TECHNICAL MEMORANDUM
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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).

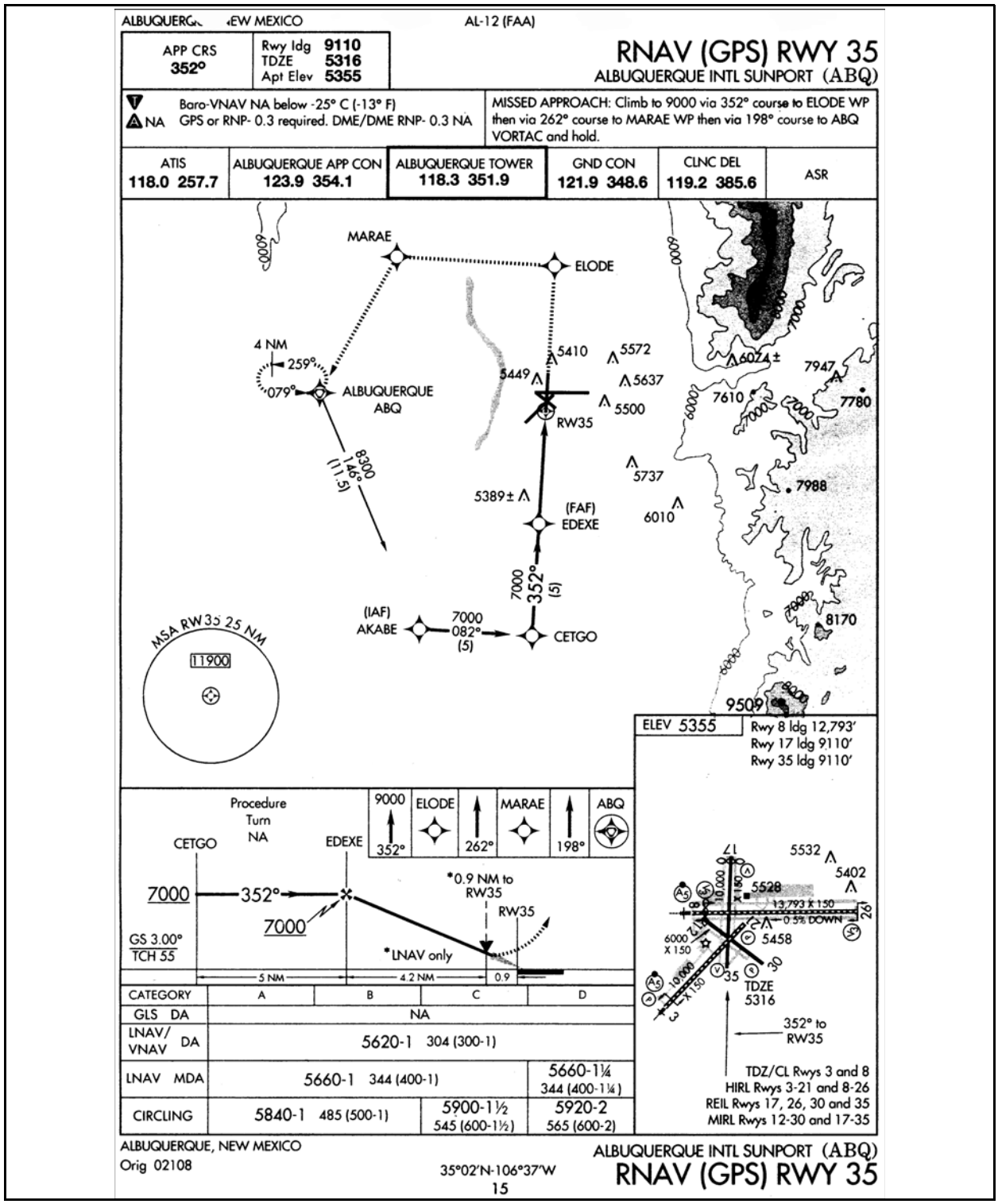

Figure 8. Example RNAV Approach Plate.

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

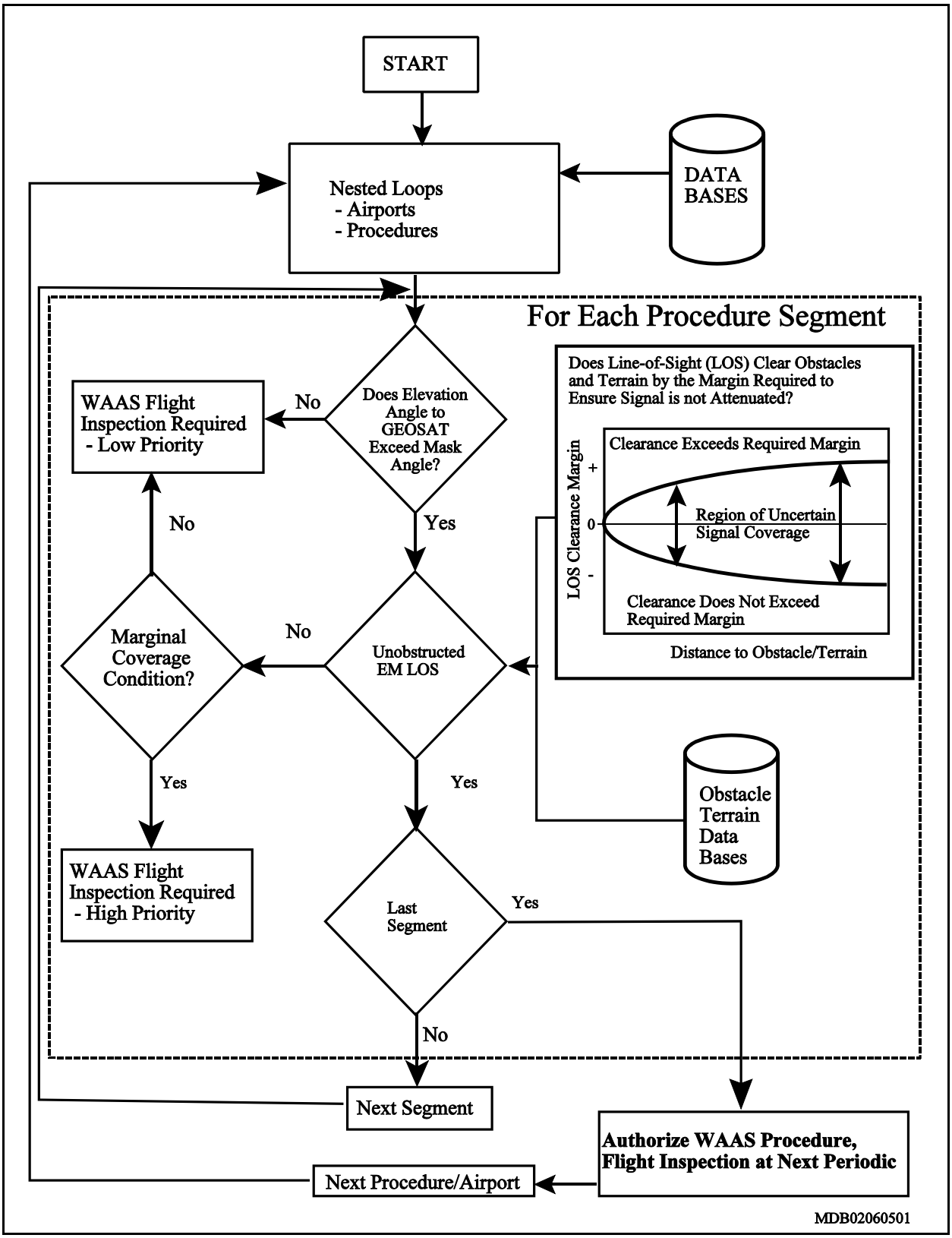

Figure 9. Process for Screening GPS/Baro VNAV Procedures for GEOSAT Signal Coverage.

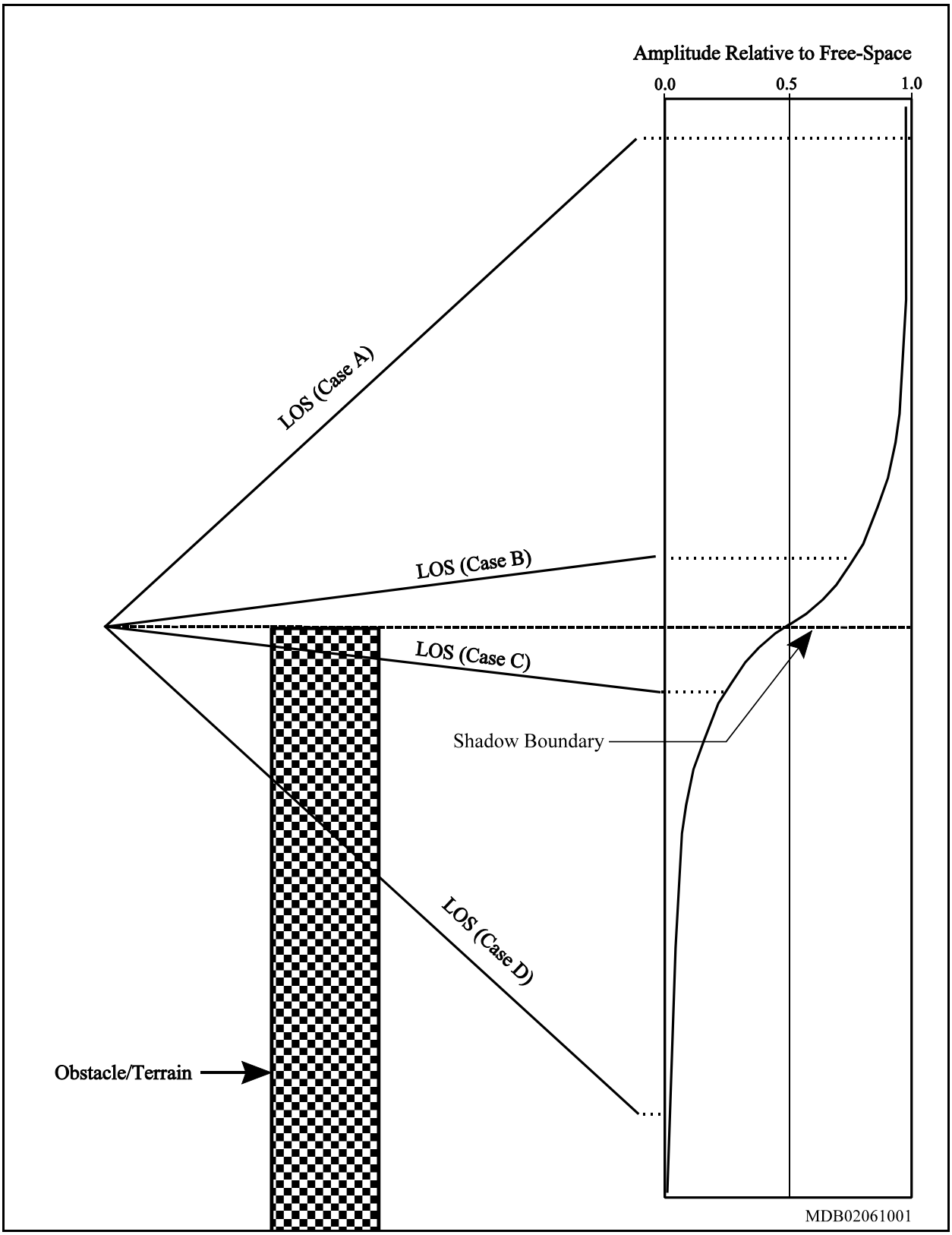

Figure 10. Signal Strength Characteristics Versus Line-of-Sight Clearance.

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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