance
Initial/Intermediate Approach Segment Procedural Design		
Magnetic Bearing to Next WP	4.1	$\pm 1.0^\circ$
Distance to Next WP	4.1	± 0.1 nm
Final Approach Segment Procedure Design		
Magnetic Bearing to LTP	4.1	$\pm 0.1^\circ$
Distance to LTP	4.1	± 0.1 nm
Glide Path Angle	4.2	$\pm 0.2^\circ$
Horizontal Alignment	4.2	$\pm 0.2^\circ$
Missed Approach Segment Procedural Design		
Magnetic Bearing to MAWP	4.3	$\pm 1.0^\circ$
Distance to MAWP	4.3	± 0.1 nm

Table 2 WAAS Inspection Tolerances

The parameters listed from section 4.2 are measured using the AFIS corrected position, all others are geodetically calculated by AFIS from FMS data base waypoint Latitudes and Longitudes or AFIS data base facility runway data and compared to the procedure data package.

The satellite parameters called out for collection in section 4.4 have no tolerance applied and are logged by the AFIS for post mission analysis if required.

Electronic spectrum checks are only required if the lack of available signal prevents or degrades GPS/WAAS performance so that the procedure can not be completed.

4.-Flight Inspection Results These flight inspection results represent a sample of the data collected during test flights conducted in the WAAS and DME RNAV environments.

Date	FAC	PA	CS BRG	TCH	GPI
3/20/2002	OKC35L	3.00	359.97	49	942.00
3/20/2002	OKC35L	3.00	359.97	54	1033.00
3/20/2002	OKC35L	3.01	359.96	49	942.00
3/20/2002	OKC35L	3.00	359.89	52	991.00
3/20/2002	OKC35L	3.01	359.97	54	1017.00
3/21/2002	OKC35L	3.01	359.97	54	1017.00
3/21/2002	OKC35L	3.02	359.93	55	1041.00
3/21/2002	OKC35L	3.02	359.94	57	1071.00
3/21/2002	OKC35L	3.01	359.93	52	981.00
Measured	Average	3.01	359.95	52.89	1003.89
Calculated		3.00	359.96	54.00	1038.00
Difference		0.01	0.01	-1.11	-34.11

Figure 6 WAAS Inspection Results

The WAAS results in Figure 6 represent multiple runs on consecutive days on runway 35L at Oklahoma City's Will Rogers World Airport. The procedure is a strait-in RNAV approach with a calculated path angle of 3.00 degrees and course of 359.96M, with a calculated TCH of 54'. The individual runs along with the measured average are well within the draft tolerance. The TCH and GPI are within acceptable limits; these values will be further discussed later in this paper.

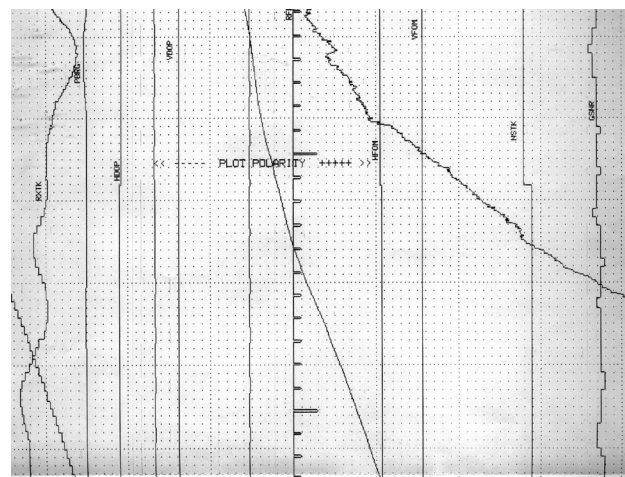
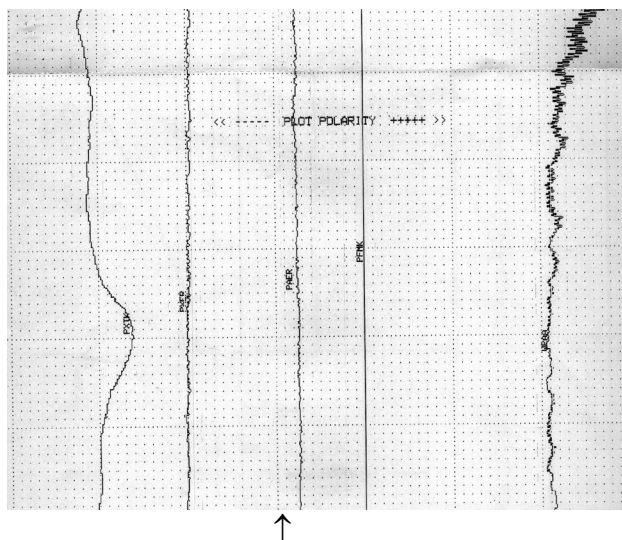


Figure 7 WAAS Real-time Plot

The WAAS mode real-time plot contains the following parameters:

WAAS Altitude	Barometric Altitude
Cross Track	Radio Altimeter
Bearing to Threshold	HFOM
HDOP	VFOM
VDOP	# of Satellites tracked
HPL	GEO SNR
VPL	WAAS Valid

For most of the listed approaches the WAAS receiver was tracking 10 GPS satellites, 9 satellites were being used in the WAAS equation and most approaches were completed through the low approach with 8 or more satellites maintained. The WAAS GEO remained in a track state with valid corrections though out the test flights.



Along Track Baseline

Figure 8 WAAS Approach Corrected Plot

The corrected plot contains Cross Track (PXTK), Cross Track Error (PXER), Along Track Error (PAER), FI Marker (FI MRK), and WAAS Path Angle (WPAA). The corrected plot is produced for the entire Final Approach Segment. Scaling of PXTK, PXER, and PAER are 100"/inch. WPAA scaling is .2 deg./inch.

This plot shows a re-occurring anomaly that is being investigated. The along track error shows a consistent 30' bias, this is evident in all plots collected in the above referenced data set. It also is substantiated in the GPI and TCH results from Figure 6. This does not seem to be a WAAS position latency error in that the error is in the negative sine. The receiver used in these test flights required some rework of the GPS timing pulse logic early

in the AVN WAAS program these were thought to be resolved. It is possible that the pulse timing logic or an AFIS correlation error remains. With the consistency and repeatability of the bias, resolution of this issue should not be difficult.

All other plotted parameters show error's well within expected limits and clearly show the stability and accuracy of the WAAS signal.

CONCLUSIONS

The incorporation of space based position and augmentation systems into the U.S. National Airspace System (NAS) will provide additional resources for the air transport and private aviation communities. The transition from conventional ground based navigation aids will require sufficient time to allow these new technologies to mature and become economically available. The merge of both conventional and space based navigation resources in the RNAV environment poses' challenges to both the flight inspection and regulatory branches of all aviation authorities. The flight inspection community must provide the aviation community with assurance of navigation system service volume, continuity of service, and accuracy. With the ever increasing use of integrated navigation solutions, where aircraft systems manage and utilize ground based, aircraft autonomous and spaced based navigational resources the certification and regulatory side of the aviation industry must remain ever vigilant. The increased use of RNP criteria on terminal airspace, air routes, and approach procedures will increase airspace efficiency and safety.

REFERENCES

- 1.- FAA Order 8260.48, Area Navigation Approach construction Criteria.
- 2.- TM3500-071 AFIS System Description Manual, Parker Haniffin Corp.
3. – TI4040.55 FAA AFIS Technitions User Manual
4. – TI4040.56 FAA AFIS Pilots Guide
5. –FAA 8200.1A, Flight Inspection Manual

6. – Draft FAA 8200.1° Paragraph 209.32.e
(9)
7. – FAA Order 8260.44, Area Navigation
Departure criteria
8. – FAA AC 90-RNP RNAV, Operational
approval for Required Navigational
Performance Area Navigation (RNP
RNAV)

