DERIVATION OF RANGING SOURCE INTEGRITY REQUIREMENTS FOR THE LOCAL AREA AUGMENTATION SYSTEM (LAAS)[*]

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ABSTRACT

Several satellite latent fault modes can cause errors that may not be removed by pseudorange corrections or be detected unless special augmentation-based integrity monitors are employed. The error classes resulting from satellite fault modes are distorted signal waveform, uncorrectable ephemeris error, excessive clock acceleration, excessive code-carrier divergence, and low signal power. The paper derives the integrity monitoring parameters for these errors through mathematical analyses and error bounding rationales. The integrity parameters are the maximum allowable error in the pseudorange corrections and the probability of missed detection of this error. The inputs to the analyses are the integrity monitoring operational requirements contained in the *Minimum Aviation System Performance Standards for the Local Area*

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Augmentation System (LAAS). The results of the analyses are used as the basic performance requirements for ranging source integrity monitoring in the FAA's LAAS Ground Facility specification. The paper includes model derivations and an example application to the signal waveform distortion error class.

INTRODUCTION

Background

The Local Area Augmentation System (LAAS) provides local area pseudorange corrections for aircraft precision approach operations. It is undergoing development for implementation by the FAA to provide Category I (CAT I) to CAT IIIb operations. Performance Type 1 (PT 1) LAAS is sufficient to support CAT I operations. The FAA in a government-industry partnership (GIP) has developed the specifications for the PT 1 LAAS Ground Facility (LGF). Industry through RTCA, Inc. is developing the LAAS Minimum Operational Performance Standards (MOPS) for the LAAS airborne equipment and the interface control document (ICD) that ensures compatibility between the LGF and the Avionics. The LAAS requirements are contained in the LAAS Minimum Aviation System Performance Standards (MASPS) [1] and the LGF specification [2].

Integrity Monitoring

Since the LGF PT 1 specification is for air navigation, it emphasizes integrity monitoring. The specification of integrity monitoring technical requirements for precision approach presents a challenge due to system complexity and the scarcity of operational satellite failure data. Figure 1 is a chart showing the LAAS integrity risk allocations [2]. The definition of these allocations and the means to achieve them are contained in [1] and [2], respectively.

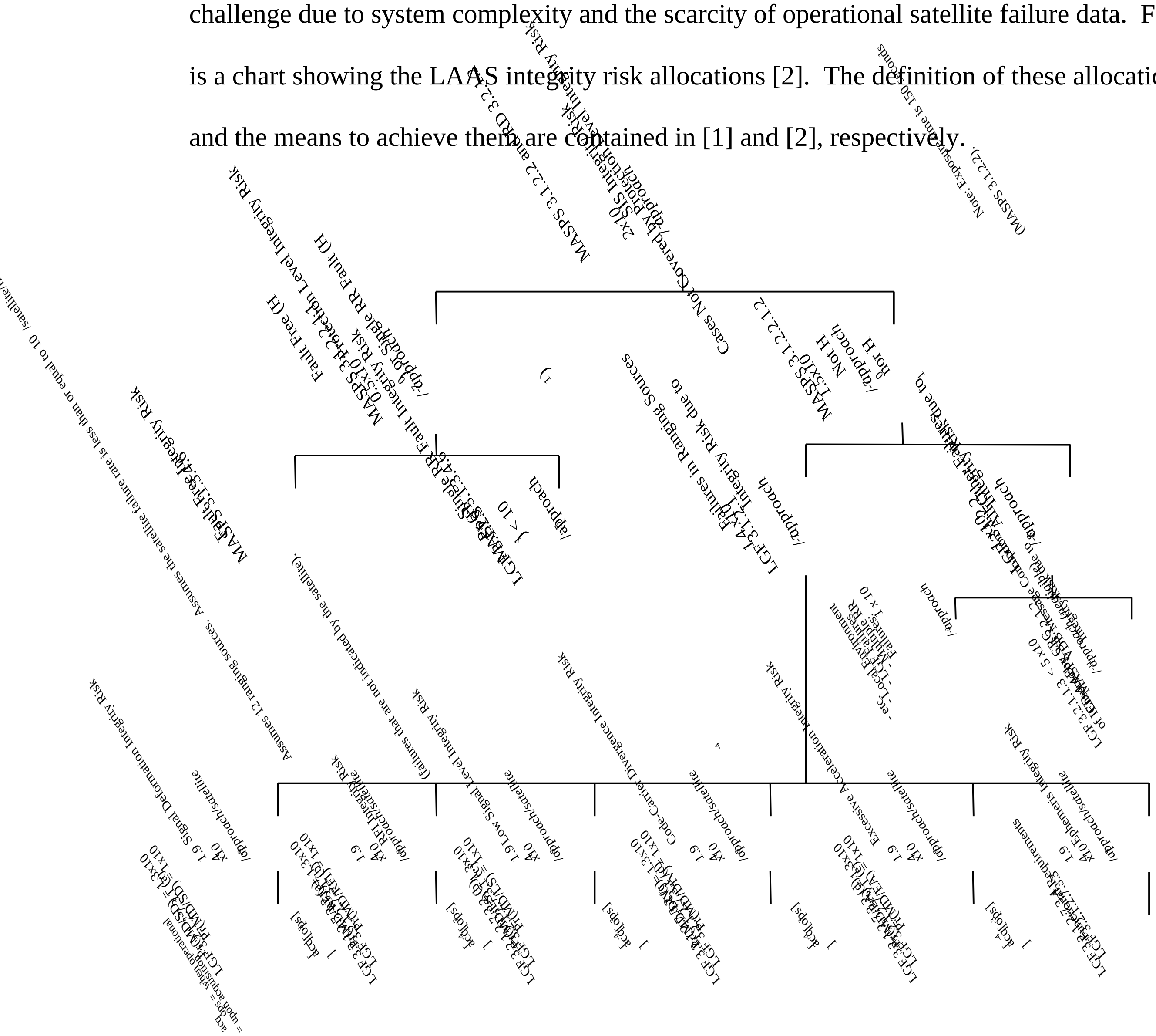

Figure 1 – LAAS Integrity Requirement Allocations

The LGF provides integrity monitoring of both its multiple reference receivers (RRs) and the ranging sources it tracks as illustrated in the top-level integrity flow diagram in Figure 2. The ranging sources required for the PT 1 LGF are the GPS and Wide Area Augmentation System (WAAS) satellites. RR integrity monitoring protects against receiver failures and excessive multipath. This is a cooperative effort between the LGF and the airborne segments using the so-called B-values and an accuracy parameter σ_{pr_gnd} for each ranging source correction. A B-value compares the correction from one particular RR to the average of the corrections from the other RRs on an individual satellite basis. A threshold test is also applied to each B-value for the purposes of detecting an RR fault prior to another RR fault occurring, and preventing the

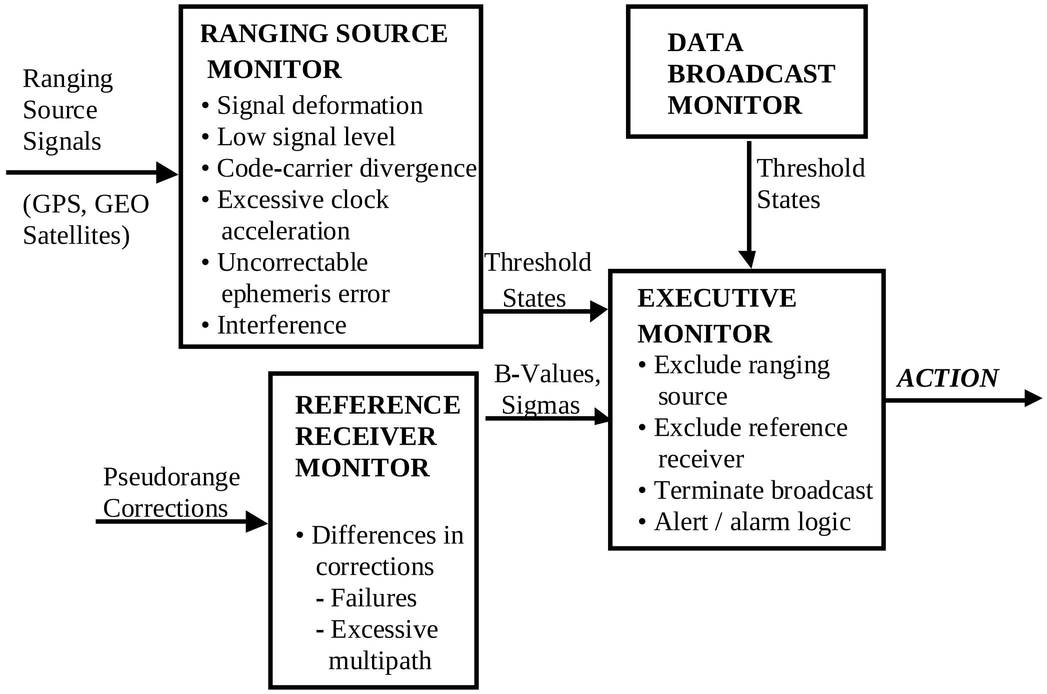

Figure 2 – LAAS Ground Facility Integrity Monitoring Flow

transmission of excessive B-value magnitudes. These parameters are broadcast from the LGF as described in [1, 2]. Based on this broadcast data, airborne algorithms determine whether any of the RR's outputs contain data that could lead to a hazardous aircraft position. However, the integrity monitoring of the ranging sources is the sole responsibility of the LGF.

This paper describes mathematical models that were used to derive the integrity technical monitoring parameters for ranging sources in the PT 1 LGF specification. These parameters are maximum allowable error in the pseudorange corrections [3] and probability of missed detection of that error [4]. To cope with complexity and lack of data, conservative parameters were used in the models. Although the models were derived for the FAA's LGF, they should be of general application to any augmentation system's integrity technical specification. Descriptions of the FAA's design concepts for the LGF are given in [5, 6].

Thresholds

Figure 3 illustrates the allowable monitor threshold constraints for a LAAS integrity test applied to a ranging source. The minimum threshold is based on the continuity allocation for a ranging source. Continuity is the probability a system provides service over a specified time interval without interruption. The continuity risk allocation is expressed as the probability a ranging source is removed due to a monitor test statistic exceeding its threshold. This probability is calculated from the fault-free detection (ffd) distribution. Fault-free detection refers to a threshold being exceeded due to the random measurement errors (usually referred to as noise) in the absence of a failure. Thus in Figure 3, the minimum threshold is defined by

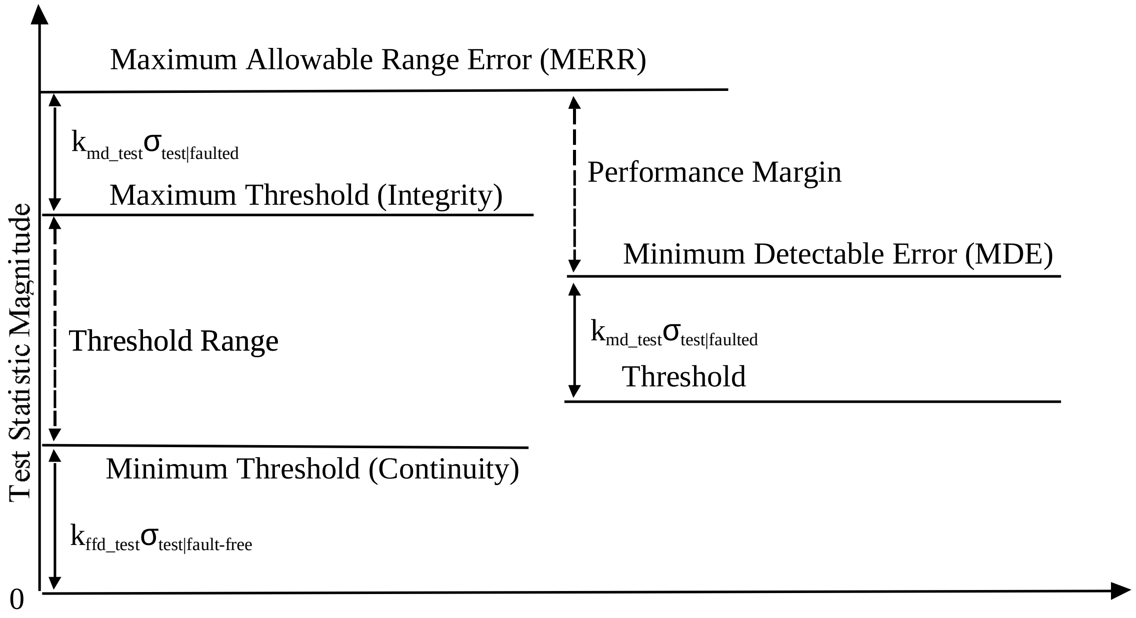

Figure 3 – Integrity Monitor Threshold Range

$$\text{min\_threshold} = k_{ffd\_test} \times \sigma_{test|fault\text{-}free} \tag{1}$$

where k_{ffd_test} is the fault-free-detection $\sigma_{test|fault\text{-}free}$ multiplier associating measurement errors with the probabilities of a zero-mean Gaussian probability distribution and $\sigma_{test|fault\text{-}free}$ is the standard deviation of the distribution under fault-free conditions. The parameter k_{ffd_test} is based on the continuity risk allocation given to the particular test under consideration.

The maximum allowable threshold is defined by

$$\text{max\_threshold} = \text{MERR} - k_{md\_test} \times \sigma_{test|faulted} \tag{2}$$

where MERR is the maximum allowable pseudorange correction error magnitude [3] and k_{md_test} is the sigma multiplier associating the missed detection probability with the measurement error distribution under the faulted condition. A violation of MERR is considered to be a safety hazard. Integrity risk is the probability that a failure occurs causing the MERR to be exceeded and that this condition is not detected. Thus, the interval defined by $k_{md\_test} \times \sigma_{test}$ provides a buffer to protect against the condition where the true error exceeds the threshold but the monitor test statistic does not, due to partial cancellation of the test statistic by measurement noise. The gap between the minimum and maximum allowable thresholds provides the range of allowable trade-off between continuity and integrity risks.

Once a threshold is established, the Minimum Detectable Error (MDE) is given by

$$\text{MDE} = \text{threshold} + k_{md\_test} \times \sigma_{test|faulted} \tag{3}$$

The amount by which MERR exceeds MDE is referred to as the performance margin of the monitor

$$\text{Performance Margin} = \text{MERR} - \text{MDE} \tag{4}$$

Integrity monitoring of the different classes of failures guarantees the ranging source integrity risk requirements are met. A ranging source failure is not an integrity risk to a LAAS user if it is indicated by a ranging source; e.g., by health word, transmission of non-standard code or transmission of non-trackable code. Thus, the LAAS integrity monitoring of ranging source failures has to identify those failures that have not yet been indicated in a timely manner by GPS relative to the LAAS requirements; i.e., within 3 s for PT 1 if MERR is exceeded. Failures that have not yet been indicated through observation of a ranging source signal are referred to as latent failures in this paper.

Outline of Paper

The following two sections discuss integrity risk in terms of failure classes and failure rates. Then a description and application of a state probability model for deriving the missed-detection probabilities are presented. Next, an analytical model for determining MERR and its application to LGF PT 1 requirements are presented. The last section contains a summary of the paper.

RANGING SOURCE RISK REQUIREMENTS

Risk Parameters

The satisfaction of an integrity risk requirement is quantified by an equation of the form

$$\text{Prior\_Prob} \times P_{md} \leq \text{Risk\_Requirement} \tag{5}$$

where Prior_Prob is the probability of a given latent failure class, and P_{md} is the probability of missed detection of the failure. Prior_Prob has to be known in order to determine the specified P_{md} to satisfy the risk requirement. The difficulty in determining P_{md} requirements is inexact knowledge of Prior_Prob, which is derived from the ranging-source failure rate. It is difficult to estimate the failure rate because it has such a small value; otherwise, GPS navigation would not be successful.

Based on the following discussion, 10^{-4} / h per SV is thought to be an upper bound for the latent failure rate of a GPS satellite. According to [1, p D-11], a conservative mean-time-between-outages for a GPS SV is MTBO = 5550 h, which is equivalent to an outage rate of 1.8×10^{-4} / h. Since the latent failure rate is less than the outage rate, its order-of-magnitude is taken as an upper bound latent failure rate in the estimation of required P_{md}.

Quantification of Risk

The LAAS integrity risk requirement for ranging sources was taken from the requirements in [2]. Its value is $R_{req} = 1.4 \times 10^{-7}$ per 150 s final approach segment duration. It was assumed there will be a maximum of 12 GPS ranging sources available in the earliest implementation of LAAS. Therefore, the integrity risk for the jth ranging source is given by

$$R^{j} = R_{req}/12 = 1.167 \times 10^{-8} \text{ per ranging source per approach} \tag{6}$$

Reference [5] identified six failure classes that could occur with respect to ranging. Five classes of ranging source failures were identified with respect to specification [2]: signal deformation, low signal power, code-carrier divergence, excessive ranging source clock acceleration, and uncorrectable ephemeris error in the navigation message. Radio frequency interference (RFI) is also included as part of this risk branch even though it is a local disturbance. Although a risk requirement is placed on ephemeris errors, the probability of their missed detection is not considered here because the method to protect their integrity is stated explicitly in the LAAS specification [2]. As assumed in Figure 1, the risk has been equally allocated among the six failure classes, yielding a value of $R^j / 6 = 1.94 \times 10^{-9}$ per failure class. Equation (6) is modified to reflect the treatment of ephemeris integrity monitoring in the LAAS specification

$$R^j_{mod} = R^j - 1.94 \times 10^{-9} = 9.73 \times 10^{-9} \text{ per ranging source per approach} \qquad (7)$$

MODEL FOR DETERMINING PROBABILITY OF MISSED DETECTION

Model Description

The state probability model is a 3-state Markov Chain [7] with a discrete parameter. The discrete parameter is the number of sequential independent integrity checks. This model provides a structured approach for explanation of parameters and calculations. Figure 4 is a state diagram of the process.

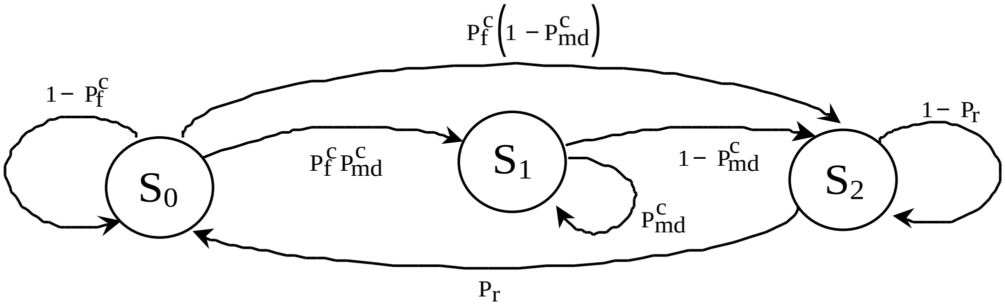

Figure 4 – State Probability Process

The state probability equation is derived from the diagram as

$$\begin{bmatrix} \Pi_0^c(i) \\ \Pi_1^c(i) \\ \Pi_2^c(i) \end{bmatrix} = \begin{bmatrix} 1 - P_f^c & 0 & P_r \\ P_f^c P_{md}^c & P_{md}^c & 0 \\ P_f^c\left(1 - P_{md}^c\right) & 1 - P_{md}^c & 1 - P_r \end{bmatrix}^i \begin{bmatrix} 1 - \Pi_1^c(0) \\ \Pi_1^c(0) \\ 0 \end{bmatrix} \qquad (8)$$

The $\Pi_i^c(i)$ are the state probabilities where $\Pi_0^c(i)$ is the probability that there are no class-c failures after i independent integrity checks (i = 1,2…), $\Pi_1^c(i)$ is the probability of a latent class-c failure not yet detected by LAAS and is defined as the risk, and $\Pi_2^c(i)$ is the probability that a latent class-c failure has been detected by LAAS. The first term on the right-hand-side of (8) is the transition probability matrix describing the modeled random process. P_f^c is the probability of a class-c latent failure occurring between independent integrity checks, P_{md}^c is the required probability of missed detection of a class-c failure, and P_r is the probability that any failure will be restored by the GPS Operational Control Segment between independent integrity checks. The second term on the right side contains the initial state probability conditions (i = 0). $\Pi_1^c(0)$ is the prior probability that a latent class-c failure exists at the time when LAAS first acquires a ranging source.

The total risk for the five ranging source failure classes considered needs to be smaller than or equal to the risk requirement allocation per ranging source. The risk requirement allocation per ranging source R(i) is satisfied after i independent integrity checks if

$$R(i) = \sum_{c=1}^{5} \Pi_{I}^{c}(i) \le R_{mod}^{j} \tag{9}$$

P_{md}^{c} is determined by varying its value in equation (8) until (9) is satisfied with equality.

Latent Failure Probability During Correction Broadcast

Since there is at present a lack of knowledge of P_f^c for each of the failure classes, they are all assumed to be equal. The results are probably not significantly sensitive to this assumption, as will be illustrated subsequently. Therefore

$$P_f^c = \lambda T/(3600 \times 6) = 4.63 \times 10^{-5} \lambda T \tag{10}$$

where λ is the assumed latent failure rate of 1×10^{-4} / h per ranging source, and T is the exposure time in seconds. T is taken to be equal to a 150 s approach duration. This is a conservative exposure time because some integrity monitors may operate on non-smoothed data such as carrier phase. For the assumed values of λ and T, equation (10) gives the result

$$P_f^c = 6.94 \times 10^{-7} \tag{11}$$

Latent Failure Probability at Acquisition

The latent probability of Class C failures at initial satellite acquisition is approximated as

$$\Pi_1^c(0) = \mathrm{MTTR}/(\mathrm{MTBF} + \mathrm{MTTR}) \approx \mathrm{MTTR}/\mathrm{MTBF} \tag{12}$$

where the mean-time-to-respond (MTTR) is the average GPS Operational Control Segment failure response time and MTBF is the mean-time-between-latent-failures. Reference [8] estimates the maximum failure response time to be 6 h and the nominal response time to be 10–30 min. Since there are some gaps in the GPS Operational Control Segment coverage, the MTTR for this analysis is assumed to be 1 h. MTBF for each failure class is $1 / (\lambda / 6) = 6 / \lambda = 6 \times 10^4$ h. Thus, for the assumed values of MTTR and MTBF, equation (12) becomes

$$\Pi_1^c(0) = \frac{1}{6 \times 10^4} = 1.67 \times 10^{-5} \tag{13}$$

A 150 s duration is also taken as the exposure time for latent failures to appear during the ranging source acquisition process since it approximately corresponds to the specified smoothed pseudorange filter time constant of 100 s.

Probability of Failure Restoration

$$Pr = T / MTTR = 150 \text{ s} / 3600 \text{ s} = 0.042 \qquad (14)$$

MISSED DETECTION REQUIREMENTS RESULTS

First, the latent failure P_{md} requirements at acquisition were obtained from (8) using the above model input parameters, setting i =1, and varying P_{md} until (9) was satisfied with equality. Then, the P_{md} requirements were calculated for when the LAAS first begins transmitting corrections after acquisition. This calculation was accomplished by using the resulting state probability vector from the first step as the new initial condition, setting i = 1, and varying P_{md} until (9) was satisfied with equality. The results are shown in Figure 5. In Table 1, these P_{md} requirements are an order-of-magnitude larger than those calculated at acquisition because the process has already completed one independent check. It can be shown that as more independent samples are taken (i increases), the integrity risk of the correction broadcast becomes somewhat less than the values in Table 1.

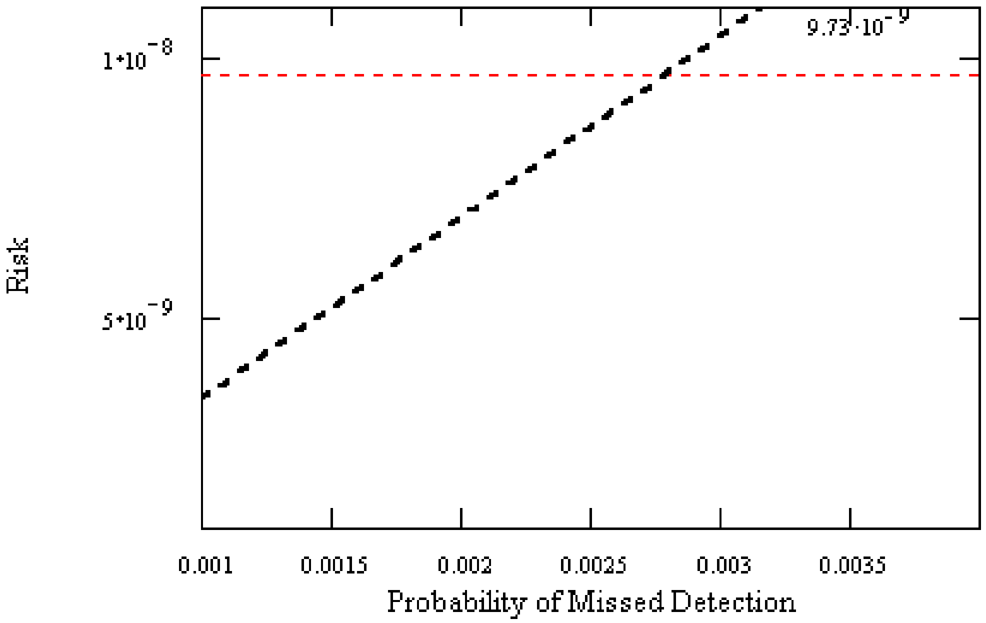

Figure 5 – Relationship Between Risk and Probability of Missed Detection

Table 1 – Required P_{md} *Values and Associated Risks for PT 1*

(Risk Requirement $\leq 9.73 \times 10^{-9}$ *)*

Latent Failure Rate (λ)	Acquisition of Ranging Source P_{md} / Resulting Risk	During Correction Broadcast P_{md} / Resulting Risk
1×10^{-4}	1.1×10^{-4} / 9.55×10^{-9}	2.7×10^{-3} / 9.40×10^{-9}
1×10^{-4} (80% / 20%)	1.1×10^{-4} / 11×10^{-9}	2.7×10^{-3} / 11×10^{-9}
1×10^{-4} (80% / 20%)	1.1×10^{-4} / 11×10^{-9}	1.0×10^{-3} / 4.0×10^{-9}

The sensitivity to unequal failure rates among the failure classes was examined. For example, it is suggested that the acceleration class of failures may have a significantly higher failure rate than the other five classes. Assuming the acceleration failure rate accounts for 0.8 and the remaining five classes account for 0.2 of the failures, the resulting latent failure prior probabilities at acquisition are $\Pi_1^1(0) = 8.0 \times 10^{-5}$ and $\Pi_1^{c\neq 1}(0) = 4 \times 10^{-6}$. The resulting probabilities of failures when broadcasting corrections are $P_f^1 = 3.33 \times 10^{-6}$ and $P_f^{c\neq 1} = 1.67 \times 10^{-7}$. Using (8) and (9), the resulting risk is 11 × 10^{-9} for the derived P_{md} = 2.7 × 10^{-3}. This result indicates that there could be a slight degradation in meeting the risk requirement if the failure rates are unequal.

The risk during transmission of corrections assuming P_{md} = 1 × 10^{-3} was calculated to be 4.0 × 10^{-9} for the 80/20 percent case. This P_{md} value was recommended because it provides margin in the event that the prior failure rates are not equal. For example, assume that during a 150 s final approach 12 SVs are in view. The LAAS Ground Facility has already been broadcasting corrections for ten of the SVs. The other two SVs have recently been acquired, and the LGF has just begun broadcasting corrections for them. Using the values from the last row in Table 1 and accounting for the ephemeris risk (1.94 × 10^{-9}), the total ranging-source risk is 2 × (11 + 1.94) × 10^{-9} + 10 × (4 + 1.94) × 10^{-9} = 0.85 × 10^{-7}. This result provides good margin with respect to the required risk of R_{req} = 1.4 × 10^{-7}.

DERIVATION OF MAXIMUM ALLOWABLE PSEUDORANGE CORRECTION ERROR

Background

It is necessary to limit the impact of undetected ranging source error (after application of the differential correction) that is transformed to vertical position error in the aircraft. This transformation involves the aircraft-to-satellite geometry, and the worse the geometry, the larger could be the amplification of ranging error when transformed into the position domain. The geometry of satellites in the solution is limited by the fault-free vertical protection level (VPL_{H0}) test in the aircraft. Therefore, it is possible to derive the maximum ranging source error that, if missed by LGF integrity monitoring, will not cause the position error in the aircraft to exceed the maximum allowable error in vertical position (MERV) at the worst satellite geometry permitted by the VPL_{H0} test. A detailed derivation of this maximum allowable ranging error was previously presented in [3]. Two cases were considered in that paper: 1) MERPRAS - maximum error in pseudorange, assumed present on all satellites and 2) MERPROS - maximum error in pseudorange, assumed present on only one satellite. This paper will illustrate the concept and derivation for the case of error on a single satellite and will use the more generic term MERR to refer to the resulting error limit. The derivation will be simplified somewhat and will be followed by an example application to satellite signal waveform distortion.

Simplified Derivation

Suppose that the error in the pseudorange correction of the faulty nth satellite must be limited to a value $MERR_n$ which is given by the product of a constant F and σ_n

$$MERR_n = F \times \sigma_n \tag{15}$$

where σ_n is the post-correction pseudorange error standard deviation including ground, airborne and residual errors defined in [1]

$$\sigma_n = \sqrt{\sigma^2_{pr\_gnd,n} + \sigma^2_{pr\_air,n} + \sigma^2_{residual,n}} \tag{16}$$

The corresponding limiting relationship to be satisfied for vertical position error is

$$MERR_n \times S_{v,n} = F \times \sigma_n \times S_{v,n} \leq MERV \tag{17}$$

where $S_{v,n}$ is the vertical geometry factor for the nth satellite in the weighted position solution, and MERV is the maximum allowed error in the vertical position. Let σ_v denote the standard deviation of the vertical position error due to all satellites. Then it must be that

$$\sigma_n \times S_{v,n} \leq \sigma_v \tag{18}$$

Thus, substituting equation (18) into equation (17) gives

$$\mathrm{MERR}_n \times S_{v,n} \leq F \times \sigma_v \leq \mathrm{MERV} \tag{19}$$

In general, the VPL_{H0} test performed by the aircraft may be expressed as [1]

$$\mathrm{VPL}_{H0} = K_{ffmd} \times \sigma_v \leq \mathrm{MERV} \tag{20}$$

where K_{ffmd} is the multiplier that determines the probability of fault-free missed detection. It is necessary to derive MERR_n to protect at the worst geometry (maximum σ_v) allowed by VPL_{H0}, which is given by

$$\sigma_{v,max} = \frac{\mathrm{MERV}}{K_{ffmd}} \tag{21}$$

Substituting $\sigma_{v,max}$ into equation (19) gives

$$F \times \frac{\mathrm{MERV}}{K_{ffmd}} \leq \mathrm{MERV} \tag{22}$$

which is satisfied if

$$F = K_{ffmd} \tag{23}$$

$$\mathrm{MERR}_n = K_{ffmd} \times \sigma_n \tag{24}$$

For CAT I approaches and 3 ground reference receivers, $K_{ffmd} = 5.8$ [1], and equation (24) becomes

$$\mathrm{MERR}_n = 5.8 \times \sigma_n \tag{25}$$

Values of MERR

Figure 6 illustrates values of $\mathrm{MERR}_n = 5.8 \times \sigma_n$ [9]. The values of $\sigma_n = \sigma_{pr\_gnd}$ used in MERR are for accuracy designator B3 [1], which is associated with 3 reference receivers having delay-lock-loop discriminator correlator spacing of 0.1 chips in conjunction with choke-ring antennas. Thus, the values of MERR increase significantly for lower satellite elevation angles, corresponding to the increase in σ_{pr_gnd} due to multipath being admitted by the choke-ring antenna. For this illustration it is assumed that $\sigma_{residual} = 0$. Several curves are shown for different aircraft correlator spacings [1, 9]. Note the curves are very similar for the smaller spacings, and the only curve that differs noticeably from the others is for the 1.0 chip spacing.

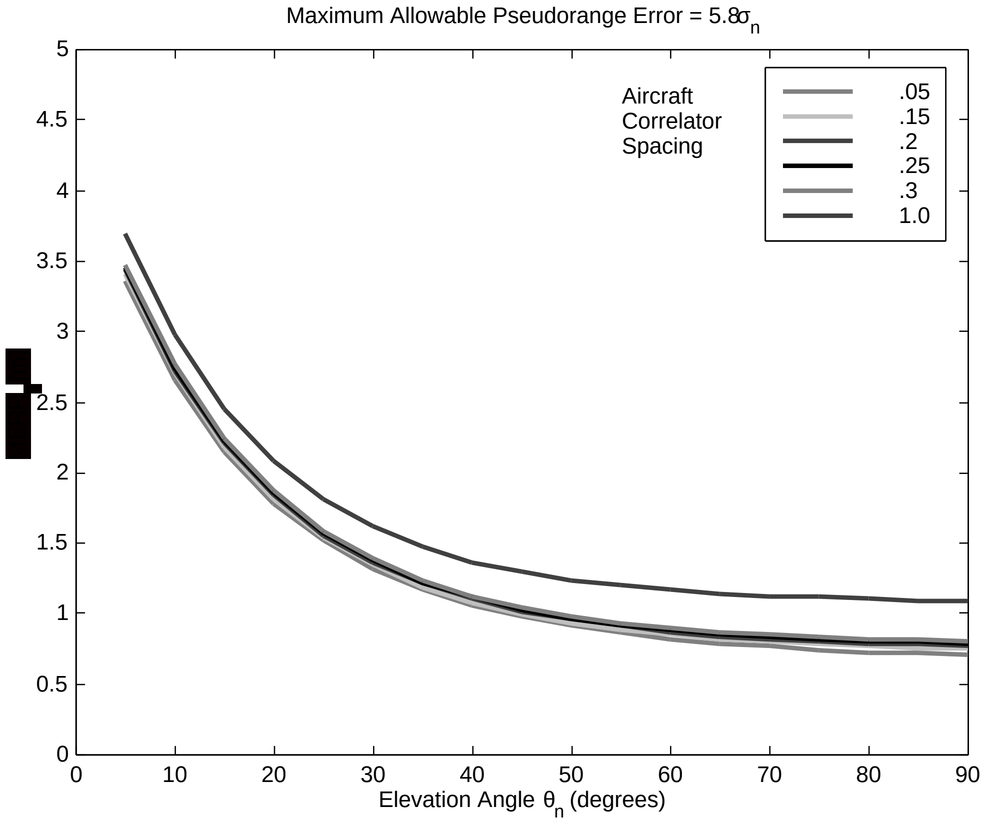

Figure 6 – MERR$_n$ for Different Aircraft Correlator Spacings

ILLUSTRATIVE APPLICATION OF MERR

An example is now presented to illustrate the application of the missed detection and maximum allowable error requirements to integrity monitoring of signal waveform distortions. A simplified view of the test in this case involves comparing the range measurement at the monitored correlator spacing to the measurement at 0.1 chip correlator spacing [9]. A more sophisticated test for signal waveform distortions is described in [10]. Referring back to Figure 3 and equation (4) recall that the essential assessment of an integrity monitor involves determining whether there is performance margin between the minimum detectable error (MDE) and the maximum allowable error (MERR). For this example assume that MDE is represented by the graph in Figure 7 [9]. Note that $MDE_n = 8.74 \times \sigma_{test,n}$, which includes the threshold setting to meet continuity and a missed detection buffer ($k_{md\_test} = 3.09$) to meet the integrity requirement of 10^{-3} for a failure occurring during correction broadcast (see Table 1). Therefore, MDE_n varies in a similar fashion with satellite elevation angle, as does $MERR_n$.

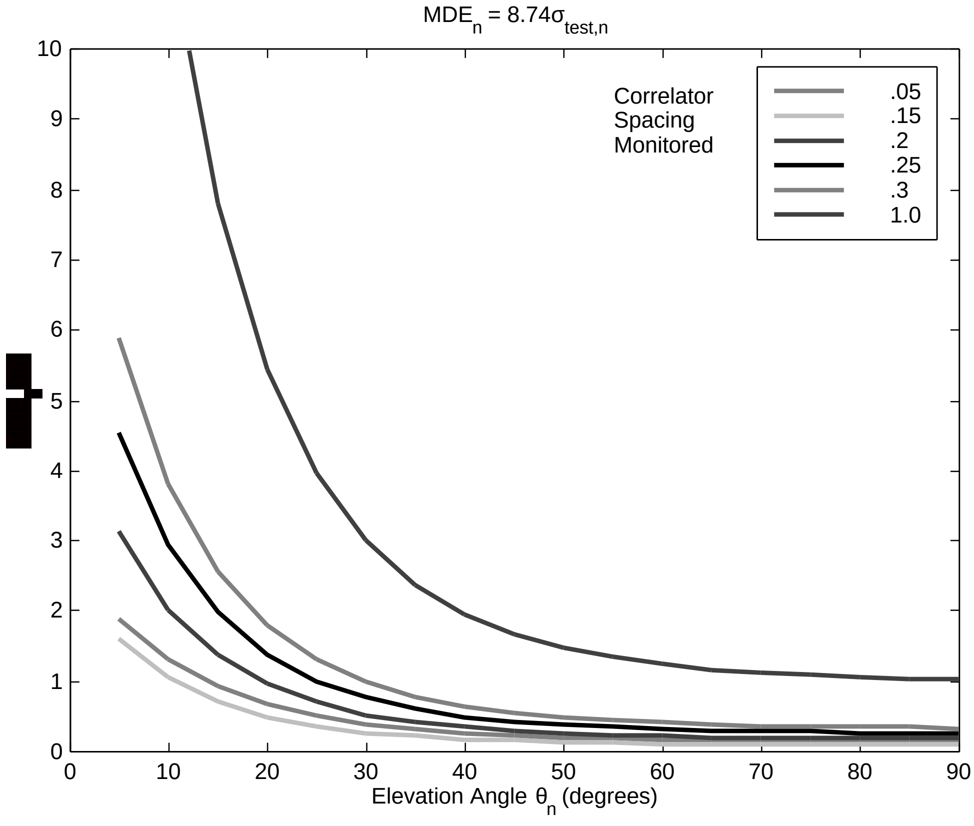

Figure 7 – Minimum Detectable Error for Different Monitored Correlator Spacings

Values of margin for the n^th^ satellite = $MERR_n - MDE_n$ for various correlator spacings are plotted in Figure 8. If the margin is not less than zero, the largest error that the ground may miss detecting (with acceptable probability) does not exceed the maximum undetected error for which VPL_{H0} provides protection in the position domain. In other words, the ground test in the range domain performs well enough that the airborne geometry test sufficiently limits the resulting error in the position domain. In this example, tests at several of the smaller chip spacings always

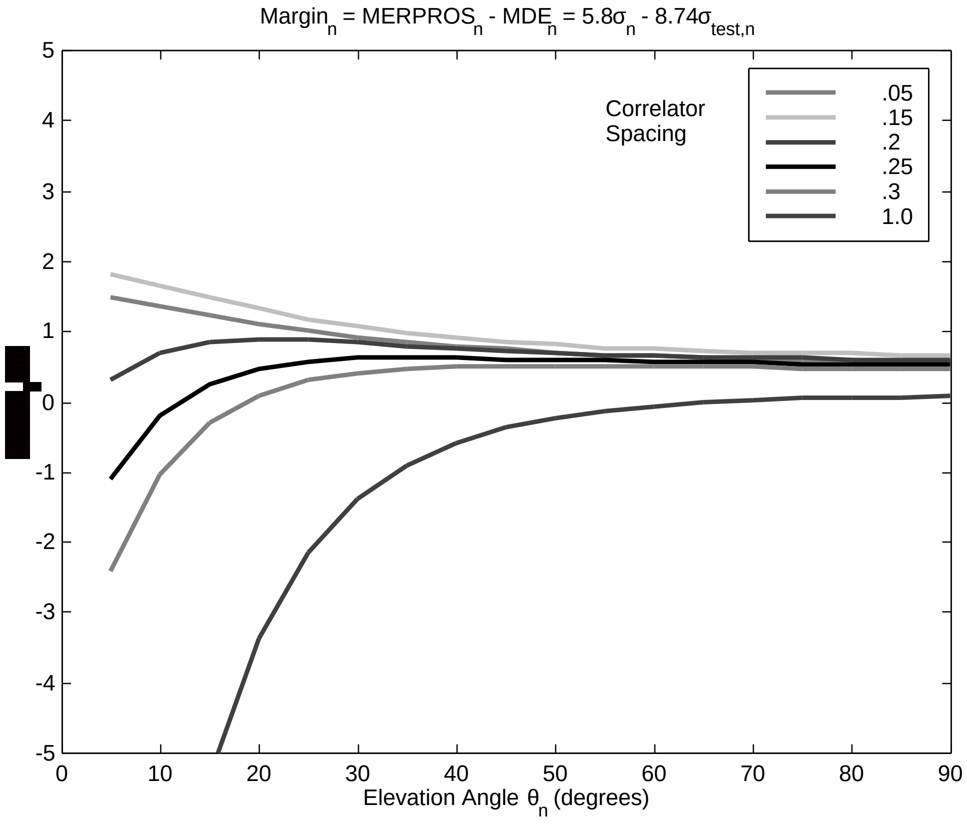

Figure 8 – Test Margin for Different Correlator Spacings

have margin. However, it is more of a challenge for tests at larger chip spacings to have margin, especially at low elevation angles.

SUMMARY

The LAAS Ground Facility will include integrity monitors for ranging source signal faults. The threshold for such monitors must be set within limits that meet both integrity and continuity performance requirements. The minimum threshold value just achieves the required continuity risk allocation for fault-free detections. The maximum threshold value just achieves the required probability of missed detection of a fault by providing a buffer between the threshold and the maximum allowable range error (MERR). The minimum detectable error (MDE) of the monitor is the sum of the actual threshold setting and this missed detection buffer. If the MDE is less than MERR, the monitor is said to have performance margin.

The overall integrity risk requirement is allocated among 12 ranging sources to give 1.67×10^{-8} per ranging source per approach. Assuming equal allocation of risk among six failure classes and accounting for the specified satellite ephemeris integrity monitoring gives an integrity risk allocation of 9.73×10^{-9} per ranging source per approach. This integrity risk allocation must be satisfied by the ranging source monitor missed detection probability, considering the prior probability of satellite failure. To be conservative, a latent failure rate of 1×10^{-4} / h per satellite is assumed and is equally divided among the failure classes. Based on a state probability model, the resulting required probabilities of missed detection are shown to be 1.1×10^{-4} during acquisition of a ranging source and 2.7×10^{-3} during correction broadcast. The correction broadcast probability of missed detection is recommended to be 1×10^{-3} to account for the possibility of unequal failure class probabilities.

The maximum allowable pseudorange error (MERR) is derived to prevent the maximum tolerable vertical position error (MERV) from being exceeded at the worst geometry allowed by the fault-free vertical protection level (VPL_{H0}) test in the aircraft. MERR is found to be independent of MERV, but is proportional to the satellite ranging error standard deviation. This proportionality factor is the fault-free detection multiplier K_{ffmd} used in the VPL_{H0} equation. An example is given to illustrate application of MERR and the required missed detection probabilities in the monitoring of ranging source signal waveform distortions. A simplified model for the test involves comparing the range measurement at a monitored correlator spacing to the range measurement at 0.1 chip correlator spacing. For the assumed values of MDE, the example test works well at small correlator spacings, but has difficulty providing performance margin at larger correlator spacings, especially at low satellite elevation angles.

The methodology contained herein for determining the technical performance parameters for Performance Type 1 (PT 1) is now being applied to determine similar parameters for PT 3.

Based on two papers [3, 4] presented at ION GPS-99, Nashville, TN, September 1999. A version of this paper was presented at GNSS-2000, Edinburgh, UK, May 2000.

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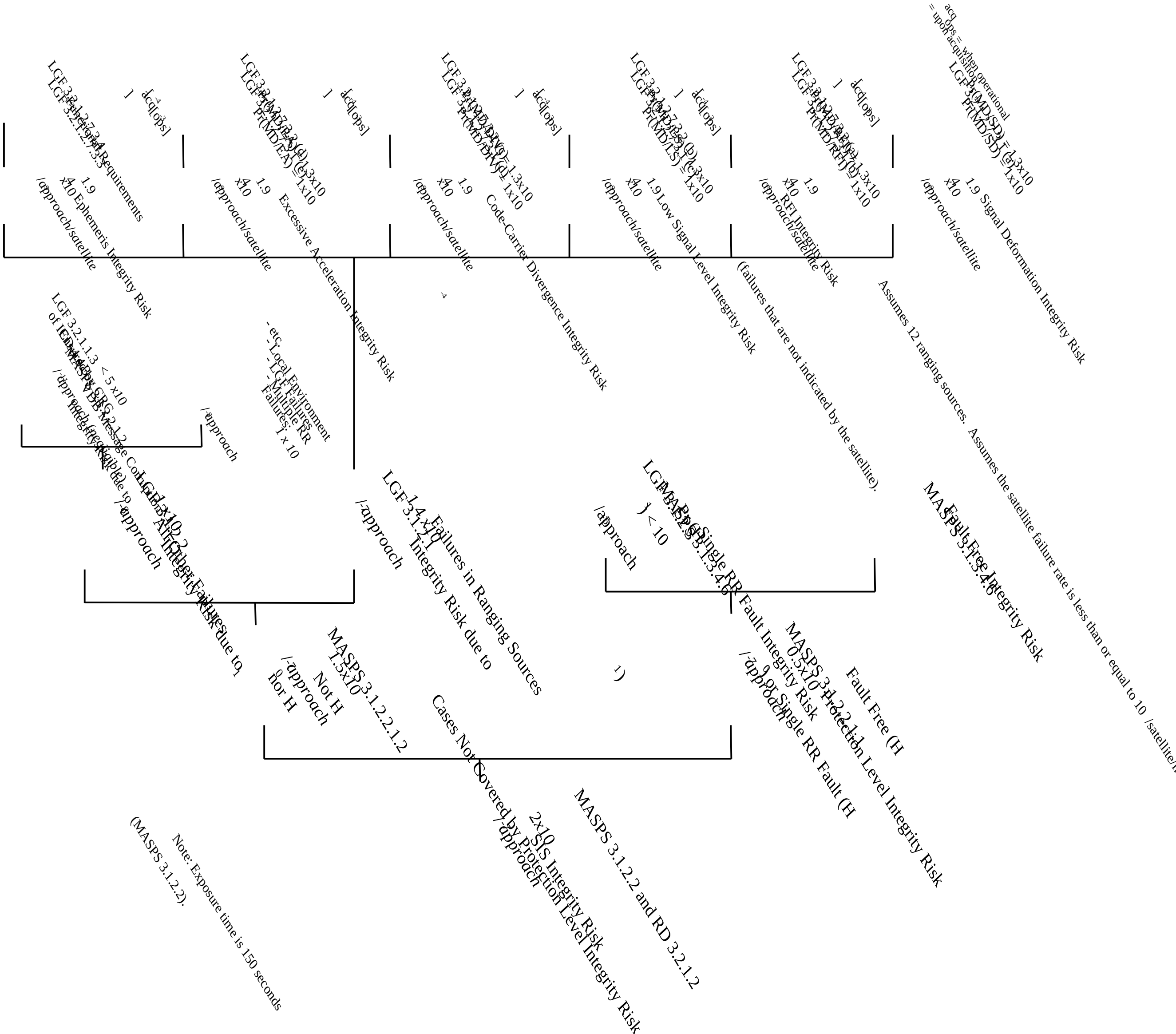
Figure 1 – LAAS Integrity Requirement Allocations



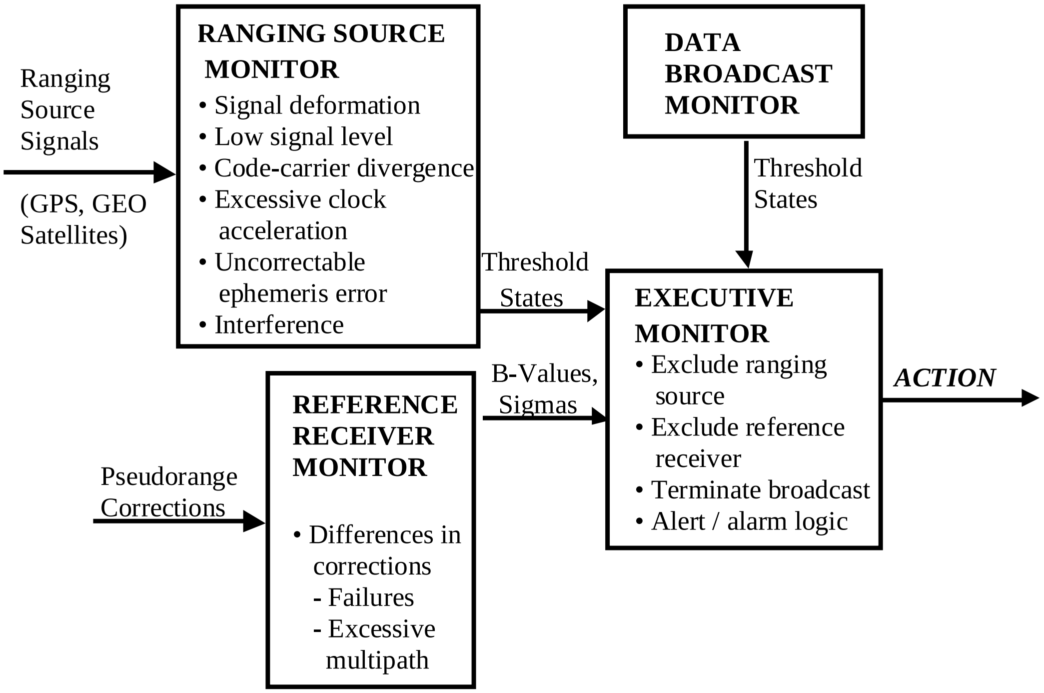


Figure 2 – LAAS Ground Facility Integrity Monitoring Flow

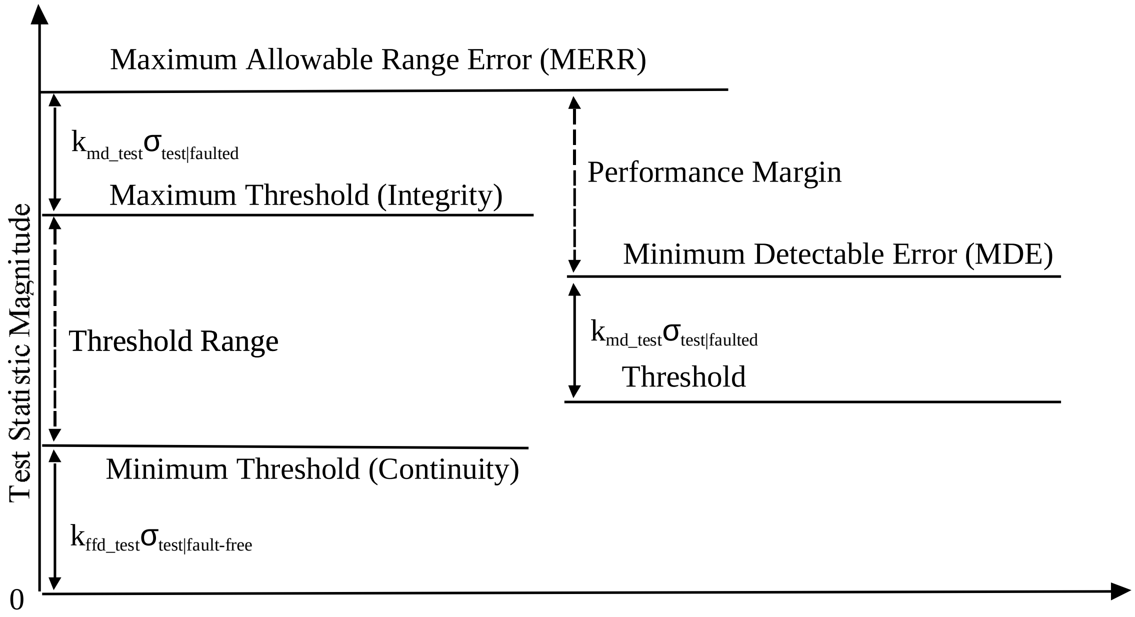


Figure 3 – Integrity Monitor Threshold Range

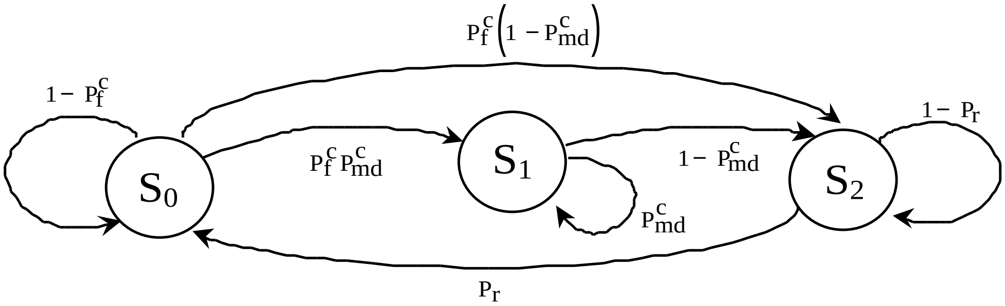


Figure 4 – State Probability Process

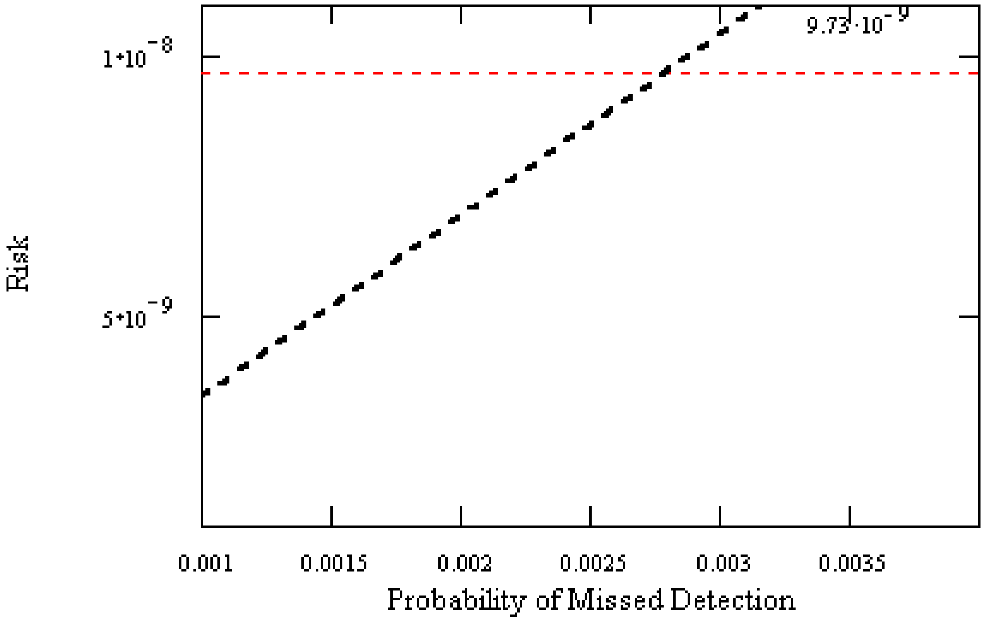


Figure 5 – Relationship Between Risk and Probability of Missed Detection

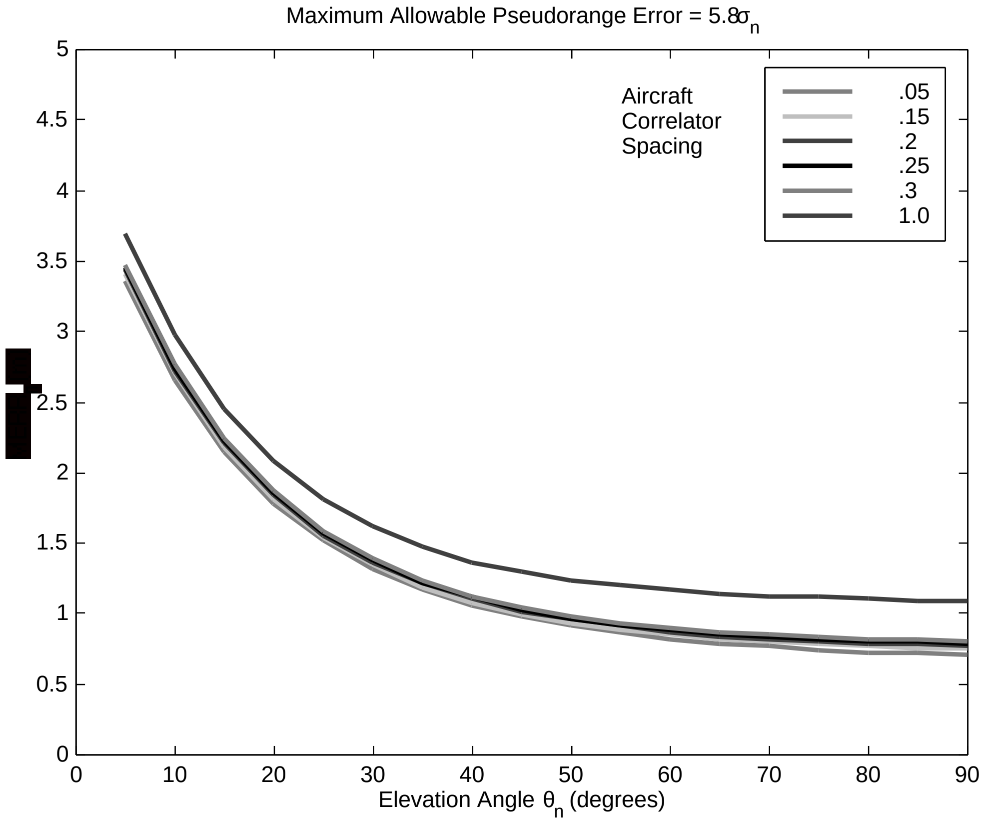


Figure 6 – MERR$_n$ for Different Aircraft Correlator Spacings

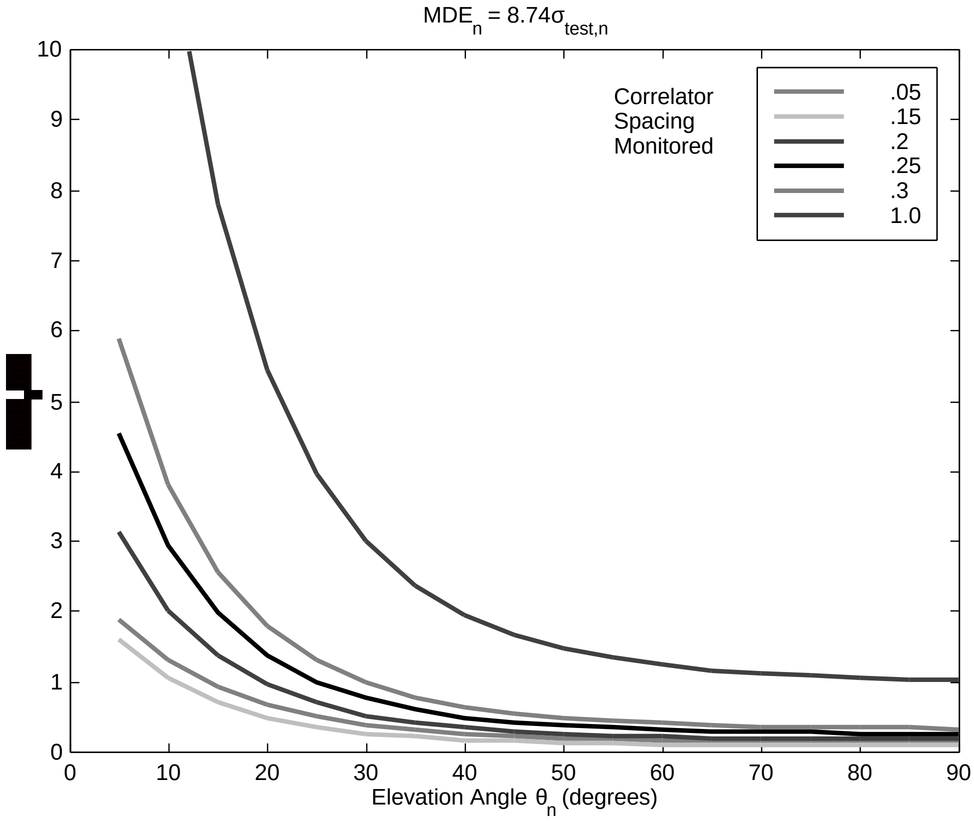


Figure 7 – Minimum Detectable Error for Different Monitored Correlator Spacings

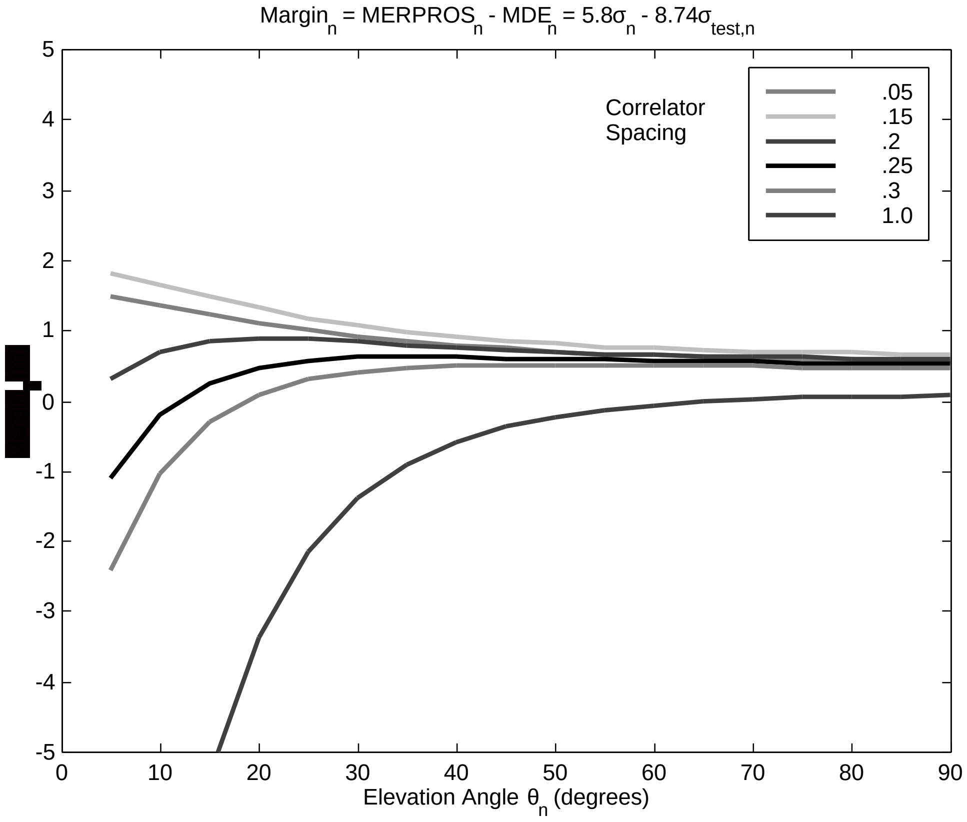


Figure 8 – Test Margin for Different Correlator Spacings