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September 16, 2005

Mr. John Lufkin
FAA, MMAC, AVN-7
P.O. Box 25082
Oklahoma City, OK 73125

Dear Mr. Lufkin:

Enclosed is a copy of our report, "Recommended Flight Measurement Methodology for Periodic Flight Inspection of GPS/RNAV Approach Procedures." This submission is intended to partially satisfy the requirements for Contract DTFAAC-03-A-15689, Task Performance Work Statement 0001.

Please contact us if there are any questions.

Sincerely,

for David W. Diggle, Ph.D.
Associate Director

DWD:lp
Encl: OU/AEC 05-03TM15689-1, Final (electronic))

TECHNICAL MEMORANDUM
OU/AEC 05-03TM15689-1

RECOMMENDED FLIGHT MEASUREMENT METHODOLOGY FOR PERIODIC FLIGHT INSPECTION OF GPS/RNAV APPROACH PROCEDURES

Currently, the FAA is in the process of commissioning a substantial number of GPS/RNAV approaches. The periodic inspection for an increasing number of procedures, combined with the need to continually commission new procedures, creates a high-demand for GPS/RNAV equipped flight inspection aircraft and crews. This report documents a study performed to investigate ways of maximizing the effectiveness of the flight inspection fleet for these procedures without compromising the integrity of the flight inspection process. It includes recommendations for revision of the United States Standard Flight Inspection Manual.

by

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September 2005

FAA Aeronautical Center
Aviation Systems Standards
Oklahoma City, OK 73125

Contract DTFAAC-03–A-15689
Task Performance Work Statement 0001

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I. INTRODUCTION

Standard Instrument Approach Procedures (SIAPs) contain the procedural information that allow pilots to safely transition from the enroute to the landing phase of flight during periods of low cloud ceilings and poor visibility. Until the age of the microprocessor, approach procedures were developed based on the specific guidance or landing system to be used. Non-directional beacon (NDB), VOR/DME, and ILS procedures are all examples of non-precision and precision instrument approaches that are based on a specific navigational aid. The methods for defining the flight path, determining decision altitudes, evaluating obstacles, and flight inspecting the procedure are system specific in these cases.

Microprocessor-based navigation receivers provide a means for conducting area navigation (RNAV) operations. The flight path is generically defined by waypoints that may be entered manually or loaded from a navigation database, depending on the criticality of the operation. The navigation information may be provided by a single system or a combination of different systems. GPS, WAAS, LAAS, VOR/DME and DME/DME integrated with inertial or non-inertial flight management systems (FMS) are all examples of systems or combinations of systems that can be used to support RNAV operations. RNAV approaches can be of the precision and non-precision type. Precision RNAV approaches provide both lateral and vertical navigation (LNAV/VNAV) information while non-precision approaches provide lateral navigation (LNAV) guidance; vertical guidance, if optionally provided, is advisory only. It can be based on barometric and/or GPS data. The development and implementation of RNAV approach procedures provide two unique challenges for flight standards. These challenges are ensuring the integrity of the database used for these procedures and developing an efficient charting method. Both of these topics are discussed in the following paragraphs.

RNAV operations impose accuracy, reliability, and integrity requirements on the development and processing of aeronautical databases within the time constraints of the aeronautical information publication cycles. Currently, factions other than official source suppliers can and do originate and/or modify aeronautical data to supplement customer requirements, or resolve compatibility issues with user equipment. Most modifications or additions in the data typically prove to be inconsequential as far as aircraft performance is concerned. However, conformance with procedure design criteria, such as obstacle clearance surfaces and course/track requirements, as well as obstacle data requirements may be compromised.

Accordingly, Aviation System Standards (AVN) has taken the position that RNAV procedures completed within the organization will be developed, flight inspected, and published in a manner that ensures the source data will not be degraded. This position applies to both conventional publications (paper charts) and aeronautical database and is assured as follows:

a) Procedure development centers on compliance with criteria, governing policies, and standards established by Flight Standards Service (AFS), which is compliant with Navigation System Data Base ARINC 424 specifications.

b) Flight Inspection is provided guidance through FAA Order 8200 to complete RNAV procedure inspections by using data/database compliant with "official government source documentation". Verification to source data is critical, because variations of

ARINC 424 path and terminators can result in different navigator performance and aircraft ground and vertical tracks.

c) Verification of published information is being extended to electronic databases by having flight inspection conduct inspections using an FAA developed aeronautical database developed exclusively with source documentation.

Applying the above factors will ensure that the lateral and vertical track designed and evaluated by the procedure designer is the same one flown by an aircraft. In addition, the procedure must meet existing criteria, is operationally safe, practical, and flyable. The aeronautical database path and terminators are the same ones used in procedure development and validation, and are identical to the conventional paper chart available to the pilot.

For example, the Final Approach Segment (FAS) Data Block for WAAS LPV approach procedures contains critical data elements used in the development of the final approach segment of the designed procedure. This information is coded into binary files by the procedure developer and the integrity is then protected with a Cyclic Redundancy Check (CRC), a test to see whether data has been transferred properly. The sender of the data adds a check number to the end of the data being sent, and the receiver applies the same CRC check to the data and compares the number it gets with the check number. If they don't match, the data errors must be resolved.

Although RNAV approaches use many different types of navigation systems or combinations of systems, all of these approaches have essentially the same operational procedure. Consequently, the FAA developed an operational concept that defines approach procedures for all RNAV systems using a single approach chart where the system title is “RNAV RW XX”. An example approach chart is shown in Figure 1.

RNAV approach procedures typically have up to four lines of minima, each having a specific decision altitude (DA) or Minimum Decent Altitude and visibility requirement [1]. The capability of the navigation equipment on the aircraft determines which minima are authorized for use. The four levels of minima are: LPV, LNAV/ VNAV, LNAV, and circling (see Figure 1). An LPV approach is a precision instrument approach based on WAAS lateral and vertical guidance to a DA not less than 250 feet. The LNAV/VNAV landing minimums are applicable if both lateral and vertical guidance information is available while the LNAV minimums are used if vertical guidance is unavailable. The circling minimums typically apply when winds do not favor landing on the runway served by the approach or a requirement exists to land on a different runway.

It is widely recognized that vertically-guided approach procedures are safer than purely laterally-guided approaches. Step-down fixes, associated with non-precision approaches, increase pilot workload because the approach lacks vertical stability. This realization provides the motivation for developing and commissioning procedures with vertical guidance. Since the year 2000, FMS GPS/Baro VNAV systems have been certified for conducting select specialized LNAV/VNAV approach procedures.

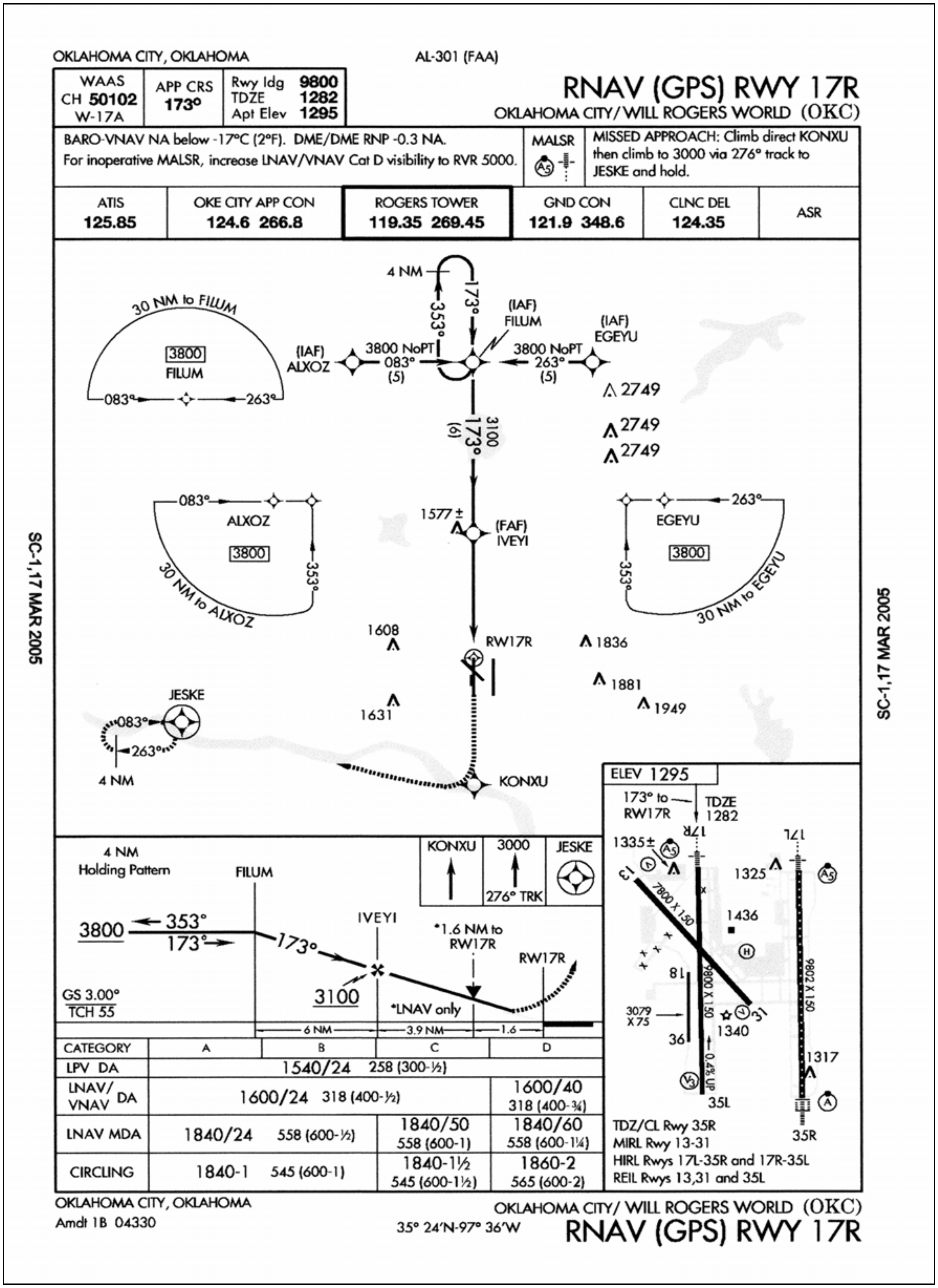

Figure 1. Example RNAV Approach Chart.

II. BACKGROUND

Ohio University has a long history of conducting studies to develop, refine, or evaluate flight inspection criteria for the Office of Aviation Systems Standards. Ohio University completed a study in September 1998 that developed provisional flight inspection criteria intended for WAAS commissioning flight inspections, with emphasis on the criteria to be applied to the Final Approach Segment [2]. The project report for this study is provided in Attachment A.

While WAAS was progressing towards operational approval, the FAA commissioned a substantial number of GPS/RNAV approach procedures. It was estimated that approximately 700 of these procedures could be commissioned and published prior to WAAS obtaining authorization to support such procedures [3]. Conventional thinking would have been that a "WAAS flight inspection" needed to be conducted before WAAS was authorized for use in performing said procedure. The consequences of such a case were not desirable considering the following two possible inspection strategies. One strategy would have been to conduct an intensive WAAS flight inspection effort once WAAS was operational. This approach would not be practical given the extremely high flight-inspection workload that would result from such a surge effort. The other strategy would have been to perform the WAAS flight inspections when the existing GPS/RNAV periodic inspections were conducted. However, this approach was undesirable since WAAS authorization for some procedures would have been unnecessarily delayed by as much as 600 days.

In response to this situation, the Office of Aviation Systems Standards tasked Ohio University to develop recommended requirements for the commissioning inspection of WAAS LPV approach procedures that serve the same runway end as existing GPS LNAV/VNAV approach procedures [4]. To accomplish this task, existing GPS LNAV/VNAV commissioning flight inspection requirements were reviewed and then compared to anticipated WAAS LPV commissioning flight inspection requirements. The results of this comparison indicated that Geostationary Satellite (GEOSAT) signal coverage was the only WAAS LPV commissioning flight inspection requirement not accomplished during the commissioning flight inspection of the corresponding GPS LNAV/VNAV approach procedures. Ohio University developed the concept for a computer-based screening model that could be used to determine if GEOSAT signal coverage would exist, be marginal, or would not exist. This concept streamlined the flight inspection process for WAAS LPV procedures without compromising the integrity of the flight inspection process. One needs to realize that this approach was feasible for the WAAS LPV procedures since the GPS LNAV/VNAV procedure to the same runway end had already passed commissioning flight inspection, as well as any subsequent periodic inspections. For further details, the project report is provided as Attachment B.

At the present time, the FAA is in the process of commissioning a substantial number of WAAS LPV and GPS/Baro VNAV approach procedures. For the purpose of this latest report, WAAS LPV and GPS/Baro VNAV approach procedures will be referred to as GPS/RNAV approaches. The coverage of WAAS/GPS provides the potential for an unlimited number of procedures to be supported if the required airport infrastructure and data exists. After commissioning, these GPS/RNAV approaches are required to have a periodic inspection every 540 days [5]. The periodic inspection for an increasing number of procedures, combined with the need to continually commission new procedures, creates a high-demand for GPS/RNAV equipped flight inspection aircraft and crews.

The number of aircraft and crews that are expected to be available in the near future will be limited as compared to the number of GPS/RNAV procedures. Thus, the Office of Aviation Systems Standards has tasked Ohio University to conduct a study that investigates ways to maximize the effectiveness of the flight inspection fleet for GPS/RNAV approach procedures without compromising the integrity of the flight inspection process. Included is the identification and evaluation of alternative candidate flight inspection methods or concepts. This report documents the work performed and results obtained during the course of this study.

III. DEVELOPMENT OF METHODOLOGY

This section begins with a detailed comparison of the commissioning versus the periodic requirements for the flight inspection of GPS/RNAV approaches. The particular requirements relating to the periodic checks are discussed. The conclusion reached is that flight inspection efficiency can be boosted by combining some of the RNAV flight measurement runs with those associated with other types of approaches serving the same runway. A discussion of radio frequency interference issues is also presented. The information used in this portion of the report is primarily from Sections 209, 210, and 214 of the United States Standard Flight Inspection Manual [5].

A. Comparison of Flight Inspection Commissioning Versus Periodic Requirements for RNAV and WAAS/RNAV Approaches

Table 1, taken from Section 209 of Reference 5, is a checklist showing the various checks for an RNAV instrument approach procedure. The flight inspection checklist for the WAAS/RNAV approaches (Section 210) is identical. The table also indicates which portions are required to be checked for commissioning and periodic evaluations.

The intermediate, final, and a portion of the missed approach segments are required to be flown for a periodic inspection. The SIAP periodic review includes verification of the non-flight items associated with the charted procedure for which an aircraft is typically not needed. The one exception is that the SIAP review does include validating the altimeter setting source. Those SIAPs which reference a local automated weather system (AWOS/ASOS) to provide a current altimeter setting require use of an inspection aircraft in order to tune to the specified radio frequency and confirm the source. Flight measurements for Radio Frequency Interference (RFI) are required if measured GPS/WAAS parameters indicate the potential for RFI.

The GPS parameters measured are shown in Table 2. This table is divided into two sections: GPS and GPS WAAS. These include horizontal/vertical dilution of precision (DOP), horizontal/vertical protection level (VPL/HPL), horizontal integrity limit (HIL), horizontal figure-of-merit (HFOM), signal-to-noise ratio (SNR), number of satellite vehicles (SVs) being tracked and WAAS GEOSAT tracking status. In the case of a commissioning inspection for either an LNAV or LNAV/VNAV procedure, the parameters listed in Table 2 are monitored during the inspection and recorded if an anomaly is observed. The parameters listed in Table 2 are always recorded for a commissioning flight inspection of a WAAS LPV procedure. Table 3 provides values for the GPS parameters that can be used to baseline the approach.

Table 1. Flight Inspection Checklist for RNAV and WAAS/RNAV Approaches.

TYPE CHECK	COMMISSIONING	PERIODIC
DP/SID	X	
Route	X	
STAR	X	
Transition/Feeder Route Segment	X	
Initial Approach Segment	X	
Intermediate Approach Segment	X	X
Final Approach Segment	X	X
Missed Approach Segment	X	X
SIAP	X	X
RFI	See Note 1	See Note 1
Note 1: When GPS/WAAS parameters indicate possible RFI		

Table 2. Measured GPS Parameters for RAV Approaches.

GPS (LNAV or LNAV/VNAV)	GPS WAAS
HDOP	HDOP
VDOP	VDOP
HIL	HPL
HFOM	VPL
SV's Tracked	SV's Tracked (including GEOSAT)
SV's SNR	SV's SNR (including GEOSAT)

B. Discussion of Flight Inspection Procedures

A periodic inspection of a GPS/RNAV approach involves maneuvering the aircraft along the intermediate, final, and a portion of the missed approach segments of the procedure and evaluating the following: CDI/VDI guidance data; GPS parameters (see Table 2); obstacle clearance; and, as required, investigation of any RFI issues seen in the measured GPS parameters. The CDI/VDI guidance data is used to verify the flyability, alignment, and distances associated with the approach. For each segment, the "true course" and "distance to" measured values are compared to the procedural design values to verify that flight inspection tolerances are met. The data from Tables 2 and 3 is used to investigate anomalous system performance and spot potential RFI issues. Obstacle clearance verification is performed visually while flying the approach segments.

Table 3. Expected Values for Measured GPS Parameters.

PARAMETER	EXPECTED VALUE
HDOP	1.0 - 4.0
VDOP	1.0 - 4.0
HIL	0.3meters or less
HFOM	22 meters or less
SV's Tracked	5 minimum
SNR	30 dB/Hz minimum

It is also important to note that a vertically guided RNAV approach procedure and the LNAV-only procedure are designed with different obstruction criteria. The final segment of the approach may have different obstructions controlling the LNAV/VNAV and the LNAV-only minima. The final segment may require repeated flights for obstacle evaluation.

C. Modification of the Flight Inspection Procedures

As described in the previous sections, the flight inspection manual already specifies, in detail, the requirements and procedures for the periodic flight inspection of GPS/RNAV approach procedures. Deviation from these requirements will be required to reduce the periodic flight inspection workload associated with these procedures. In order to determine if deviations to, or reduction in, the flight inspection process can be made without compromising its integrity, one must consider both what is done during a periodic inspection and why it is done. In general, the need for periodic inspections stems from the fact that as time passes the performance of a system can degrade from that measured during commissioning or the obstacle environment can change. Table 4 lists high-level items that can cause degradation of system performance over time and is based on the authors' experience with a wide-range of navigation aids. For each item, a particular concern is noted as well as the method of mitigation. References cited in the table can be found in Section V of this study. Those items with concerns mitigated by periodic flight inspection include a change in the environment, RFI, and modification of the instrument approach procedure. These items are discussed in further detail in the following paragraphs.

Changes in the airport environment that result in the addition of new objects can cause electromagnetic scattering (multipath) or blockage of radiated signals. Thus, system performance may be degraded by multipath from man-made structures constructed subsequent to commissioning, or coverage adversely affected by vegetation/tree growth. In this case, the factors affecting guidance quality for ground-based navigation systems are quite different than for satellite-based technology. Since ray tracing will be used to illustrate this difference, a short introduction to ray tracing will be provided herein.

Ray tracing is a general technique that is used to determine where multipath or signal blockage may occur in space. Thus, it can be used to determine if an object can cause multipath or blockage along an approach procedure, and it can be applied for either ground-based or satellite-based systems. Simply stated, ray tracing for multipath is the application of Snell's law at building edges or corners. Snell's law states that the incident angle ($\mathbf{2}_i$) is equal to the reflection angle ($\mathbf{2}_r$) and is shown in the top panel of Figure 2 [13]. The middle panel of Figure 2 shows a two-dimensional application of ray-tracing at the vertical edges of a building, which produces a plan view of the multipath region. For determining regions where the signal may be blocked, or shadowed by a building, rays are drawn from the subject antenna "through" building edges or corners. A two-dimensional (plan view) example is provided in the bottom panel of Figure 2.

Figure 3 shows a three-dimensional example for a ground-based system in the top panel and a satellite-based system in the bottom panel. Since the antenna heights are typically shorter than building heights, ground-based navigation systems can be more susceptible to multipath from man-made structures or blockage by tree lines, etc. As illustrated in Figure 3, the multipath region due to the reflection of the signal from a ground-based antenna is typically projected upwards. Conversely, the multipath region due to the reflection of the signal from satellite antenna is typically projected downward, especially considering a satellite mask angle of 5 degrees elevation may be used in the case of satellite-based systems. Thus, provided the DA for a GPS RNAV approach procedures is above the tops of surrounding objects, the exposure of an airborne GPS antenna to multipath from such objects is unlikely.

The reader should note that the multipath discussion presented herein addresses the typical case. The electromagnetic scattering of navigational aid signal by objects in the environment is a complex subject, and that there are exceptions to the typical cases presented in this report.

Changes in the airport environment subsequent to a commissioning flight inspection can also change the obstruction environment. Thus, periodic flight inspections are performed to provide a continual check of the environment ensuring that obstacle clearance surfaces are not violated, or in the event there is a violation, it is noted and addressed appropriately. Thus, the requirement to periodically verify obstruction clearance with an aircraft must be performed for GPS RNAV approach procedures. However, such inspection can be combined with other flight inspection activities to increase fleet efficiency. That is, obstruction checks could be associated with runway ends as opposed to the navigational aids servicing that runway.

Airborne receivers, such as those for NDB, VOR, ILS and GPS, can be adversely affected by RFI; both the nature of the effect and level of susceptibility are sensor dependent [14]. Given the sometimes sporadic nature of RFI and the length of time between periodic evaluations, it is not unexpected that user complaints will arise before RFI is observed during a periodic inspection. Since the subject of this report is periodic inspection of GPS RNAV approach procedures, the discussion will focus on the effect of RFI on GPS service.

RFI can affect a GPS receiver in two ways. The presence of severe RFI can prevent the GPS receiver from tracking or acquiring any satellites. This situation results in an outage, and is viewed primarily as an availability issue. Further, it is likely that the presence of such a condition for any length of time would trigger user complaints. In other cases, RFI can result in increased noise on the pseudorange measurements. Since the increased pseudorange noise can degrade the accuracy of the position estimate, the GPS integrity monitor must be capable of determining when such degradation would cause the error in the estimate to exceed the alarm limit.

Table 4. Items, Considerations, and Methods of Mitigating Performance Degradation..

ITEM	CONCERN	MITIGATION
Equipment Performance	Performance degrades due to aging of electronic components	*Terrestrial/Conventional:* Periodic Maintenance and Built-in-Test (BIT) capabilities are used to monitor performance [6-8]. Built-in integrity monitors may provide alerts when secondary performance parameters exceed established limits. *Satellite-Based:* The Operational Control Segment (OCS) of GPS is responsible for maintaining satellites and ensuring they function properly [9].
Equipment Failure	Short-term partial/complete failure of equipment components such that primary performance parameters exceed tolerances	*Terrestrial/Conventional:* Built-in integrity monitors shut down equipment when primary, safety related, performance parameters exceed established limits. *Satellite-Based:* OCS deactivates defective satellites, and activates spares if available. Receiver Autonomous Integrity Monitors (RAIM) required for IFR certified GPS receivers, and WAAS integrity monitor used to detect satellite failures [9-11].
Equipment Replacement	Verify service/system performance acceptable subsequent to component, equipment replacement, or system restoration	*Terrestrial/Conventional:* Certification procedure by technician and/or special fight inspection, as appropriate [5-8]. *Satellite-Based:* RAIM or WAAS monitoring for SV changes; if geostationary satellite replaced by satellite in different location, exiting screening model and assessment methodology should be applied [4].
Environment	New obstacles cause electromagnetic scattering or signal blockage	*Terrestrial/Conventional:* Application/assessment required for on-airport construction [12], and/or periodic flight inspection [5, 15-18]. *Satellite-Based:* Not anticipated to be a concern for GPS RNAV procedures with DA of not less than 250 feet AGL.
Environment	Change in obstacle environment	*Terrestrial/Conventional:* Periodic flight inspection. *Satellite-Based:* Periodic flight inspection.
RFI	Presence of new emitter	*Terrestrial/Conventional:* Periodic flight inspection or user complaints. *Satellite-Based:* User complaints, periodic flight inspections performed for obstruction checks could provide additional detection opportunities if GPS data were collected/evaluated.
Modification of Instrument Approach Procedure	Need to verify integrity of modified procedure	*Terrestrial/Conventional:* Equipment adjustment may be required; signal-in-space characteristics and obstruction environment may change; flight inspection performed as required, requirements sensor specific [5, 19, 20]. *Satellite-Based:* If database parameters are modified as result of procedure modification, it is recommended that a flight inspection be performed for segments affected by the change, commissioning flight inspection requirements should be used unless studies/analysis support a reduction in requirements.

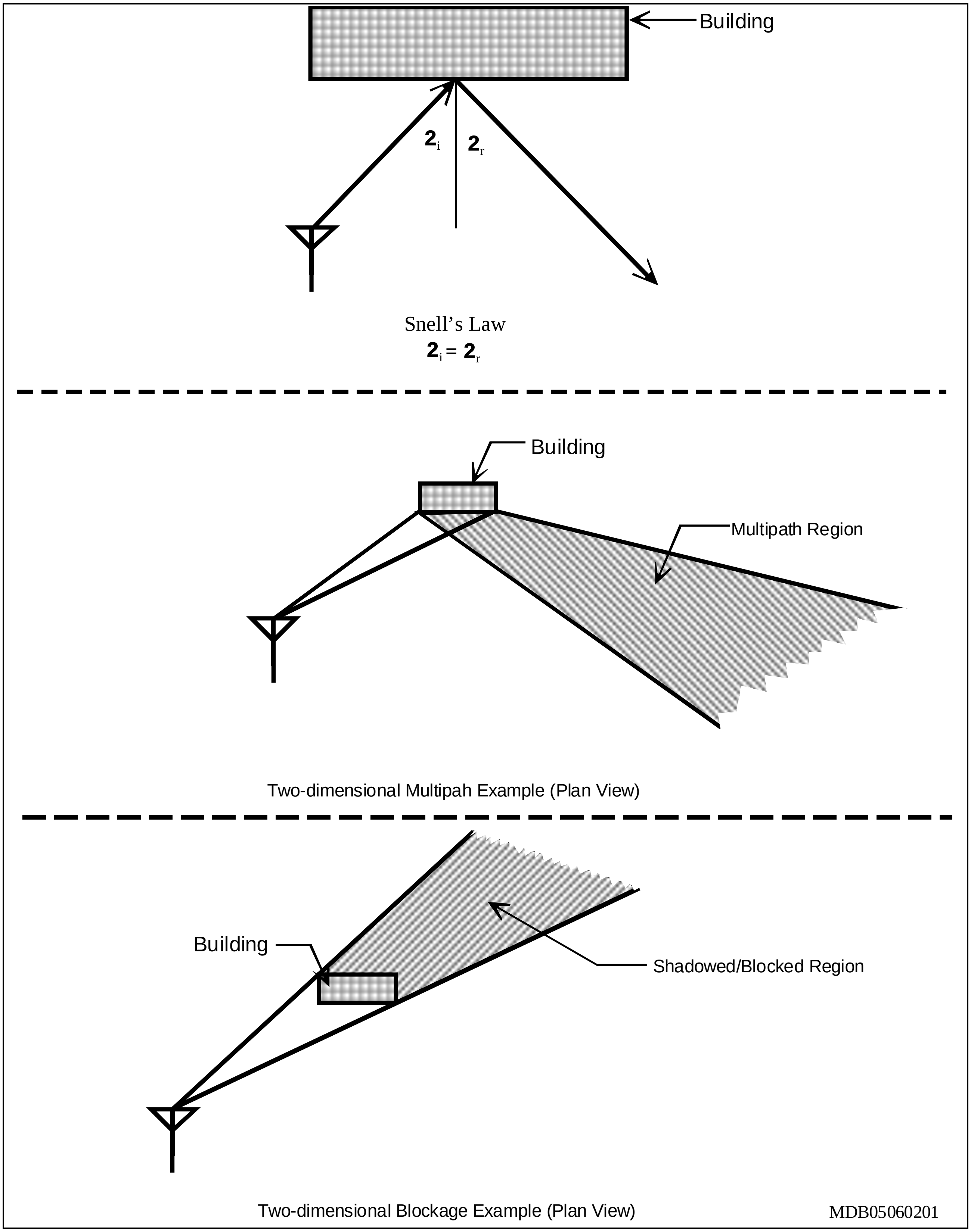

Figure 2. Illustration of Ray Tracing Technique for Multipath/Blockage Analysis.

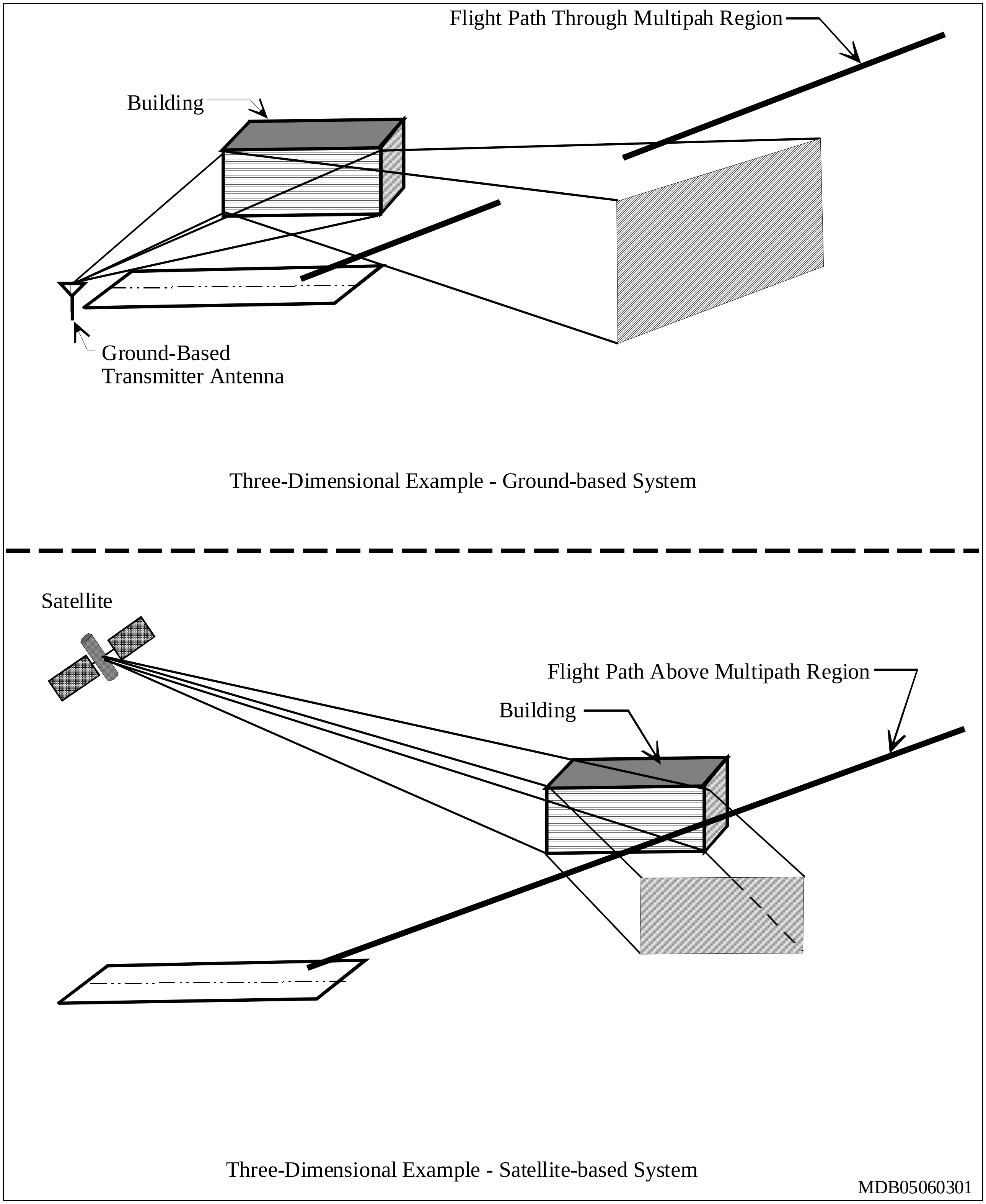

Figure 3. Illustration of Multipath Phenomenon for Ground and Satellite-Based Systems.

In addition to the monitoring of GPS provided by the Operational Control Segment, two methods are used to provide further integrity monitoring for civil aviation applications [21]. One is the Receiver Autonomous Integrity Monitoring (RAIM) concept and the other is a ground-based approach commonly referred to as a GPS integrity channel (GIC). WAAS is an example of a system that provides a GIC. Since the concern in this case is RFI at the user (receiver) location, RAIM is the method that must be relied upon for protection against harmful RFI during GPS RNAV approach procedures. RAIM employs a self-consistency check among redundant measurements, and there are many ways of implementing RAIM [22-24]. A GPS receiver must implement RAIM in order to hold an Instrument Flight Rule (IFR) certification [10].

Given the preceding discussion, it is not unreasonable to modify the flight inspection manual [5] to eliminate the airborne data collection portion of the periodic flight inspection of GPS/RNAV approaches. The system performance was assessed during commissioning and suitable monitoring is used to detect system degradation over time or system failure. Similarly, the procedure and associated database information were verified at commissioning and there is no expectation for these items to degrade over time. However, if database parameters are modified as a result of procedure modification, it is recommended that a flight inspection be performed for segments affected by the change. In this case, commissioning flight inspection requirements should be used.

Verification of obstruction clearances for GPS/RNAV approach procedures should still be a periodic requirement. However, in the case of multiple instrument approaches serving the same runway end, the obstruction check can be performed at the same time a ground-based NAVAID associated with that runway end is checked. Data for those items listed in Table 2 should be collected. The collection and analysis of such data enables one to confirm the current understanding regarding the stability of satellite-base navigation performance over time. That is, the various methods currently employed to mitigate those items that can cause degradation of system performance over time are effective. The only items that need to be mitigated by periodic flight inspections are changes in the obstruction environment or changes in the procedure.

Before concluding, one should note that the FAR Part 77 surfaces do not coincide with the surfaces that control aircraft operations under FAR Part 97 Subpart C (TERPS). Specifically, the lateral dimensions of the imaginary surfaces (Part 77) do not encompass the same lateral airspace that the FAA uses to establish instrument procedures. Because of this inconsistency in the dimensions of surface airspace, certain structures do not fall within the surface area for FAA required obstruction notification and consequently are not studied by the agency. These unknown obstructions may affect the safety of the instrument approach procedure.

IV. CONCLUSIONS AND RECOMMENDATIONS

The existing periodic flight inspection safety requirements specified in the United States Standard Flight Inspection Manual where reviewed and assessed. In addition, those items which can cause degradation of system performance over time were identified and the methods typically employed to mitigate these items listed. Those items mitigated by periodic flight inspection include a change in the environment, RFI, and modification of the instrument approach procedure. No recommendations are being made in regard to commissioning flight inspections requirements. The following recommendations are based on an assessment of these items for GPS/RNAV approach procedures with a DA of not less than 250 feet and apply only to periodic flight inspection:

1) The data in Table 2 should be logged during periodic flight inspections. The collection and analysis of such data would enable one to characterize the stability of satellite-based navigation performance over extended periods of time, and such characterization can be used to verify and refine periodic flight inspection requirements for GPS RNAV approach procedures;

2) The requirement to verify obstruction clearance with an aircraft should be retained in the periodic inspection of GPS/RNAV approach profiles since it is the only means currently that provides comprehensive evaluation of the obstruction environment. Relaxation or removal of this requirement would be possible if the FAA changed existing policy to require notification and verification when objects violate a Part 97, Subpart C (TERPS) surface;

3) In cases where VOR, NDB, and ILS approach procedures serve the same runway end as does a GPS/RNAV approach procedure, the obstruction clearance checks for all procedures should be combined, when practical, to further minimize flight inspection workload; and,

4) If database parameters are modified as a result of procedure modification, a flight inspection using commissioning requirements should be performed for each segment affected by the modification.

V. REFERENCES

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ATTACHMENT A

Technical Memorandum, OU/AEC 98-16TM00078/2-1

DEVELOPMENT OF PROVISIONAL FLIGHT INSPECTION CRITERIA FOR WIDE AREA AUGMENTATION SYSTEM (WAAS) APPROACH PROCEDURES

TECHNICAL MEMORANDUM
OU/AEC 98-16TM00078/2-1

DEVELOPMENT OF PROVISIONAL FLIGHT INSPECTION CRITERIA FOR WIDE AREA AUGMENTATION SYSTEM (WAAS) APPROACH PROCEDURES

Provisional flight-inspection criteria are provided for Wide Area Augmentation System (WAAS) precision approach procedures.

by

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September 1998

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Contract DTFA01-97-C-00078
Technical Task Directive - 2

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I. INTRODUCTION

Technical Task 2.0 to FAA Contract DTFA01-97-C-00078 entitled, “Flight Inspection Criteria for Satellite-Based Navigation Systems”, supports the development and verification of flight inspection criteria for satellite-based navigation systems. These criteria are intended to provide a suitable means for implementation and integration of satellite-based navigation systems into the National Airspace System (NAS).

In order to facilitate the integration of satellite-based navigation systems into the NAS, standards must be developed based on specific operational requirements and system architectures. The objective of these standards is to detail, in terms of system-architecture-specific parameters, the minimum performance required to support a given procedure. The standards development process includes the generation of flight inspection criteria. These criteria address the specific system parameters to be assessed and the assessment methodology required to ensure that the installed-system performance is suitable for supporting the intended procedure(s). Such flight inspection criteria must be developed and verified to enable the implementation of the Wide Area Augmentation System (WAAS).

The following specific work items are intended to be performed under this technical task directive:

- **Parameter Identification -** Develop a list of specific system parameters that will be recorded during flight inspection of WAAS procedures.
- **Assessment Methodology -** Develop methodologies for assessing the data collected for the system parameters identified.
- **Criteria Development -** Provide technical support for the development of WAAS flight inspection material for inclusion in the appropriate FAA Orders.
- **Verification -** Through the use of FAA and Ohio University facilities and resources, verify the flight inspection criteria that have been developed. Through actual implementation, assess the technical merit of the specific parameters considered, data collection and assessment methodologies utilized, and any implementation issues that may arise during the actual application of the criteria.

This report describes the WAAS Precision Approach (PA) procedure and its components. A preliminary description of the parameters that must be recorded and the assessment methodology needed during flight inspection are described. Due to schedule constraints, this preliminary report does not provide an in-depth analysis of the criteria development. At the present time, this report provides insight into the WAAS flight inspection procedure from an analytical viewpoint. There were no attempts to verify the procedure via actual implementation of a WAAS airborne system. The Avionics Engineering Center feels strongly that verification of the WAAS Flight Inspection procedure must be performed.

II. OVERVIEW OF GPS/WAAS PROCEDURES AND FLIGHT-INSPECTION REQUIREMENTS

The development of the WAAS Flight Inspection criteria is based on the site-specific components of a WAAS instrument approach procedure. While the space and ground components of both GPS and WAAS affect the WAAS approach, the flight inspection procedure relies on the inherent monitoring of those systems to determine faults. The same philosophy applies to the WAAS/GPS receiver. The flight inspection procedure is not intended to provide an assessment of receiver performance as this matter is appraised during equipment certification. This philosophy does not exclude the recording of GPS and WAAS parameters. The parameters are needed to determine why an inspection run may have failed and for determining if there has been any local corruption or interference of the signal.

A. Overview of GPS/WAAS Procedures

1. **Basic "T"**

As illustrated in Figures 1 and 2, the GPS approach procedure uses the Basic "T" with the addition of a terminal arrival area (TAA). The Basic "T" is used for stand-alone GPS approaches (TSO C-129), WAAS, and LAAS approaches.

The Basic "T" aligns the final approach segment with the runway centerline. The Missed Approach Point (MAP) is at the runway threshold and the Final Approach Fix (FAF) is 5 nmi from the threshold. The Intermediate Fix (IF) is 5 nmi beyond the FAF, along the runway centerline. There are two Initial Approach Fixes (IAF) located 4 or 5 nmi either side of the IF. The IAFs are typically located 90 degrees with respect to the runway centerline. The GPS procedure is designed to eliminate the procedure turn. If a course reversal is required, a holding pattern will be specified in lieu of a procedure turn.

The TAA (shown in Figure 2) provides the transition from enroute airspace to the GPS approach. Step-down altitudes and transitions are provided for all approach paths except for areas where terrain clearance or ATC limitations are required. The TAA is typically defined for a 30 nmi arc from the IAF. There are three areas in the TAA. Aircraft transitioning to the Basic "T" from a heading that is within 90 degrees of the final approach course are directed to the IAF/IF. The IAF/IF is located at the IF on the extended runway centerline. Aircraft that are approaching the GPS procedure with a bearing greater than 90 degrees to the final approach course are directed to one of the IAFs. These aircraft are approaching the GPS procedure from the Left or Right Base.

To accommodate FMS and RNAV approach equipment, waypoints are designated as Fly-Over or Fly-By. Fly-By waypoints are used when the navigation system is allowed to transition from one segment to the next segment before passing the waypoint. This technique provides what is known as turn anticipation. Terrain and obstacle clearance must compensate for turn anticipation.

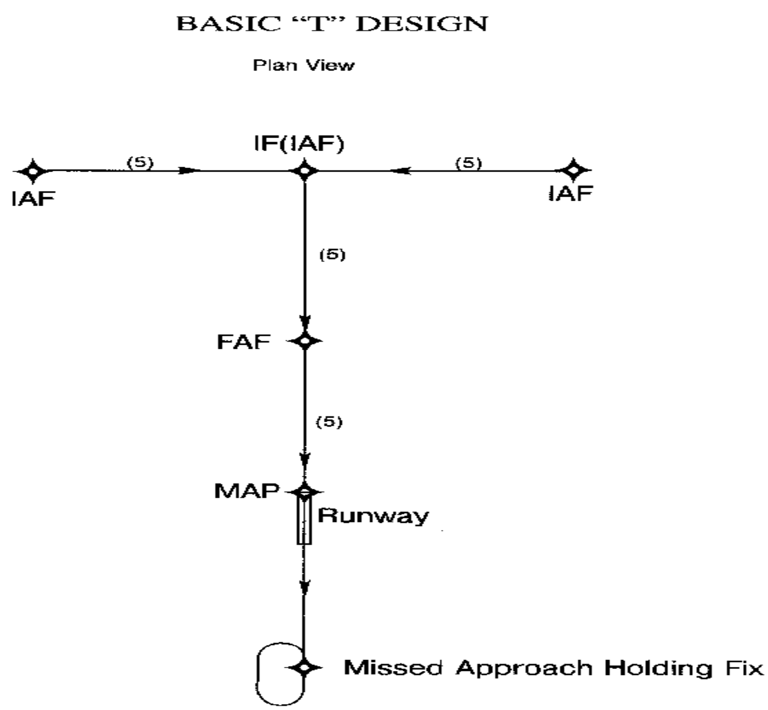

Figure 1. Basic "T" GPS Approach Procedure [1].

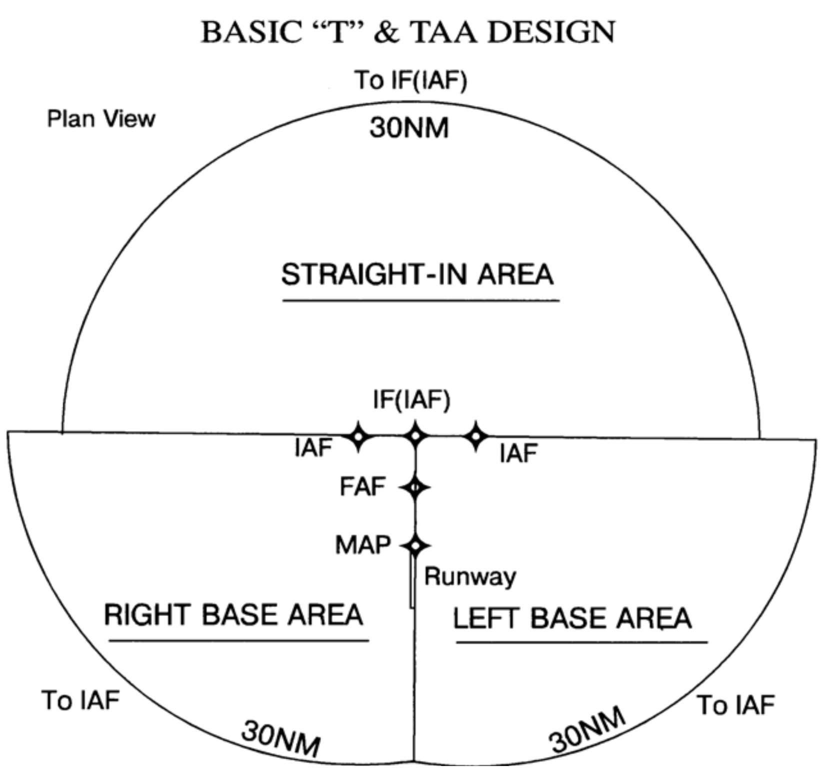

Figure 2. Terminal Arrival Area for GPS Approaches [1].

2. Non-Precision Approach (NPA)

A GPS NPA is defined for aircraft equipped with GPS receivers certified for non-precision approach (TSO C129 A1, B1, B3, C1, or C3) and WAAS/GPS receivers. The C129 receivers do not receive differential corrections and therefore are not sufficiently accurate for a precision approach. The WAAS/GPS receivers may use a NPA in two situations. First, the pilot may select a NPA. Second, system accuracy, availability, or integrity may inhibit a PA which causes the system to revert to a NPA.

A GPS NPA consists of sequenced waypoints from the initial approach waypoint (IAWP) to the Missed Approach Waypoint (MAWP). After the aircraft passes the FAWP, it is allowed to descend to the Minimum Descent Altitude (MDA). There is no vertical guidance for a NPA. During the commissioning Flight Inspection, all the Initial Approach Segments (IAS) and Missed Approach Segment (MAS) are flown at the procedural altitudes. An IAS may be evaluated when flying by the IAWP if it is a Fly-By waypoint for turn anticipation. The Final Approach Segment (FAS) is verified to be a straight line from the FAWP to the MAWP. The flight inspection procedure starts 3 nmi outside the first waypoint in a straight line with the FAWP and MAWP. This may be either an IWP or the FAWP. All the waypoints that are on this line are evaluated by flying over the waypoints. The FAS is flown to 100 feet below the published altitude (MDA) from the FAWP to the MAWP. Only the FAS is checked during periodic flight checks.

The procedure database is evaluated to verify the geodetic coordinates of each waypoint and the distance/bearing between waypoints. The acceptable tolerances for GPS C-129 procedures are defined for each segment. During the IAS/IS, the true bearing to the next WP must be within ± 2 degrees and the distance must be within ± 0.5 nmi. For the FAS, the bearing and distance to the next WP are ± 2 degrees and ± 0.3 nmi, respectively. The bearing and distance to the next WP on the Missed Approach Segment is ± 2 degrees and ± 0.5 nmi.

The Standard Instrument Approach Procedure (SIAP) is evaluated during the commissioning and periodic flight checks per 8200.1A, Section 214.3 [2]. The SIAP evaluation considers: flyability, cockpit workload, navigation chart data, runway markings and lighting, and navaid (GPS, ILS, VOR, etc.) support.

GPS system parameters are also collected during the flight inspection. There are no flight inspection requirements for these parameters. They provide analysis data if any GPS signal anomalies or interference are encountered. The GPS parameters and their expected values are shown in Table 1.

Table 1. GPS Parameters Collected During the Flight Inspection [2].

Parameter	Expected Value
HDOP	4.0 maximum
HFOM	835 ft./ 255 m.
Satellites tracked	4 minimum
CNR	30 dB/Hz minimum

The electromagnetic spectrum in the GPS L1 and L2 bands are monitored if RF interference is suspected. The frequencies to be monitored are in the range of 1200 to 1250 MHz and 1555 to 1595 MHz. The normal GPS signal strength is –130 to –123 dBm. Particular attention shall be given to harmonics on or within 20 MHz of GPS L1 (1575.42 MHz) and those on or within 10 MHz of GPS L2 (1227.6 MHz).

3. Precision Approach (PA)

The WAAS PA can be established via the Basic "T" Approach configuration presented in Figure 1 or via the Vector To Final (VTF) procedure. In the Basic "T", the Initial/Intermediate Approach Segments are similar for the WAAS and C-129 approach procedures. In the VTF procedure, the aircraft discontinues the initial/intermediate segments on the published approach and is vectored to an extended final approach segment. In both cases, the main difference between the PA and the NPA is the Final Approach Segment. The WAAS receiver has sufficient accuracy to support the vertical guidance required for the FAS.

The horizontal and vertical components of the Final Approach Segment (FAS) are calculated from waypoints associated with the runway environment as shown in Figure 3. The horizontal course is defined as an extended runway centerline using the Runway Datum Point (RDP) and the Flight Path Alignment Point (FPAP). A straight-in approach is currently defined for WAAS PA operations although the approach path may be offset from the runway centerline. This is accomplished by moving the RDP and/or FPAP to a point off the runway surface.

A linear path defined by the Datum Crossing Height (DCH) and the glidepath angle establish the vertical course. The glidepath angle is defined with respect to the local tangent plane of the WGS84 ellipsoid. The Glide Path Intercept Point (GPIP) is where the glidepath intersects the local tangent plane. The GPIP is not part of the FAS database, but is only included for reference.

The parameters defining the FAS are stored in the WAAS receiver database for each approach. The parameters stored in the FAS data block are airport identification, runway designation and position, procedure type, procedure name, and runway surveyed points. The procedure type is included for the development of advanced approach procedures such as curved approaches. Only straight-in approaches are currently defined.

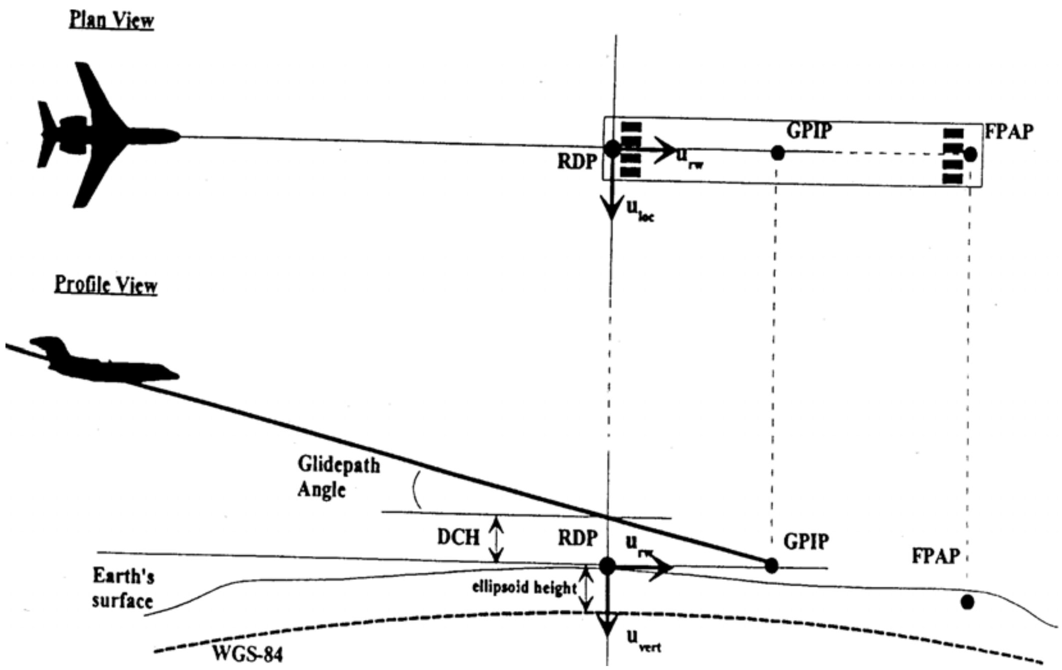

Figure 3. Final Approach Segment of WAAS Precision Approach [5].

B. General Inspection Requirements

WAAS DGPS Flight Inspection criteria outline the parameters and their respective tolerances which will define whether an approach is approved or not. Criteria used in this determination are listed below.

Waypoint Displacement Error (WPDE) – WPDE describes the positional error associated with a waypoint. WPDE can be caused by incorrect geographic coordinates or the resolution in which they are stored in the database.

Horizontal Protection Limits (HPL) / Vertical Protection Limits (VPL) – HPL/VPL are values calculated by the WAAS receiver. They denote the uncertainty associated with the 3-dimensional positional accuracy that is output by the receiver. HPL/VPL are affected by the number of GPS satellites, GPS satellite geometry (HDOP/VDOP), tropospheric delays, and airborne receiver accuracy. HPL/VPL are compared to the Horizontal Alert Limit/ Vertical Alert Limit (HAL/VAL). If either the HPL (VPL) exceeds the HAL (VAL), then the WAAS receiver must flag all or parts of the approach procedure.

Obstruction Clearance - All aircraft paths approved by the approach procedure must be free of obstacles and obstructions. This may include towers, buildings, and terrain. Obstruction clearance is initially determined by examining FAA and other government databases. During the Flight Inspection, obstacle clearance is determined by pilot observation.

Standard Instrument Approach Procedure (SIAP) - The instrument approach procedure must be checked for flyability, waypoint accuracy, obstructions, and interference. The entire SIAP is checked from Initial Approach Waypoints to the Missed Approach Holding Waypoint.

III. DEVELOPMENT OF WAAS PRECISION APPROACH FLIGHT INSPECTION CRITERIA

Four types of assessments should be accomplished during flight inspection of the published WAAS precision approach procedure. The first assessment validates the location of any way points or database information used to construct or execute the approach, e.g., FPAP, DCH, RDP, etc. The second assessment relates to documenting the flyability of the procedure, while the third assessment addresses the identification of RF interference. The fourth assessment verifies the obstruction environment surrounding the procedure.

Specifications for the WAAS signal-in-space and WAAS airborne equipment were reviewed to determine what system parameters need to be recorded and what analysis is required to complete these four assessments [3,5]. At this writing, it appears that flight inspection of WAAS precision approach procedures should include at least the following two maneuvers: flying the published approach procedure; and, performing below procedure runs.

Example flight inspection data plots (records) have been developed to aid the explanation of what system parameters need to be recorded and how these parameters can be analyzed to accomplish the four types of assessments mentioned above. Further, these example data plots are not intended to suggest any requirements or recommendations on the graphical format of the flight inspection record.

A. Approach Procedure Maneuver

The approach procedure maneuver involves flying the final approach segment of the published WAAS precision approach procedure. Since the horizontal and vertical course widths are not a function of the signal-in-space, the need to fly approach maneuvers at the horizontal and vertical course limits is not anticipated at this time.

Three of the four types of assessments are performed during the approach procedure maneuver. The three assessments are: validating the location of the waypoints; documenting the flyability of the procedure; and, identifying the presence of RF interference.

Figures 4 and 5 show example flight inspection records for the approach procedure maneuver. Each of these records is comprised of a header and seven data windows. One such record would be generated to assess horizontal performance (Figure 4) and one to assess vertical performance (Figure 5). The data content and analysis to be performed using these records is explained as follows.

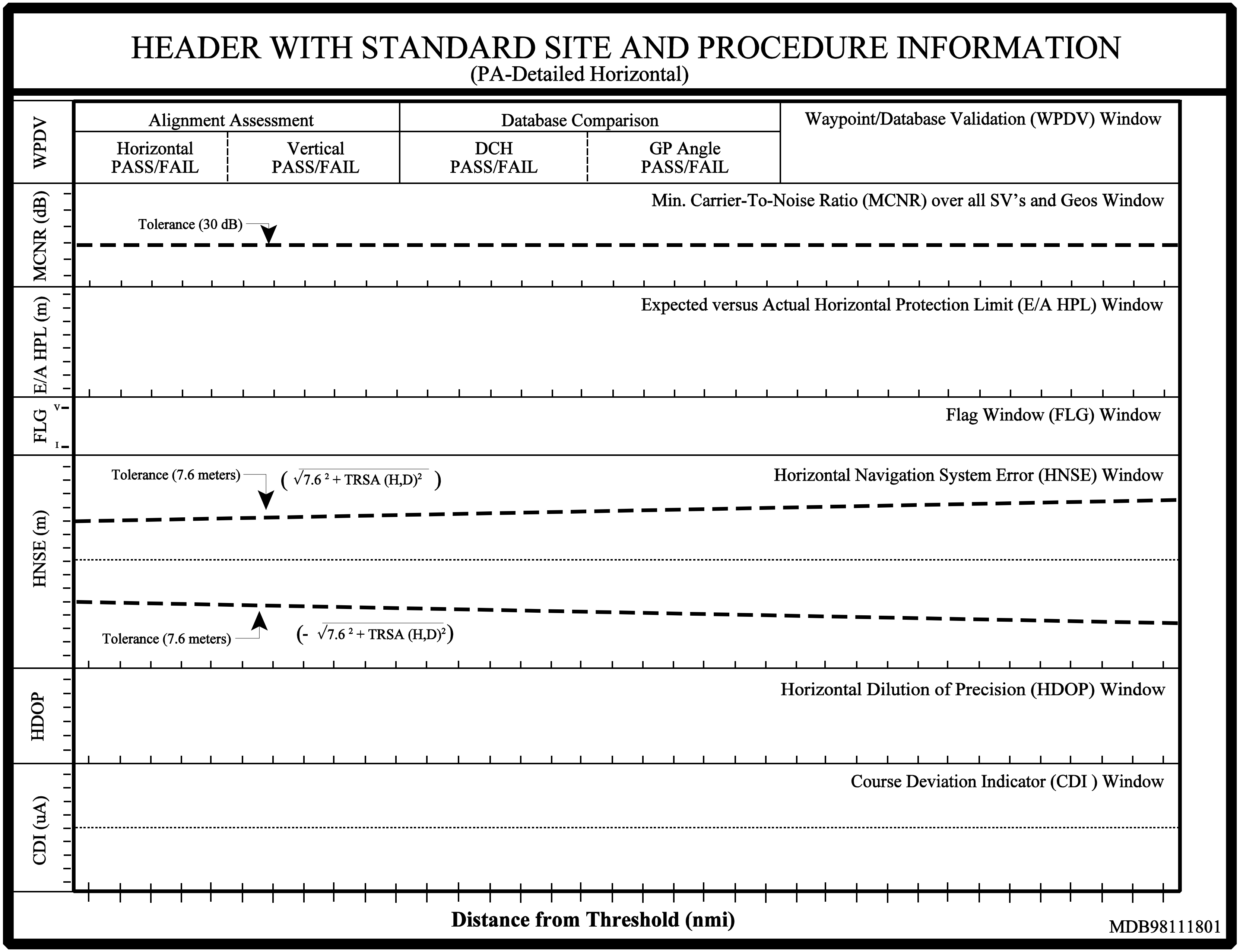

Figure 4. Example Record for the Approach Procedure Maneuver, Horizontal Performance, Detailed Format.

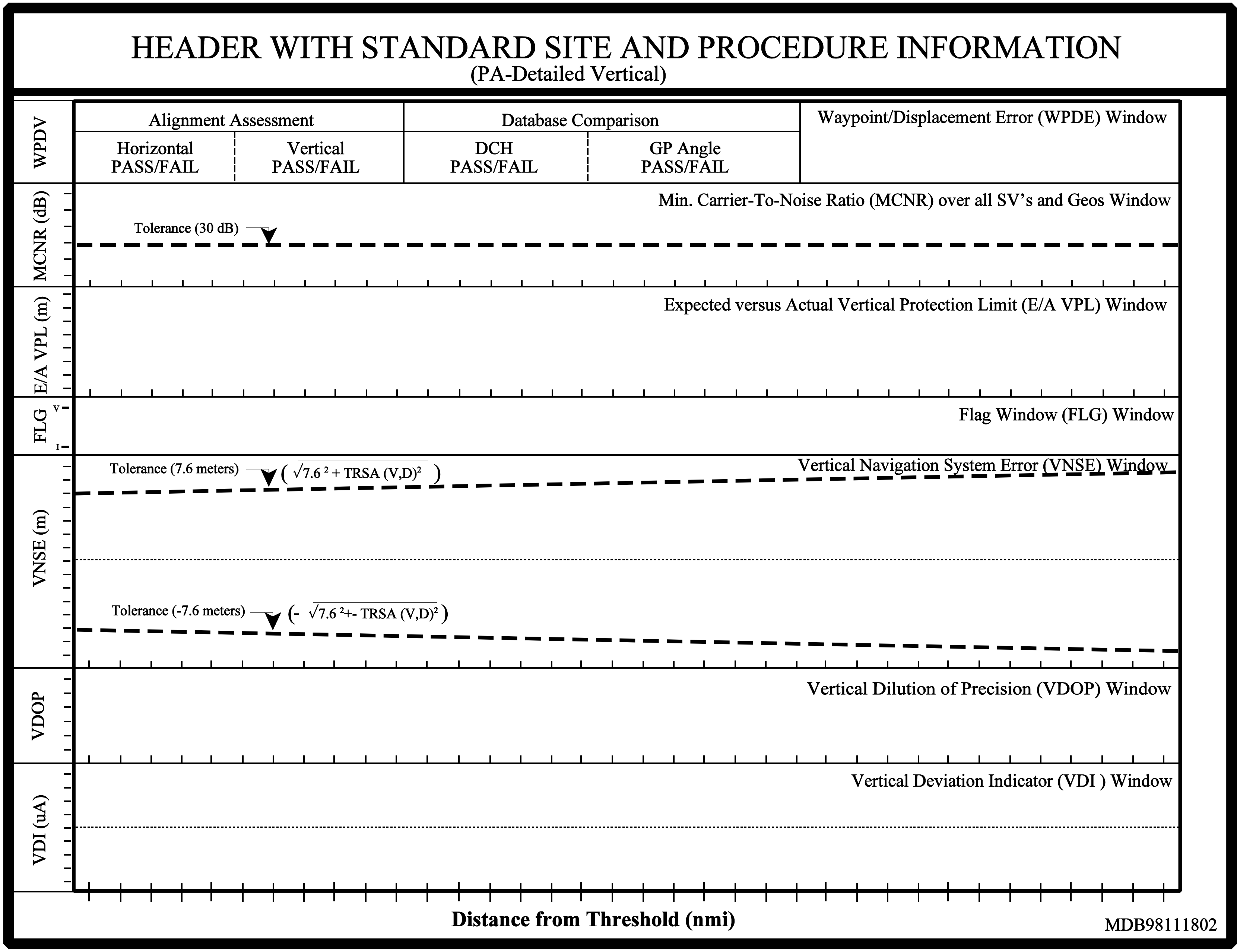

Figure 5. Example Record for the Approach Procedure Maneuver, Vertical Performance, Detailed Format.

Header Block: The header (Figure 4) should consist of the standard site and procedure information used by the FAA to document flight inspection of a precision approach procedure.

Waypoint / Database Validation: The top data window (vertical label WPDV in Figure 4) is used to present data for verifying the location of any waypoints and database information used to construct the approach procedure. The waypoint information is obtained from an on-board database that contains the approach procedure. Applicable standards [3, 5] do not provide practical requirements for measuring waypoint accuracy using an airborne platform given the tolerances that are required for waypoints in the runway region. Thus, an alternate method for verifying the location of the waypoint is required.

For Category I operations, there may not be any operational benefit gained by explicitly measuring waypoint displacement error (WPDE), since the effect of WPDE on the approach procedure may be assessed sufficiently when the procedure is flown by the flight inspection aircraft. A method for performing such an assessment, as well as verifying pertinent database information, is described in the following paragraphs.

The horizontal course is defined by the line containing both the RDP and the FPAP (Figure 3). The values for these parameters are obtained from a database containing the Final Approach Segment (FAS) Data Block [5]. Error in surveying or recording the values for these waypoints can result in a horizontal track that is rotated or/and offset from the desired track. Thus, the waypoint and database information can be verified by assessing the angular/linear alignment of the horizontal course. The assessment is performed by ensuring that the average horizontal course is within the NSE tolerance brackets, which are discussed in a subsequent paragraph. This assessment could be performed using a method similar to the one used for assessing the ILS localizer alignment [2]. The result of the assessment may be displayed as illustrated in Figure 4.

The vertical course is defined by a DCH, glidepath angle, and RDP (Figure 3). The values for both the DCH and glidepath angle are obtained from a database containing the FAS Data Block [5]. Error in the values used for the DCH and/or error in the location of the RDP can result in an unacceptable threshold crossing height. Error in the value of glidepath angle will result in angular bias in the vertical course. Since the DCH and glidepath angle are specified values as opposed to values for surveyed locations, an independent comparison of these values should provide a sufficient assessment. In this case, the AFIS could serve as the independent reference for the correctness of the values obtained from the FAS Data Block. Given the resolution specified for these values in Reference 5 and assuming the AFIS would store these data with at least the same resolution, the DCH values should agree within 0.2 feet and the glidepath angle values should agree within 0.02E.

The RDP waypoint information may be verified by assessing the alignment of the vertical course. The assessment is performed by ensuring that the average vertical course is within the NSE tolerance brackets, which are discussed in a subsequent paragraph. This assessment could be performed using a method similar to the one used for assessing the ILS glide slope alignment [2]. The result of the assessment may be displayed as illustrated in Figure 4. The achieved DCH could be compared to the desired DCH (value in FAS Data Block); this assessment may be considered optional considering that the WAAS is intended to support NPA and Category I PA operations. Further analysis is required to determine if there would be any operational benefit obtained from performing such an assessment.

Minimum Carrier-to-Noise Window: The minimum carrier-to-noise (C/N) window (vertical label MCNR in Figure 4) is used to present data for assessing the presence of moderate RF interference and determining if it is of operational concern. That is, interference that is not strong enough to prevent acquiring or tracking of the satellites, but may degrade WAAS performance. Although C/N data should be collected for all tracked satellites, only the minimum ratio obtained for each measurement set is presented. The threshold to be used for this assessment should be developed based on the WAAS interference mask and WAAS receiver performance requirements [3], if practical. Though there was not sufficient time to accomplish a threshold analysis for this effort, operational experience indicates that the C/N ratio should be greater than 30 dB the vast majority of the time. Thus, a threshold of 30 dB is proposed as an initial value, until an analysis can be undertaken to determine a more suitable value.

Expected versus Actual Horizontal Protection Limit Window: The expected versus actual horizontal (or vertical) protection limit window (vertical label E/A H/VPL in Figure 4) is used to assess the presence of strong RF interference and to determine if it is of operational concern. That is, interference strong enough to prevent acquiring or tracking one or more satellites. Since the satellite is not tracked, C/N data can not be collected. Thus, there is a need for an additional assessment to alert the inspector of a problem. The expected horizontal (or vertical) protection limit is calculated based on WAAS provided information and the satellites that should be in view at that particular time and location. The actual horizontal protection level is calculated in a similar manner, except it is based on the satellites that were actually tracked. This approach assumes that the flight inspection receiver is required to track all satellites in view. The expected and actual protection limits should be nearly identical. Further work and operational experience will be required in order to establish a meaningful assessment limit(s).

Although it may be easier to determine the number of satellites tracked versus the number that should be tracked, such an approach is limited in terms of assessing the operational impact of the situation in a quantified manner.

Flag Window: The navigation flag window (vertical label Flg in Figure 4) is used to present the status of the horizontal (or vertical) navigation sensor flag. As with other precision approach aids, the flag is expected to remain valid during the entire approach.

Horizontal Navigation System Error Window: The horizontal (or vertical) navigation system error window (vertical label HNSE in Figure 4) is used to present the NSE data for assessment. For WAAS precision approach procedures, Table 3.2-2 in Reference 3 specifies a 7.6 meter tolerance for both vertical and horizontal NSE. Ideally, the measured NSE would be assessed against the 7.6 meter tolerance. However, this tolerance may be impractical to apply to the measured NSE data, particularly during the initial portion of the precision approach procedure, depending on the truth-reference system used. That is, for a truth system where the linear accuracy degrades as the distance from threshold increases, the truth-system measurement error may exceed the 7.6 meter tolerance at a distance from threshold that is less than 5 nautical miles. Therefore, the actual tolerance brackets to be used for the NSE assessment may depend on the characteristics of the truth-reference system. The following general equation provides a method for generating the magnitude of such tolerance brackets as a function of distance from threshold:

$$|T(H/V,D)| = \sqrt{7.6^2 + |TRSA(H/V,D)|^2}$$

Where:

T(H/V, D) is the horizontal (H) or vertical (V) NSE tolerance at distance D
D is the distance from threshold
TRSA is the expected horizontal (H) or vertical (V) accuracy, in meters, of the truth reference system at distance D

If the horizontal and vertical accuracy characteristics of the truth system are different, then the preceding equation is applied twice: once to generate the horizontal tolerance brackets, and once to generate the vertical tolerance brackets. It is recommended that the truth reference system used be capable of assessing the measured NSE against tolerances that are at least as stringent as those specified in Reference 2 for Category I ILS precision approach procedures (structure and alignment).

Horizontal (Vertical) Dilution of Precision Window: The horizontal (or vertical) dilution of precision window (vertical label HDOP in Figure 4) is used to present the HDOP data output by the WAAS Flight Inspection Receiver. These data are presented for informational and consistency purposes. Optionally, the expected HDOP (VDOP) data may be presented in this window, also. As with the expected HPL (VPL) data, the expected HDOP (VDOP) data may be useful in assessing interference effects. In addition, the information in this window may indicate the reason for out-of-tolerance NSE or HPL data.

Course Deviation Indicator Window: The course deviation indicator window (vertical label CDI in Figure 4) is used to present the CDI data. This data provides an indication of how well the procedure was flown. Depending on the linearity of the CDI indication (recorded sensor output), excessive flight technical error may result in inadvertently failing the waypoint displacement assessment. This situation is likely to result when the sensor CDI output scaling is “capped” or of lower resolution in the full-scale deflection region.

There are various ways to present the required data and analysis, and some suggestions are provided in this paragraph. The example flight inspection records shown in Figures 4 and 5 are intended to provide a reasonably detailed assessment of the approach procedure from a flight inspection perspective. Optionally, Figure 6 shows a more basic format that could be used for the approach maneuver. This format presents only the data necessary for making a pass/fail determination, and it presents the horizontal and vertical performance data on the same record. The formats shown in Figures 4 and 5 could be used for commissioning flight inspection missions, where a more thorough assessment of the procedure is desired. In addition, this format could be used to enable further assessment of the situation when the more basic format indicates an out-of-tolerance condition. The format shown in Figure 6 could be used for periodic flight inspection missions.

B. Below Procedure Maneuver

The below procedure maneuver involves flying straight-line segments with specified horizontal and vertical profiles. The below procedure maneuver is performed routinely along the procedure horizontal track (normally centerline extended) as described below:

- Horizontal track aligned with the approach procedure horizontal track (typically the runway centerline extended) and a vertical profile which clears all obstructions and is below the vertical course width region (full scale fly-up).

The data collected are analyzed in order to identify the presence of RF interference, a method for performing such an analysis is discussed in a subsequent paragraph of this section. If interference is suspected, then below procedure maneuvers are performed as described below:

- Horizontal track along the left course width limit (full scale left) and a vertical profile which clears all obstructions and is below the vertical course width region.

- Horizontal track along the right course width limit (full scale right) and a vertical profile which clears all obstructions and is below the vertical course width region.

Two of the four types of assessment are performed during the below procedure maneuver. The two assessments are: verifying the obstruction environment, and identifying the presence of RF interference. Part of assessing the presence of RF interference includes assuring that a full fly-up indication is provided below the approach procedure.

Figure 7 shows an example flight inspection record for the below procedure maneuver. This record consists of a header block and six data windows. One such record is generated for each below procedure maneuver performed. The header block and the MCNR, FLG, E/A HPL, and E/A VPL data windows are utilized in the same manner as discussed above for the approach procedure maneuver.

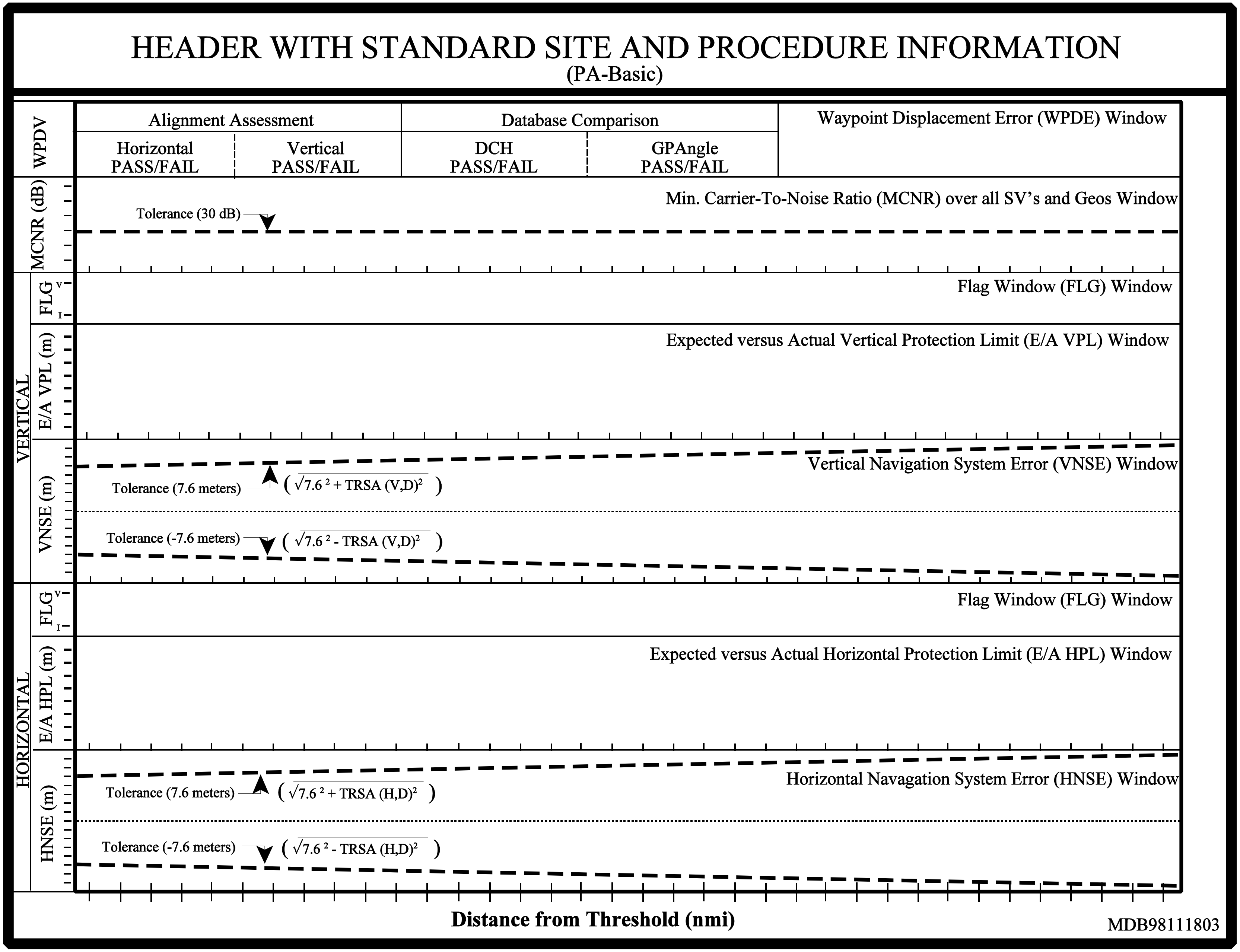

Figure 6. Example Record for the Approach Procedure Maneuver, Basic Format.

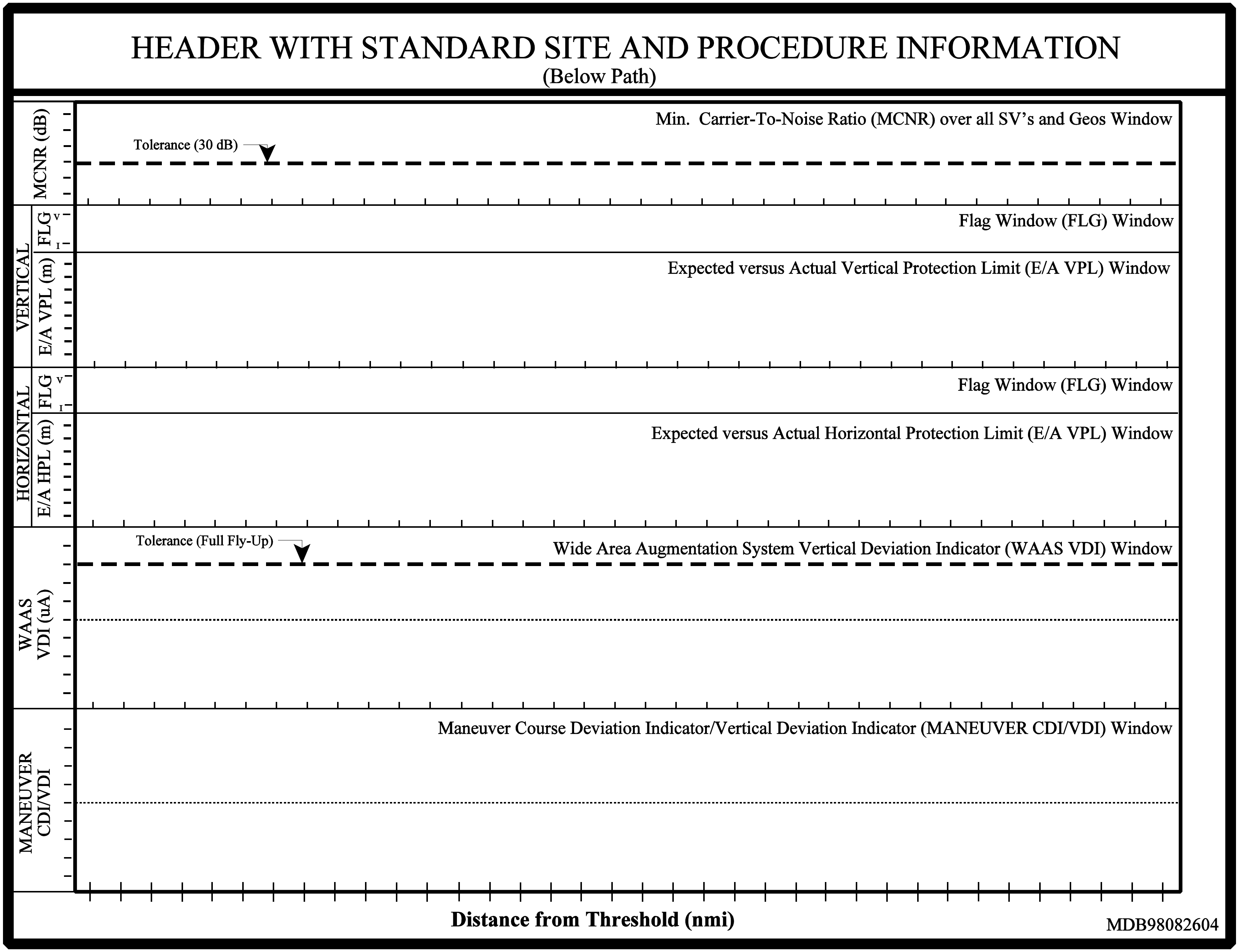

Figure 7. Example Record Format for the Below Procedure Maneuver.

Wide Area Augmentation System Vertical Deviation Indicator Window: The WAAS vertical deviation indicator window (vertical label WAAS VDI in Figure 7) is used to present the WAAS-based vertical-deviation indicator data for assessment during below procedure maneuvers. That is, the vertical-deviation data is provided by the WAAS flight-inspection receiver, which is using the published waypoint information.

Maneuver Course Deviation Indicator/Vertical Deviation Indicator Window: The maneuver course deviation indicator/vertical deviation indicator window (vertical label Maneuver CDI/VDI in Figure 7) is used to present the course/vertical deviation data (two data traces) corresponding to the particular below procedure maneuver. These data document how well the intended below procedure maneuver profile was flown. In this case, it is assumed that a separate guidance system/set-up is used to provide guidance information relative to the intended below procedure maneuver.

IV. DATA COLLECTION/REDUCTION REQUIREMENTS

The current WAAS receiver (modified Rockwell-Collins E-MAGR) is presently in the last stages of development and precise data formats and their content have not been finalized. As a result, the data collection requirements will be presented from a generic perspective: the data source will be identified but source specifics will be omitted. Complete details of the finalized WAAS receiver interface [7] should be available through NAWC/AD, Patuxent River, MD, Attention: Mr. Glen Colby.

There are three basic sources for flight inspection data: the Aircraft Flight Management System (FMS), the Automated Flight Inspection System (AFIS), and the WAAS receiver. Serial data, output at 76.8 kbps from the receiver, are expected to be available on the RS-422 instrumentation bus. It is assumed that ultimately all data elements from the receiver will be stored by the AFIS for subsequent retrieval--either during the actual flight-check event or at some later time. In order to be certain that the collection of data is properly initialized, no flight inspection event should be conducted until it is verified that all WAAS message types, with consistent Issue of Data (IOD) information, have been received and recorded. This will generally require a wait of from five up to a maximum of 20 minutes--20 minutes is the time-out interval for the Ionospheric Grid Mask information [5: A-61]. Verification of WAAS data shall be implemented within the WAAS receiver resulting in a go, no-go flag for the precision approach.

Appropriate data reduction algorithms shall be developed for the AFIS to support the flight inspection event(s). It is anticipated that data elements from the WAAS receiver and information from the aircraft flight management system, as well as some manually entered data, will be used to accomplish this task. The information available through data reduction, the so-called derived data, along with truth data supplied through the AFIS, will be used to generate the actual flight inspection records.

A. Essential Data Elements for Flight Inspection

1. Position (ecef or llh), velocity (m/s) and heading (rad) with time tags -- source: WAAS Receiver

2. CNR (dB/Hz) for all SVs (GPS and GEO) used in position solution with time tag -- source: WAAS Receiver

3. VDOP, HDOP (value) with time tag -- source: WAAS receiver

4. VPL_{WAAS}/HPL_{WAAS} (m) with time tag -- source: WAAS receiver

B. Auxiliary Data Elements for Diagnostic/Historical Usage

1. Pseudorange (m), CNR (dB/HZ), Carrier Phase (count), Ephemeris Data (record), Smoothed Pseudorange (m) for all SVs (GPS and GEO) tracked: all elements with applicable time tag -- source: WAAS receiver

2. WAAS message(s) with time tag -- source: GEO via WAAS receiver. From ICD information [7: Appendix D], this data should be available in decoded ("WAAS Type" message format) or in undecoded (raw data) form. A full complement of WAAS messages is received every 20 minutes (worst case). All WAAS information of this nature should be archived for later analysis (diagnostic or historical); thus, raw data are probably the best form to retain since all WAAS messages can be recovered therefrom.

C. Derived Data

1. HEADER BLOCK -- consistent with AFIS identification data and FAA requirements

2. Waypoint displacement error(s) (units consistent with HEADER BLOCK)

3. Minimum CNR (dB/Hz) of all SVs used in position solution versus distance from threshold (nmi)

4. Expected $\{HPL_{WAAS}/VPL_{WAAS}\}$ (m) versus distance from threshold

5. Horizontal Navigation Sensor Error (m) versus distance from threshold (nmi)

6. Expected {HDOP,VDOP} (value) versus distance from threshold (nmi)

7. CDI(μA)/FLG(discrete) versus distance from threshold (nmi)

8. Vertical Navigation Sensor Error (m) versus distance from threshold (nmi)

9. VDI(µA)/FLG(discrete) versus distance from threshold (nmi)

V. CONCLUSIONS AND RECOMMENDATIONS

Provisional flight inspection criteria have been developed for the inspection of the WAAS precision approach procedures. These criteria are intended to be applied to the Final Approach Segment; inspection of all other segments should be accomplished by using the applicable criteria for C129 procedures (need more formal reference).

The following recommendations are offered for consideration:

- Further work should be performed to assess the suitability of the tolerance proposed for the minimum carrier-to-noise ratio data. This work should review receiver performance and certification requirements, as well as the assumed WAAS interference mask to determine the suitability of the 30 dB/Hz tolerance that has been proposed.

- The operational acceptability of the waypoint displacement error tolerances proposed in Table 2 should be assessed by FAA certification personnel.

- Further work should be performed to determine an operationally suitable tolerance for the difference between the expected and actual horizontal/vertical protection limits. This work should consider employing analytical, simulation, and field measurements as means of establishing a suitable tolerance.

- The practicality of implementing the proposed criteria on a routine, day-to-day manner should be assessed. Flight trials should be performed to assess the feasibility of implementing these criteria, as well as identify implementational and efficiency issues.

VI. REFERENCES

1. Jeppesen Sanderson Inc., Federal Aviation Regulations/Aeronautical Information Manual 98, 1998.

2. Departments of the Army, the Navy, the Air Force, and, the Federal Aviation Administration, United States Standard Flight Inspection Manual 8200.1A Chg 2, August 1998.

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4. Federal Aviation Administration, NAS Operational Implementation Plan, Sept. 26, 1997.

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6. Federal Aviation Administration, Technical Standard Order TCS-C129a, Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS).

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ATTACHMENT B

Technical Memorandum, OU/AEC 02-15TM00078/5-1

RECOMMENDED WAAS FLIGHT MEASUREMENT REQUIREMENTS FOR INSPECTION OF COMMISSIONED GPS/BAROMETRIC VNAV APPROACH PROCEDURES

TECHNICAL MEMORANDUM
OU/AEC 02-15TM00078/5-1

RECOMMENDED WAAS FLIGHT MEASUREMENT REQUIREMENTS FOR INSPECTION OF COMMISSIONED GPS/BAROMETRIC VNAV APPROACH PROCEDURES

This report provides recommendations for WAAS flight inspection requirements for the flight inspection of WAAS procedures that overlay existing, GPS/Baro VNAV approach procedures. Prior to WAAS obtaining Initial Operational Capability the FAA will have commissioned a substantial number of GPS/Baro VNAV approach procedures. Since the commissioning and periodic flight inspection of these procedures will accomplish many of the WAAS flight inspection requirements, a more efficient, streamlined WAAS flight inspection process can be conducted in these instances.

by

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I. INTRODUCTION

Traditionally, approach procedures have been developed based on the specific guidance or landing system to be used to support the flight operation. Examples of this situation include a non-precision approach using VOR/DME or a precision approach procedure using ILS. The methods for defining the flight path, evaluating obstacles, and flight inspecting the procedure are system specific in these cases. Thus, the particular system that supports the procedure is specified on the associated approach plate, and the procedure can be conducted using only that system.

The use of a microprocessor-based navigation system provides a means for conducting area navigation (RNAV) operations. The flight path is generically defined by waypoints that may be entered manually or loaded from a navigation database, depending on the criticality of the operation. The requisite navigation information may be provided by a single system, or any combination of different systems that provide the performance necessary to conduct the operation. GPS, combined with fault detection and exclusion (FDE) algorithms, WAAS, LAAS, multiple VOR/DME, and DME/DME integrated with inertial are all examples of systems, or combinations of systems, that may be used to support RNAV operations. For the purpose of the discussion presented herein, a system or combination of systems/sensors that may be used to support RNAV operations will be generically referred to as an RNAV system.

RNAV operations are conducted for various phases of flight, including approach operations. Generally, RNAV instrument approach operations may be divided into the following four major classifications: circling; lateral navigation (LNAV); lateral navigation/vertical navigation (LNAV/VNAV); and, GNSS landing system (GLS). The latter three are germane to the discussion presented herein. An LNAV approach procedure (RNAV terminology for a non-precision approach) is an instrument approach that uses positive lateral guidance but does not require positive vertical guidance. An LNAV/VNAV approach (RNAV terminology for an instrument approach with vertical guidance) is an instrument approach that uses both positive lateral and vertical guidance. A GLS approach (RNAV terminology for a precision instrument approach) is a precision instrument approach that uses both positive lateral and vertical guidance to decisions altitudes of 200 feet or less. A GLS approach is intended to be the RNAV equivalent of the Category I, II, and III precision approach procedures conducted with ILS.

A particular RNAV system may be capable of supporting approach operations for one or more of the above three procedure classifications, and a particular RNAV approach operation may be performed with any one of several certified RNAV systems. Without further consideration, this situation could have resulted in the proliferation of numerous RNAV-system-specific approach charts for what is essentially the same operational procedure. Consequently, the FAA developed an operational concept that defines approach procedures for all RNAV systems using a single approach plate where the system title is “RNAV RW XX”. An example approach plate is shown in Figure 1. A decision altitude is provided for each instrument approach procedure that uses vertical guidance (i.e., GLS, LNAV/VNAV). Additionally, a minimum descent altitude is provided for each instrument approach that uses only lateral guidance (i.e., circling, LNAV).

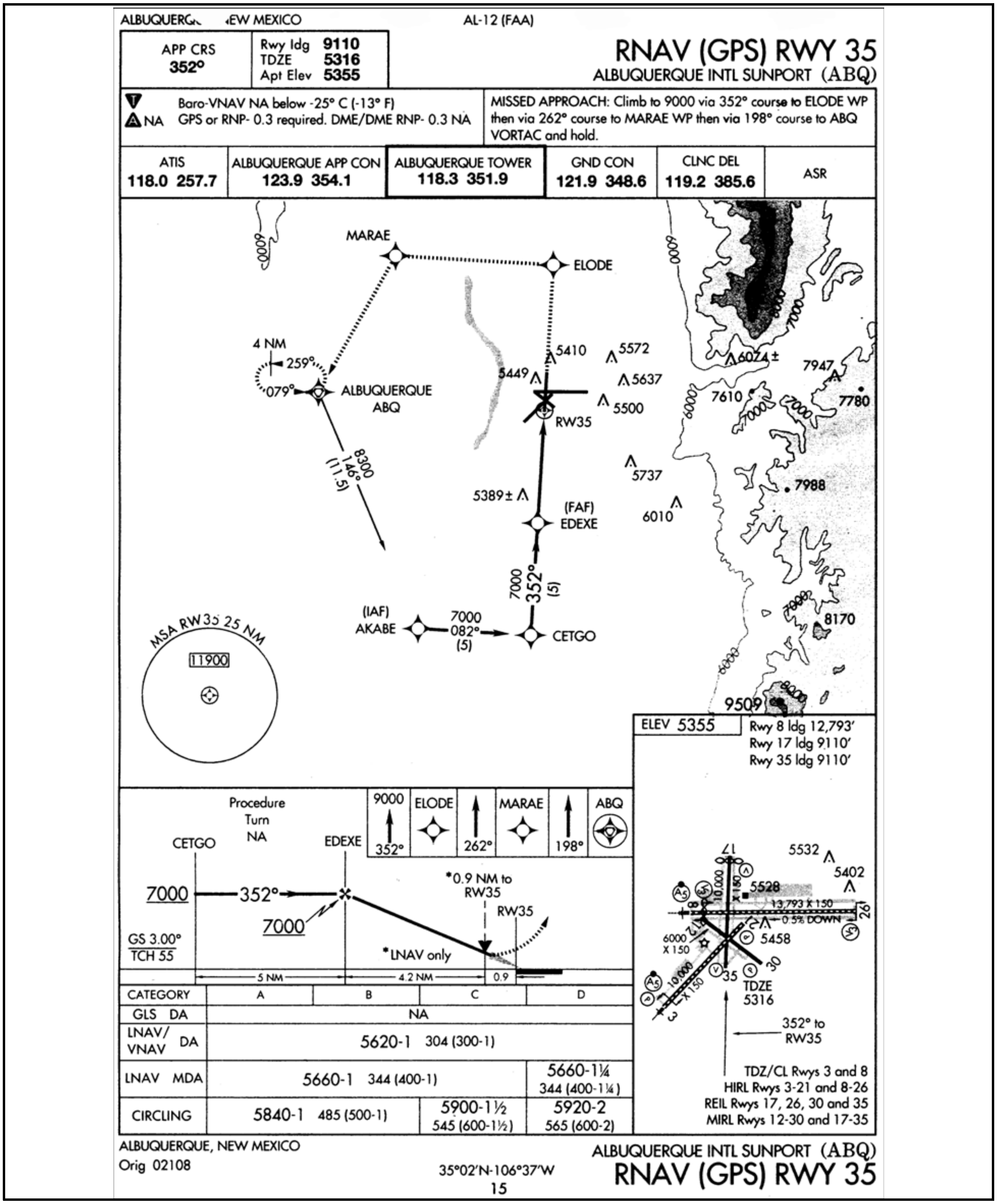

Figure 8. Example RNAV Approach Plate.

It is widely realized that vertically-guided approach procedures are safer than purely laterally guided approaches. This realization provides the motivation for developing and commissioning such procedures. Since the late 1990s, FMS and GPS/Baro VNAV systems have been certified for conducting select specialized LNAV/VNAV approach procedures.

The FAA is in process of commissioning a substantial number of GPS/Baro VNAV approach procedures each year. It is estimated that approximately 700 of these procedures will be commissioned and published prior to WAAS obtaining authorization for supporting such procedures [1]. Conventional thinking would be that a "WAAS flight inspection" would be conducted before WAAS is authorized for use in performing the procedure. The consequences in this case are not desirable considering the following two possible inspection strategies. One strategy is to conduct an intensive WAAS flight inspection effort once WAAS is operational. This approach would not be practical given the extremely high flight-inspection workload that would result from such a surge effort. The other strategy would be to perform the WAAS flight inspections when the existing GPS/Baro VNAV periodic inspections are conducted. However, this approach is undesirable since WAAS authorization for some procedures could be unnecessarily delayed by as much as 600 days.

Fortunately, the flight inspection of these GPS/Baro VNAV procedures will likely accomplish many of the WAAS flight inspection requirements associated with these procedures. Given the number of GPS/Baro VNAV procedures expected to be commissioned prior to WAAS being authorized, flight inspection resources would be better utilized if a more efficient WAAS flight inspection process were conducted for these cases. That is, there is a need to determine what WAAS flight inspection requirements remain for the previously commissioned GPS/Baro VNAV authorized procedures, as well as a means to identify ways to streamline the process without compromising the integrity of the flight inspection process.

Thus, the objective of this report is to develop recommended WAAS flight measurement requirements for the inspection of WAAS procedures that overlay existing GPS/Baro VNAV approach procedures. In accomplishing this objective, existing GPS/Baro VNAV flight inspection requirements have been reviewed and then compared to anticipated WAAS flight inspection requirements.

III. DEVELOPMENT OF REQUIREMENTS

The initial discussion in this section presents a comparison of the flight inspection requirements for GPS/Baro VNAV approach procedures with those anticipated for WAAS approach procedures. The results of this comparison indicate that GEOSAT signal coverage is the only WAAS flight inspection requirement not accomplished during the flight inspection of GPS/Baro VNAV approach procedures. Accordingly, the significance of GEOSAT signal coverage for WAAS and proposed WAAS flight inspection requirements for previously commissioned GPS/Baro VNAV procedures are discussed. The section concludes with a discussion of how screening models can be used to prioritize the flight inspection of existing GPS/Baro VNAV procedures for the purpose of authorizing WAAS approach operations.

A. Comparison of Flight Inspection Requirements.

Flight inspection requirements are contained in the "United States Standard Flight Inspection Manual" [2]. Requirements for GPS/BaroVNAV procedures are contained in Section 209; at this time the manual does not include requirements for flight inspection of WAAS approach procedures. However, it is anticipated that WAAS flight inspection requirements will be developed based on the concepts presented in Reference 3, which are intended for inspection of Category I precision approach operations. Thus, only the type of parameters assessed or type of flight inspection analysis performed were considered when comparing the existing GPS/Baro VNAV flight inspection requirements to those anticipated for WAAS. Logically, the tolerances proposed for inspection of WAAS supported Category I precision approach operations are more stringent than those specified in Section 209 for GPS/BaroVNAV approach procedures. However, this situation is not relevant to this particular effort since RNAV performance requirements are procedure-type specific and not sensor-type specific.

The results of the comparison between GPS/Baro VNAV and WAAS flight inspection procedures show that in either case the following four types of assessments are to be accomplished:

1) Assessment of Obstacle Environment: The controlling obstacles are verified during the flight inspection of the procedure.

2) Assessment of Standard Instrument Approach Procedure: Human factors such as situational awareness, workload, complexity, interpretability, and potential for pilot error are assessed. It is assumed that communications, navigation system performance, and radar (if required) are assessed to ensure they are adequate for safely performing the procedure.

3) Assessment of Procedure Design: The location of any geodetic coordinates (way points) or other database/approach plate information used to construct or execute the approach are validated. Ensures that waypoint spacing allows for stable flight along each segment, and that procedure satisfactorily delivers aircraft to an established point at the termination of the procedure.

4) Assessment of Electromagnetic Spectrum: The presence of RF interference at levels which may adversely affect the GPS receiver performance is evaluated. This may result in restriction of the procedure.

Consequently, flight inspection of GPS Baro VNAV procedures will accomplish those requirements anticipated for the GPS element of WAAS when WAAS is used to support those same procedures. However, flight inspection to ensure that adequate GEOSAT signal coverage exists has not been performed for commissioned GPS/Baro VNAV procedures, since GEOSAT coverage is not a requirement and the FAA currently does not have an inspection system authorized for WAAS (GEOSAT) flight inspection [4]. Further, such a system is not anticipated to be available until April 2003, thus assessment of GEOSAT coverage is unlikely to be accomplished for those GPS/Baro VNAV procedures commissioned prior to April 2003 [4]. Thus, the significance of GEOSAT coverage and the potential impact on WAAS must be considered when determining the WAAS flight inspection requirements for previously commissioned GPS/Baro VNAV procedures.

B. Significance of GEOSAT Coverage for WAAS

In general, the development of the WAAS flight inspection criteria is based on the site-specific components of a WAAS instrument approach procedure. While the space and ground components of both GPS and WAAS affect the WAAS approach, the flight inspection procedure relies on the inherent monitoring of those systems to determine faults. The same philosophy applies to the WAAS/GPS receiver on board the aircraft. The flight inspection procedure is not intended to provide an assessment of receiver performance as this matter is evaluated during equipment certification. This philosophy does not exclude the recording of GPS and WAAS parameters. The parameters are needed to determine why an inspection run may have failed and if there has been any local corruption or interference with the signal.

WAAS uses GEOSATs to broadcast additional ranging signals, integrity information, and differential corrections. GEOSAT coverage is broad in nature, and four GEOSATs can provide non-redundant coverage of the entire globe from about ±70E in latitude, assuming that the corresponding ground reference stations are in operation [5]. In the United States, the WAAS service volume is supported by two Inmarsat III geosynchronous satellites: the Pacific Ocean Region and the Atlantic Ocean Region - West [6,7]. These two GEOSATs provide coverage for essentially the entire United States. However, there will likely be a limited number of sites where GEOSAT coverage is in question due to fringe area considerations or due to blockage of the signal by significant topographical features. Thus, the potential lack of GEOSAT coverage and how it affects the capability to conduct LNAV/VNAV approach procedures must be assessed.

As previously stated, WAAS uses GEOSATs to broadcast additional ranging signals, integrity information, and differential corrections. Hence, the service provided by the GEOSATs enables WAAS to meet the integrity, continuity, availability, and accuracy required for LNAV/VNAV procedures. Although not precluded, a WAAS receiver is not required to employ barometric aiding, but shall have fault detection and exclusion capability that utilizes redundant GPS/GEOSAT range measurements to provide integrity monitoring [8]. Therefore, it is assumed that the "minimum capability" WAAS receiver does not employ barometric aiding for the purpose of the assessment presented herein.

Accordingly, the WAAS receiver is assumed to revert to a GPS only capability in the absence of GEOSAT coverage, that is, it reverts to an LNAV only capability. In this case, only GPS satellites are available to support FDE. In rare cases, this situation may even limit the ability to perform the LNAV procedure due to the inability to accomplish FDE during the time at which it is desired to perform the approach procedure.

3. Proposed Flight Inspection Requirements

The flight inspection requirements proposed herein are based on the following assumptions:

1) The inherent monitoring provided by the ground, space, and receiver elements of WAAS are capable of assessing system performance and of detecting system faults within the required time-to-alarm.

2) The WAAS receiver reverts to a GPS only capability in the absence of a GEOSAT signal.

3) The FAA has authorized WAAS to support LNAV/VNAV approach procedures.

4) The procedure has been commissioned for GPS/Baro VNAV.

5) The availability of the GPS/Baro VNAV procedure is at least 95 percent and the availability with WAAS is determined to be at least 95 percent as well.

6) The decent altitude for the WAAS LNAV/VNAV approach procedure is not lower than that authorized for the GPS/Baro VNAV procedure.

7) There is high correlation between predicted (monitoring) and actual WAAS system performance.

As previously discussed, flight inspection of the GPS/Baro VNAV procedure will accomplish all of the anticipated WAAS LNAV/VANV inspection requirements except for inspection of GEOSAT signal coverage. Thus, the flight inspection requirements proposed will differ depending on the status of GEOSAT coverage. Given the number of GPS/BaroVNAV procedures that will be commissioned before WAAS IOC, it is fortunate that flight inspection is not the only method that can be used for assessing GEOSAT signal coverage. Coverage assessments may be made using computer-based screening models. The results from such models could be analyzed to classify procedures into one of three categories. One category is for procedures where there is high confidence that GEOSAT signal coverage would exist. The second is for procedures where there is low confidence that coverage would exist. The third category is for procedures where "*marginal*" signal coverage would be indicated. More detail regarding GEOSAT signal coverage assessments is provided in Section D.

Where there is high confidence that GEOSAT coverage would exist, WAAS supported LNAV/VNAV approach procedures could be authorized prior to conducting a WAAS-specific flight inspection. For each such procedure, a WAAS-specific flight inspection should be conducted during the next periodic or special inspection of the existing GPS/Baro VNAV procedure (whichever occurs first). Should pilot reports, or other official notifications be received indicating that a problem may exist with GEOSAT coverage, authorization to use WAAS for the approach procedures should be withdrawn until flight inspection has confirmed that the GEOSAT coverage is sufficient to support the approach procedure.

Where *marginal* coverage performance is indicated, a WAAS-specific flight inspection should be performed before the WAAS supported LNAV/VNAV approach procedure is authorized. Procedures where low confidence in the GEOSAT signal coverage is indicated should not be unequivocally dismissed, but should receive the lowest priority in terms of scheduling WAAS-specific flight inspections.

3. GEOSAT Signal Coverage Assessments

Section C recommends that computer-based screening models be used to assess GEOSAT signal coverage and, thus, identify which GPS/Baro VNAV approach procedures should be flight inspected before WAAS is authorized to support such procedures. One assessment method would be to develop a high-fidelity screening model that has an elaborate obstacle, terrain, and approach procedure data base coupled with a complex propagation model. Technically, such a model would be capable of making very definitive coverage estimates, that is, accuracies of 1-3 dB depending on the specific methods used. It is likely that the components for such a model already exist; but, considerable time may be required to integrate the components and validate the model for this particular application. Also, the variability or uncertainty in some of the values used for requisite model parameters may overshadow the technical and numerical capabilities of such a model. Assumptions about aircraft flight dynamics during a particular approach procedure, or aircraft antenna reception characteristics, are examples of parameters that may vary widely or have some level of uncertainty regarding the proper values to be used.

An alternative method would be to develop or use a more basic (simple) screening model that would provide "*less-accurate*" coverage estimates, that is, accuracies of 8-10 dB. To account for the fact that the screening model will have finite accuracy, the results from such models could be analyzed to classify procedures into one of three categories. As previously mentioned, one category is for procedures where there is high confidence that GEOSAT signal coverage would exist, while the second is for procedures where there is low confidence that coverage would exist. The third category is for procedures where "*marginal*" signal coverage would be indicated.

It should be realized that the screening model will be used to solve an interim problem, i.e., avoiding unnecessary delay in authorizing WAAS operations for existing GPS/Baro VNAV procedures prior to actual FAA WAAS flight inspection. Further, models exist for estimating the decision altitude for LNAV/VNAV approach procedures [9,10,11]. These models use airport, obstacle, and terrain data bases and estimate decision altitudes by determining the height of obstacles and terrain relative to prescribed obstacle clearance surfaces. Thus, it is very probable that such models could be easily modified to determine the height of obstacles relative to a planer surface that contains an approach segment and the GEOSAT.

Given the interim nature of the problem and the availability of models that estimate decision altitudes, development and use of a simple screening model may be the better choice in this case. Although further investigation of this matter may be warranted, the use of a simple screening model will be assumed for the purpose of discussing how a GEOSAT signal coverage assessment could be conducted.

The screening model would be used to accomplish the assessment outlined in Figure 2. As illustrated in Figure 2, the model would cycle through a list of airports, and for each airport it would cycle through a list of GPS/Baro VNAV procedures, and finally for each procedure it would cycle through each procedure segment, as appropriate. That is, the GEOSAT signal coverage assessment would be performed for each procedure segment.

The initial assessment would be to determine if the elevation angle for line-of-sight (LOS) between the segment and GEOSAT exceeds a prescribed mask angle. Since signal blockage by obstacles and terrain is to be assessed separately, it should be sufficient to assume a smooth curved earth when determining a suitable value for the mask angle. The main concern for this assessment is to ensure that the GEOSAT is visible and high enough above the horizon such that ground reflections do not cause unacceptable signal fading. A 5-degree mask angle is typically used in performing generalized GEOSAT coverage estimates [5]. However, a 5-degree mask angle likely would be overly conservative for these segment-specific assessments, since blockage by local obstacles and terrain also is being performed. Further, it should be sufficient to perform this assessment at the lowest altitude point on each segment, and perturbations in the GEOSAT orbit/position and flight technical error should be taken into consideration. If the LOS elevation angle is below the prescribed mask angle, it would be unlikely that GEOSAT signal coverage existed along the segment. Thus, the procedure should be flight inspected before WAAS operations were conducted. Further, the flight inspection of such a procedure should be considered a low priority.

If the LOS elevation angle exceeds the prescribed mask angle, the next step is to determine if there would be signal blockage by obstacles or terrain. As the user progresses along the procedure segment, the change in the elevation and azimuth angles for LOS from the user to the GEOSAT will be insignificant. However, as the user progresses along the procedure, obstacles and terrain may pass through, or close to the user-GEOSAT LOS. Thus, in this step the analysis must be performed at prescribed intervals along the procedure segment. A sample interval that corresponds to the distance covered, at typical approach speeds for the slowest aircraft type, in one-quarter to one-half of the time-to-alarm may prove suitable for this analysis. For each sample point along the segment, obstacle/terrain data bases would be scanned for objects within a predetermined distance and in a predetermined sector about the sample point-GEOSAT LOS. For each object meeting the initial screening criteria, an analysis would be conducted to determine if the sample point-GEOSAT LOS passed through, or close to the object. An LOS clearance margin would be calculated (see Figure 2). A positive margin denotes that LOS is not blocked by the object, but clears the object by a given distance. A negative margin denotes that LOS is blocked by the object.

Since electromagnetic fields are continuous, the GEOSAT signal does not disappear the instant signal blockage occurs (see Figure 3). When LOS is not blocked and passes by an object by a sufficiently large enough distance, the signal strength is essentially the same as it would be if the object were not present, that is if it were in free space (see Figure 3, Case A). In this case, electromagnetic LOS is said to exist. As the distance between the object and LOS decreases, one encounters the cases where there is a slightly positive clearance margin (see Figure 3, Case B) or a slightly negative clearance margin (see Figure 3, Case C). Although signal attenuation occurs

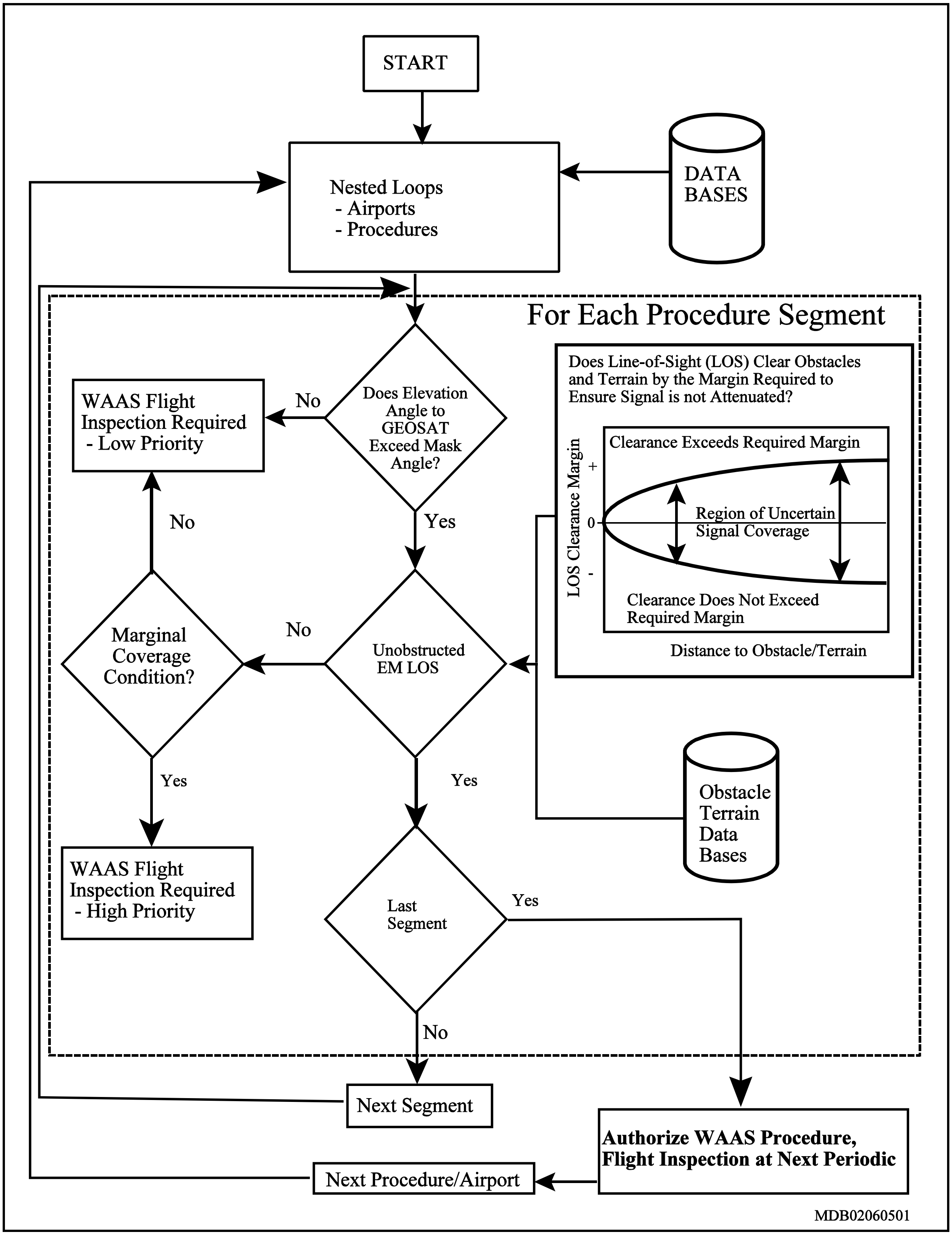

Figure 9. Process for Screening GPS/Baro VNAV Procedures for GEOSAT Signal Coverage.

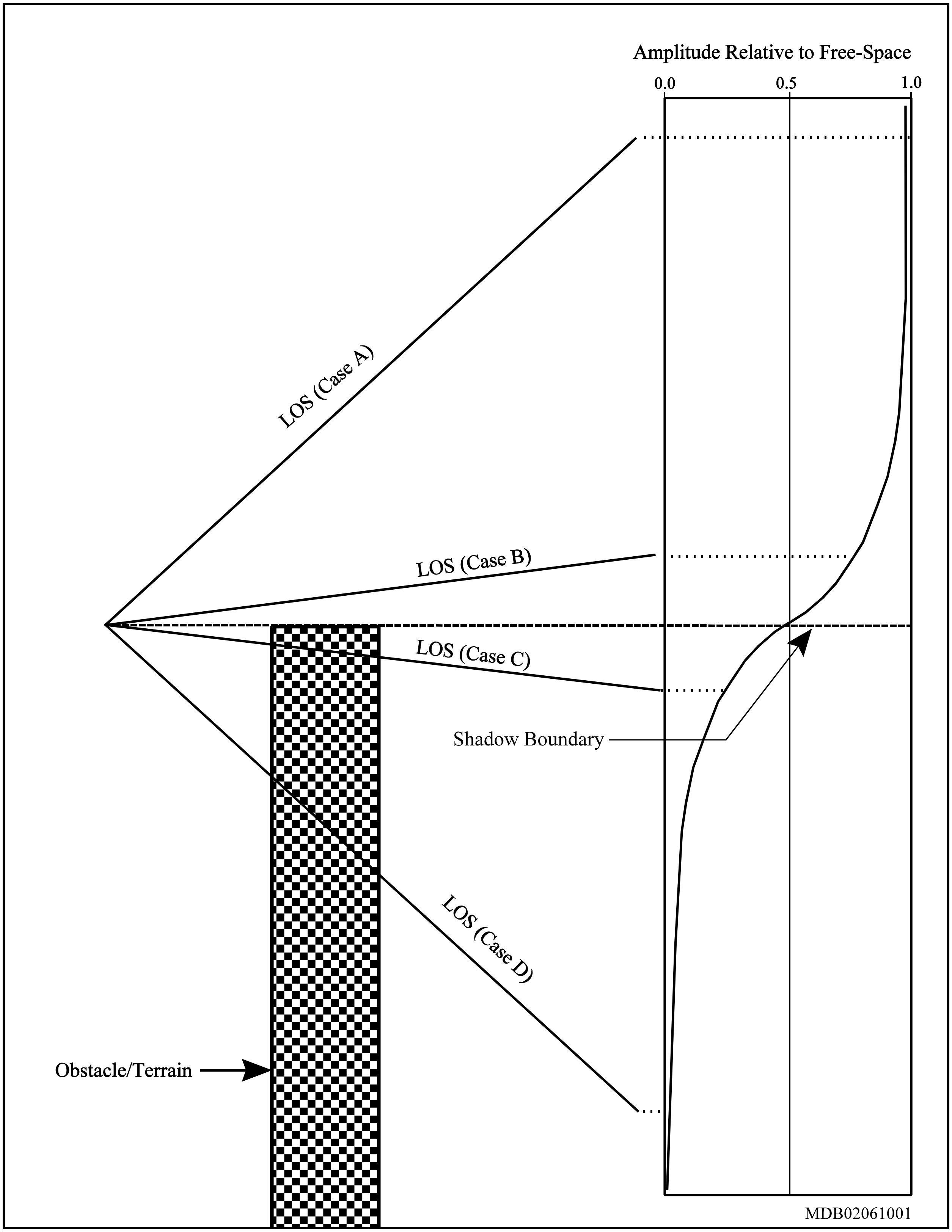

Figure 10. Signal Strength Characteristics Versus Line-of-Sight Clearance.

in the vicinity of the shadow boundary, there still may be adequate signal strength and thus coverage may exist. As LOS passes well into the interior of the object, significant signal attenuation occurs, thus it is very likely that coverage would not exist (see Figure 3, Case D). As an example, the size of the LOS clearance margin in relationship to a Fresnel Zone Radius/Radii could be used as a means of estimating if signal coverage would exist, be marginal, or not exist.

Thus, the results of the procedure signal coverage analysis could yield one of three possible outcomes. One outcome is a "large" negative clearance margin for one or more segments, indicating significant signal blockage and that GEOSAT signal coverage is unlikely to exist along the affected segment(s). In this case, the procedure would need to be flight inspected before WAAS LNAV/VNAV approach operation could be authorized. Since there is a high probability that coverage would not exist, such approach procedures should receive a low priority in terms of a flight inspection schedule. Another outcome is that the clearance margin is either slightly negative or slightly positive for one or more segments, indicating that LOS is close to the shadow boundary. This situation represents the marginal coverage case, and the procedure should be flight inspected before WAAS LNAV/VNAV approach operations could be authorized. The third outcome is that a large positive clearance margin exists for all procedure segments, which would indicate a high probability of GEOSAT coverage. In this case, WAAS LNAV/VNAV approach operations could be authorized and GEOSAT signal coverage would be formally inspected during the next periodic flight inspection of the procedure.

III CONCLUSIONS AND RECOMMENDATIONS

A substantial number of LNAV/VNAV approach procedures will be commissioned for GPS/Baro VNAV approach operations before WAAS obtains Initial Operational Capability. Mandating the flight inspection of each existing procedure prior to authorizing WAAS approach operations for the same procedure may unnecessarily delay the availability of such procedures to WAAS equipped users. Based on a comparison of requirements, the flight inspection of GPS/ Baro VNAV procedures will accomplish all of the anticipated WAAS flight inspection requirements, except for inspection of GEOSAT signal coverage. Computer-based screening models can be used as a means of determining if signal coverage would exist, be marginal, or not exist. Such a capability should streamline the flight inspection process for WAAS LNAV/VNAV procedures without compromising the integrity of the flight inspection process.

The following recommendations are offered:

1) The comparison of GPS/Baro VNAV and WAAS LNAV/VNAV flight inspection requirements should be repeated once formal criteria are available in FAA Order 8200 to confirm the results presented herein;

2) The development of a screening model for assessing GEOSAT signal coverage should be pursued;

3) Where the results of a validated screening model indicate high confidence that GEOSAT signal coverage would not exist, the WAAS LNAV/VNAV procedure should be flight

inspected before being authorized for use and inspection of such procedures should be of a low priority;

4) Where the results of a validated screening model indicate a marginal GEOSAT signal coverage condition, the WAAS LNAV/VNAV procedure should be flight inspected before being authorized for use and inspection of such procedures should be of a high priority;

5) Where the results of a validated screening model indicate high confidence that GEOSAT signal coverage would exist, the WAAS LNAV/VNAV procedure could be authorized for use prior to a formal WAAS flight inspection. The procedure would be flight inspected during the next periodic inspection subsequent to the authorization of the WAAS approach operation; and,

6) For WAAS procedures authorized prior to formal flight inspection, authorization should be withdrawn if pilot reports or other information is received that indicates a potential GEOSAT coverage problem until such time that flight inspection can verify adequate GEOSAT coverage.

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