Federal Aviation Administration Implantation of WAAS LPV Procedures March, 2004

John Heiderstadt
Sr. Engineer, DataCom, FAA (AVN-210)
6500 S. MacArthur
Oklahoma City, OK 73169
Tel. (405) 954-7363
E-mail:
John_heiderstadt@datacomsciences.com

ABSTRACT

With the acceptance of the WAAS in the third quarter of 2003 the FAA has provided an additional resource to the National Airspace System (NAS). The commissioning of 500 new WAAS LNAV/VNAV procedures has provided a significant base for the full implementation of GNSS technologies. The FAA WAAS LPV program required the introduction of new policies and procedure development guidelines with strict adherence to insure data integrity. This paper shall discuss the specific guidance as defined in ARINC 424-17, FAA WAAS LPV Procedure Development 8260-19c, WAAS MOPS 229c, and FAA Order 8200.1. There have been specialized software tools developed by the FAA to insure the integrity of data associated with the Final Approach Segment (FAS) data block Cyclic Redundancy Check (CRC) from procedure development to Flight Inspection, and publication. The modifications made to the AVN aircraft systems and AFIS in support of WAAS LPV will be described with block diagrams and the hardware utilized defined. The results of the initial LPV approach Flight Inspections will be discussed and provided for review.

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 WAAS program has been in progress for several years culminating in the commissioning of the system in 2003. The road to this achievement has been one filled with both economic and technical hurdles. Initial WAAS procedures were developed using RNAV guidance from FAA Order 8260.48, this provided approaches with waypoints representing the approach track and path to the threshold using three dimensional coordinates stored in a navigation database. This proved successful but only provide minimums coincident with existing LNAV/VNAV approach. This drove the incorporation of Final Approach Segment (FAS) data block similar to the intended format used in the emerging LAAS program. These changes in WAAS procedures drove significant changes in Flight Management System (FMS), WAAS Sensor, and Flight Inspection systems.

SUBJECT

1. LPV Procedures Development

The development of LPV 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, development of data proceses and databases with Cyclic Redundancy Check (CRC) integrity, implantation of these criteria into LPV approach procedures by AVN-100, and flight inspection procedures for commissioning prior to publication.

a. LPV Approach Criteria

The FAA order 8260.50 establishes the guidance and provides the approach construction criteria for the development of LPV procedures using GPS SBAS augmented systems (WAAS). The criteria establishes approaches with Vertical Alarm Limits (VAL) of >12 meters and <50 meters. This provides approach minima of >=250 feet .

b. LPV Approach Design

The FAA order 8260.19C defines the LPV procedure development requirements, Appendix 11 of this order defines the content of the FAS data block and associated CRC code requirement. This document references RTCA/DO-229C, MOPS for Global Positioning/Wide Area Augmentation System and FAA TSO-C146A for further definition on mandated data element content and CRC computation sequencing.

Since the concept of the FAS data block requires the computation and encoding of a CRC from procedure inception. AVN required the development of software tools to meet the strict integrity requirement. To accomplish this task AVN developed an internal system to retrieve waypoint data from AVN's AIRNAV database combine this data with data elements defined during the AVN-100 procedure development process producing a ARINC-424-17 compliant ASCII and XML file. This application also computed and encoded the FAS CRC into a binary file. This development process was accelerated by entering into a Cooperative Research and Development Agreement (CRADA) with Universal Avionics Systems Corporation. This agreement

provided a vehicle to accomplish two major goals. First providing AVN with a method of converting NAS databases resident at or available to AVN to ARINC-424 compliant format, and then produce Universal FMS databases containing pre-commissioned procedures.

Data Content Description	Bits Total	Bits Used	Example Values	Message Bit Pattern for Example Values transmitted from left to right	Message in Hexadecimal LSB First
FAS Block 1					
Operation Type	4	4	0	0000	
Spare	4	4	0	0000	00
Airport ID	32	24	KACY	10011000 11000000 10000000 11010000	19 03 01 0B
Runway Number	6	6	13	101100	
Runway Letter	2	2	no letter	00	0D
Approach Design Info	3	3	0	000	
Route Indicator	5	5	A	10000	08
Reference Path Data Selector	8	8	10	01010000	0A
Reference Path ID	32	24	GACY	10011000 11000000 10000000 11100000	19 03 01 07
LTP Latitude	32	32	N 39.464259°	10010010 00110101 11110111 00001000	49 AC EF 10
LTP Longitude	32	32	W 74.5910131°	01000011 11110100 10111111 11111011	C2 2F FD DF
LTP Altitude	16	16	-12.2 meters	01100001 11001000	86 13
FPAP Latitude	32	32	N 39.5092547°	01010011 10111001 00101111 00001000	CA 9D F4 10
FPAP Longitude	32	32	W 74.5202869°	01110111 00101111 00100000 00000111	EE F4 04 E0
Threshold Crossing Height (TCH)	15	15	50 feet	00101111 1010100	
TCH Units Selector	1	1	feet	0	F4 15
Glidepath Angle	16	11	3°	00110100 10000000	2C 01
FAS Block CRC	32	32		11000101 10110111 01010101 11111011	A3 ED AA DF

Figure 3: FAS Format

These software processes provide AVN with the digital data required to support the procedure development and FMS data base requirements. But until such time as the aircrafts FMS operational software could be modified, AVN required a means by which to download this data to the AFIS system. This drove the development of an additional software application to package the procedure specific binary FAS data packets into a supplemental database for use in the AFIS system. The compiled file was required to maintain the integrity of the individual procedure CRC.

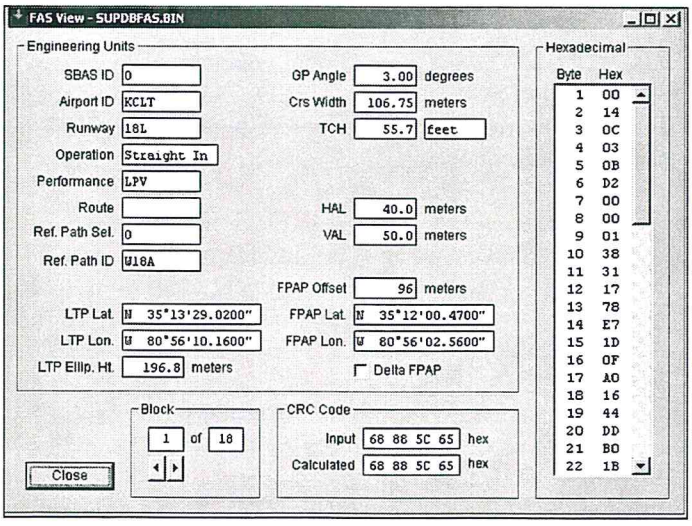

Figure 1: FAS Packing tool

e. -Sample Procedures

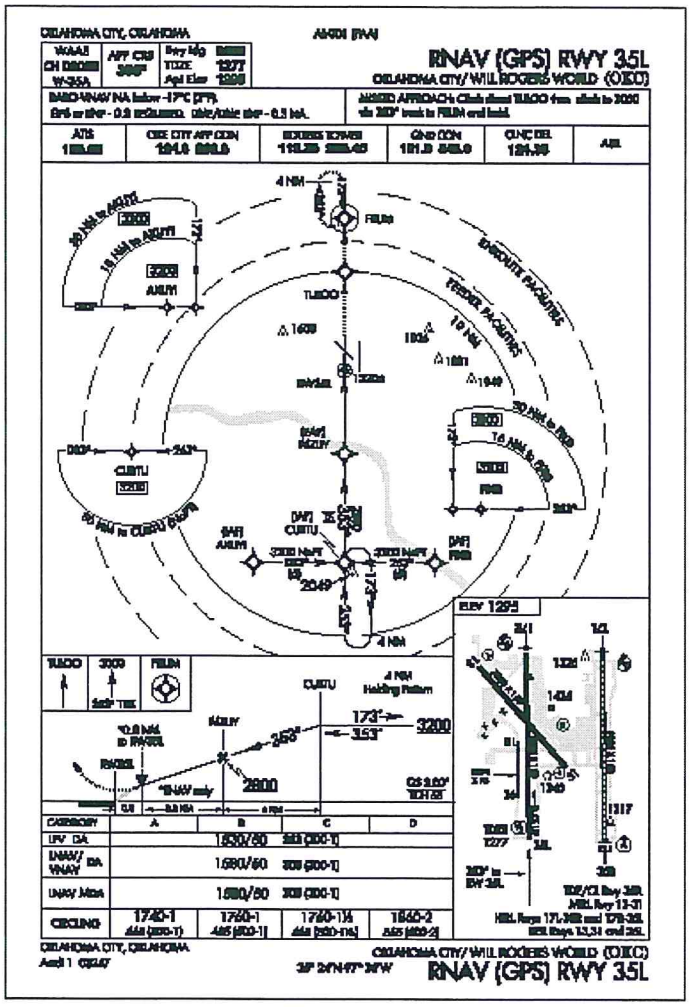

Figure 2: RNAV Approach Plate

2. Flight Inspection System.

The FAA Flight Inspection fleet contains several different aircraft types (B300 King Air, Lear 60, Bae 800-125, Challenger Cl601) 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, DGPS and pseudo-time IRU velocity measurement as the truth system during flight inspection. The RNAV LPV inspection mode is an extension of the WAAS approach mode.

a. 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.

The WAAS inspection profile is flown as designed. 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.

b. LPV Approach

The addition of WAAS LPV approach mode utilizes much of the capabilities in the existing mode, for this paper only the additions to support incorporation of the FAS data block shall be defined.

The binary FAS database resides on a removable media and is accessed by the AFIS from the systems facility page.

```
                    FI WAAS FACILITY DATA
APT ID KOKC
RWY ID 17R
SIAP ID:

TH LAT N035°24'21.42
TH LON W097°36'20.60
TH HGT    +01281FT
HE HGT    +01263FT
RW LEN     09800FT
RW BRG     179.96°
MAGVAR     W12°00.0

COUNTRY CODE US                SELECT DATUM        FAC
ACTIVE FLAG  ACTIVE
FAS DATA BLOCK INFORMATION
DATA                    DATA        DATA FIELD        DATA
OPERATION TYPE            0         FPAP LATITUDE     352242L.4900N
SBAS SERVICE PROVIDER INFO 0        FPAP LONGITUDE    0973620.5100W
AIRPORT IDENTIFIER        KOKC      TCH               00055.0
RUNWAY NUMBER             RW17R     TCH UNIT SEL      F
APPR PERF DESIGNATOR      0         GLIDE PATH ANGLE  03.00
ROUTE INDICATOR                     COURSE WID AT THR 106.68
REF PATH DATA SELECTOR    0         HAL               40.0
REF PATH IDENTIFIER       W17A      VAL               50.0
LTP/FTP LATITUDE      352421.4200N    LENGTH OFFSET     0093
LTP/FTP LONGITUDE     0973620.5000W   CRC REMAINDER     E104FC14 CRC ERROR E105AC3B
LTP/FTP ELLIP HGT       +00364        ICAO CODE         K0          OVERRIDE?
LTP ORTH HEIGHT         +00391        FPAP ORTH HEIGHT  +00391
CHG LAT/LON DSPLY FORMAT
PGM  RNV 555-050-025*                  DELETE   SAVE
     FIS 555-050-026*                  DB: NORMAL
DATA BASE SEARCH ENABLED                     EXECUTE ?
```

Figure 5.5.2.2 - FAS WAAS Facility Data Page

The SIAP ID field and its association with the selected runway identify the LPV procedure. The AFIS conducts CRC verification while reading the requested procedure from the file. Once the CRC is verified the AFIS will accept the selected approach and using the FAS data constructs a pseudo flight plan.

```
                    WAAS FLIGHT PLAN              Page 2 of 3

APT ID   KOKC      FAS BRG/M      179.00°    FAS P-ANG      03.00°
RWY ID   17R       FAS BRG/T      179.96°    FAS DIST       05.00NM
SIAP ID:           RDP-TH DIST    00001FT    FAS OFFSET     L00.0L°
RWY BRG: 179.96°   PREDICT GPI    00980FT    PREDICT TCH  +0050.0FT
                                              PREDICT E/H +0029.0M

DSG TIMER: DSG ENTRY ALLOW        ALIGN DIST:  01.00NM
CHG LAT/LON DISPLAY FORMAT
WPT   DSG     Ellip HGT    LAT              LON

PF17R PFAF    02837FT    N035°19'20.90   W097°36'20.30
A/C           01920FT    N035°22'21.20   W097°36'20.50
RW17R LTP     01244FT    N035°24'21.42   W097°36'20.60

                                  EXIT DSG?
```

Figure 5.5.3.1 - Typical WAAS NAV/Test Control Data Page 2 (Flight Plan Page)

Once the operator accepts the flight plan the system operation is consistent with the LNAV/VNAV WAAS inspection process.

3. Flight Inspection 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 Aproach 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	± 1.0°
Distance to Next WP	4.1	± 0.1 nm
Final Approach Segment		
Procedure Design		
Magnetic Bearing to LTP	4.1	± 0.1°
Distance to LTP	4.1	± 0.1 nm
Glide Path Angle	4.2	± 0.2°
Horizontal Alignment	4.2	± 0.2°
Missed Approach Segment		
Procedural Design		
Magnetic Bearing to MAWP	4.3	± 1.0°
Distance to MAWP	4.3	± 0.1 nm

Table 1: WAAS Inspection Tolerences

The parameters listed from section 4.2 are measured using the AFIS corrected position, all others are geodeticly 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 satalite parameters called out for collection in section 4.4 have no tolerence applied and are logged by the AFIS for post mission analysis if required.

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

4. Flight Inspection Results

The inspection results of the initial LPV procedure commissioning were consistent with WAAS procedures previously flown. Providing smooth transitions and accurate guidance to the runway threshold. The addition of the FAS data block to the WAAS procedures was not intended to enhance the system accuracy but lower the minima and increase integrity. The ability of the ground based software systems and the AFIS to verify the CRC provide three independent check's of the wrapping format and process, this lead to the early discovery of several differences in FAA and industry documents on the subject. This independent verification allowed the procedures to be flown with data who's integrity had been verified prior to departure.

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 addition of the CRC wrapped FAS to the WAAS LNAV/VNAV approach procedures will provide lower minima and increase integrity. The combination of lower minima and the eventual incorporation of complex approaches will provide additional options to both the Air Traffic System and the flying public. Transition from conventional ground based navigation aids will require sufficient time to allow these new technologies to mature and become economically feasible. 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 aproval for Required Navigational Performance Area Navigation (RNP RNAV)