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**APPLICATION OF THE SAFETY MANAGEMENT SYSTEM (SMS) PROCESS TO  
CERTIFICATION OF  
THE GROUND BASED AUGMENTATION SYSTEM (GBAS)**

(Presented by Brazil and the United States)

**SUMMARY**

This working paper presents an approach for a methodology using Safety Management System (SMS) concepts for development of a safety case to support GBAS (Ground Based Augmentation System) operations in low-latitude regions. The safety case is a critical path item for low-latitude system design approval (SDA).

**ICAO strategic objective:**

*A - Safety*

## **1. Introduction**

A ground-based augmentation system (GBAS) is a safety-critical precision approach system consisting of hardware and software that augments the GPS Standard Positioning Service (SPS) to support Category I, II, and III instrument approaches. In addition, GBAS is a foundational capability of the International Civil Aviation Organization's (ICAO) Aviation System Block Upgrade (ASBU) and the Federal Aviation Administration's next generation air traffic system (NextGen) [4]. In low-latitudes, where the Space Based Augmentation System (SBAS) cannot provide adequate service due to large errors induced by ionospheric delays, GBAS must provide the primary navigation function for the modernized global air traffic system. GBAS can correct the majority of the Global Navigation Satellite System (GNSS) pseudo-range errors experienced by an aircraft as a result of Satellite Vehicle (SV), atmospheric, and environmental induced errors. Compared to mid-latitude ionosphere, low-latitude (+/- 20 degrees of the equator) regions have much larger ionospheric range delay gradients, large occurrences of scintillation effects, and in some cases, larger day-to-day variability in range delay [12]. As a result, the ionospheric threat model used for mid-latitude GBAS operations does not meet the ICAO integrity requirements in the low-latitude region. In response, a threat model specific to low-latitudes was recently developed in order to certify GBAS operations in low-latitude regions and a separate safety case must be developed and approved to ensure the operational safety of aircraft using GBAS for Category-I (CAT-I) approach and landing [1].

## **2. Purpose**

The purpose of this paper is to apply safety management system (SMS) methodology to GBAS certification in low-latitudes to ensure ICAO Annex 10 and overall system safety compliance criteria are met. The results of the low-latitude threat model project have been presented and accepted at several international and ICAO forums. The next step in the process of GBAS certification for low-latitude operation will be development of a safety case. The safety case is a critical part of the certification process and requires rigor, structure, and process in order to ensure the highest levels of safety are maintained. The information in this paper outlines recommended methodology for the safety case through application of SMS tools best suited to risk mitigation in a complex systems engineering environment. The specific tools discussed in this paper will be the Functional Hazard Assessment (FHA) and the Preliminary System Safety Analysis (PSSA) [6].

## **3. GBAS and Global Aviation**

ICAO has designated GBAS as a foundational capability for its Aviation System Block Upgrade (ASBU) Blocks 0 & 1 to provide the navigation function for terminal areas, some en-route applications, and integrity for ASBU applications [8]. The GBAS provides extremely accurate position information (<1m) with integrity that will not only be used for precise navigation but for

surveillance and traffic separation as well. In addition to the above benefits, GBAS provides: a) predictable paths; b) approach flexibility; c) capacity gains of 9-12 arrivals/departures per hour; d) reduced communications; e) integrity of navigation position for NextGen/ASBU ops; f) improved Performance Based Navigation (PBN)/Required Navigation Performance (RNP) operations; g) fuel savings per constant descent arrival (CDA) & guided departures; h) automation of routine ATC functions; i) decreased workload; j) greater efficiencies through procedural separation, transitions, and clearances [11]. Figure 1 depicts the GBAS architecture showing the GBAS Ground Facility (GGF) providing differential corrections, integrity, and precision approach flight path definition to aircraft.

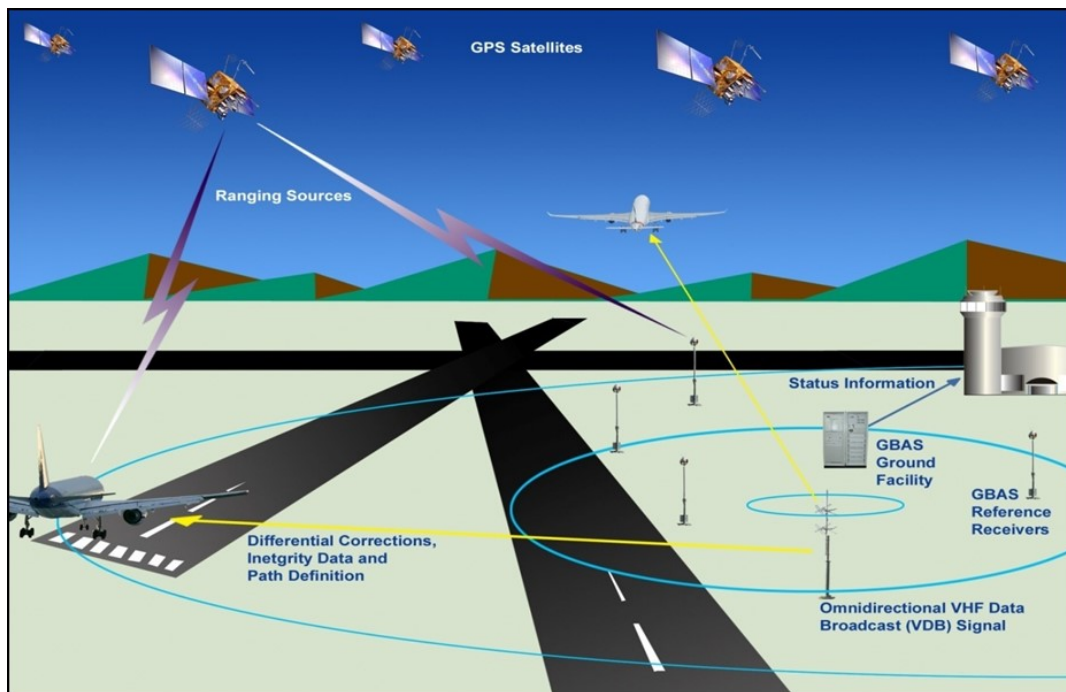


Figure 1. GBAS Architecture. From GBAS System Design Approval, Sept 2013, FAA Presentation, J. Warburton.

#### 4. System Design Approval

System Design Approval (SDA) process describes the objectives, activities, and documentation necessary to:

- Verify compliance with the requirements contained in FAA and ICAO specifications for Category I GBAS Ground Facility (GGF),
- Define the design data that substantiates compliance,
- Document the accepted equipment configuration (hardware and software), and
- Recommend regulatory approval of the accepted design in accordance with FAA and ICAO specifications.

In order to complete the SDA process, the manufacturer must present an approvable system design, the safety critical software must be certifiable, the system design tested to appropriate specifications and a safety analysis must be completed [3]. One of the activities required in the SDA process is the system safety assessment (SSA). SSA activity must occur throughout the development life cycle as the system safety process products are developed. The SSA reviews focus on the system safety process and the integration of the system safety process with other portions of the system development life cycle, e.g., software development, complex hardware development, development of installation procedures, and development of maintenance procedures. The safety case falls within the SSA activity and is a critical component necessary to demonstrate the ability of the system to provide the protections required to ensure safe operations [3] [6] [8].

The safety case for GBAS mainly revolves around the ability of the system to provide service that meets the required standards for integrity and continuity of service. ICAO Annex 10, Volume 1 defines integrity as a measure of the trust that can be placed in the correctness of the information supplied by the total system [10]. Integrity includes the ability of a system to provide timely and valid warnings to aircraft (alerts) when the system must not be used for the intended operation. When GNSS signals received by the aircraft are delayed in a different way than the GNSS signals received by the GGF, the corrections transmitted by the GGF can cause unacceptably large position errors at aircraft level while eluding the system integrity checks. Uncorrected ionospheric delays can cause position errors of several tens of meters without an alarm or an alert to the pilot [13].

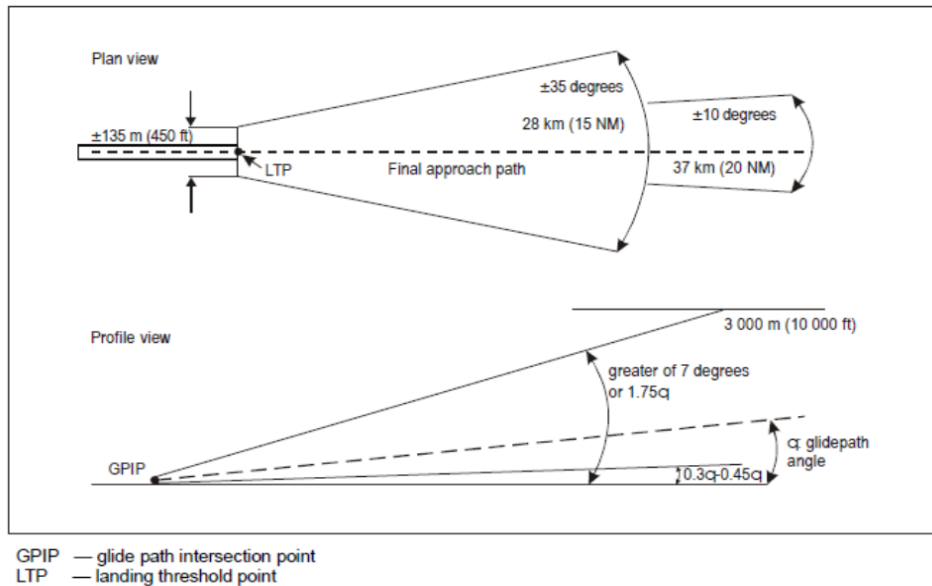
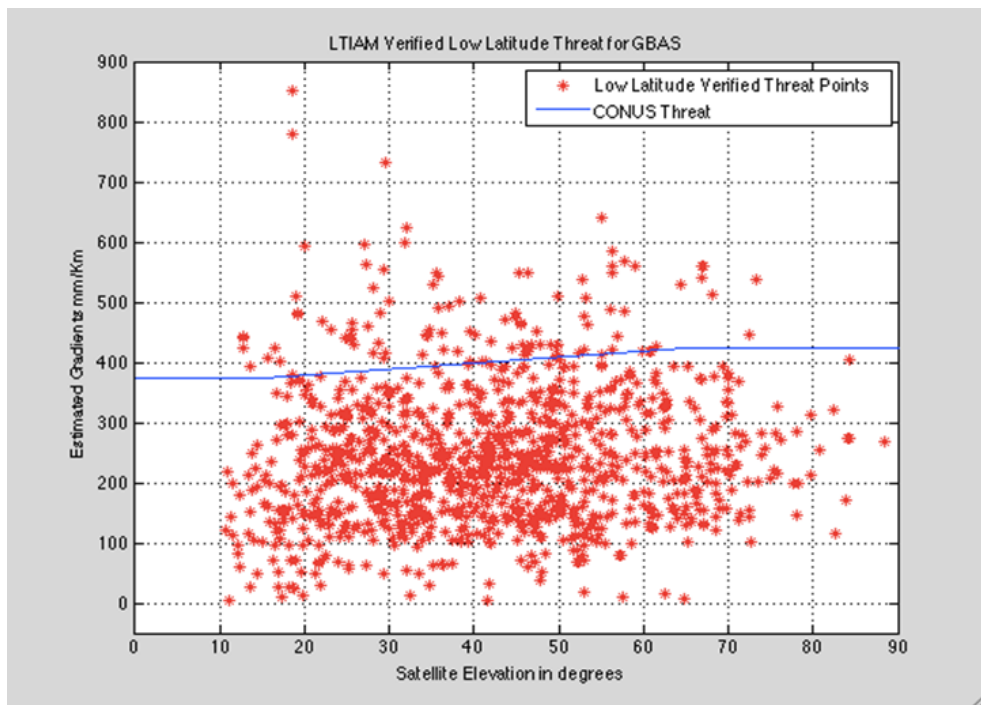


Figure 2. Minimum GBAS aerial coverage diagram. From Guide for Ground Based Augmentation System Implementation [9].

Figure 2 depicts how protected airspace is constricted due to proximity to the runway and to obstacles [8]. GNSS geometries are least accurate in the vertical axis which is also the axis most threatened by obstacles. Therefore, the Vertical Alert Limit (VAL) becomes the driving requirement for the foundation of the safety analysis. The Annex 10 requirement: Integrity risk for CAT-I approaches shall be  $< 1.5 \times 10^{-7}$  (in 150 second interval) or 1 integrity event every 6,666,667 approaches [10]. The GGF is solely responsible for protecting a user from all integrity threats within the GBAS service volume. Thus, the GGF has the responsibility to detect the ionospheric conditions that can cause the failure in meeting the allocated integrity of the ground facility [3].

While these types of errors can be tolerated for en-route operations due to larger alert limits, this is not the case for terminal area operations during which vertical guidance is provided to the aircraft using a tighter VAL. Uncorrected errors between GBAS ground and airborne subsystems must be over bounded and kept as small as possible in order to reach the required level of integrity and continuity defined by ICAO [10].



*Figure. 3.* Southern Latitude Ionospheric Threat Model. From Low-Latitude Threat Model & Validation Report, U.S. Trade Development Agency Report, 2015.

Figure 3 depicts the composition of the threat model. In the original GBAS algorithm definition an anomalous ionospheric gradient was modelled as a semi-infinite wave front with a constant propagation speed and a linear wave front slope connecting the low delay to the high delay ionospheric states. For the case of low-latitude, the threat model has been modified to include

simultaneous presence of various depletions with differing gradient, speed, width, directionality and other parameters. The low-latitude ionospheric conditions, specifically during the post sunset hours, fall outside the bounds of the current ionospheric threat model for Category I GBAS in the mid-latitudes (U.S.). Furthermore, the maximum ionospheric gradient found in the low-latitude threat model study was 850.7 mm/km, well above the peak gradient of 412mm/km found during the mid-latitude ionospheric study upon which GBAS certification was based [12]. It has been recommended that a separate safety case for GBAS low-latitude operations be conducted to ensure compliance with ICAO Standards and Recommended Practices (SARPs) and increase the flexibility of GBAS to respond to the various ionospheric environments encountered in low-latitudes some of which may yet to be encountered [12].

## **5. SMS and GBAS Safety Case Composition**

In order to gain international acceptance, the safety case must be conducted in accordance with established practices and procedures. Therefore, this section is a compilation of information from various sources (including the FAA, ICAO, industry, and academia) necessary to define an acceptable SMS based methodology capable of executing a viable safety case that will enable system design approval of GBAS in low-latitude regions. Since GBAS is certified only in the mid-latitudes, the safety risk management and safety assurance components of SMS must be re-applied into the low-latitude regime. GBAS certification in low-latitudes has never been attempted, accordingly, the authors have turned towards SAE International Aerospace Recommended Practices (ARP) to create a safety structure within which certification can be accomplished. That is, procedures derived from ARP 4761, Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment, will be used to identify the safety issues which GBAS may encounter in the low-latitudes [14].

Specifically, a Functional Hazard Assessment (FHA) defining GBAS hazards and mitigations will flow into a Preliminary System Safety Assessment (PSSA), which then maps hazards and mitigations to safety requirements. Finally, these two inputs result in a System Safety Assessment (SSA) which ultimately verifies the overall system design will meet all the defined safety requirements. The use of internationally accepted FHA/PSSA/SSA tools may not consider all hazardous outcomes however, all analysis and data will be reviewed by a group of GBAS subject matter experts (SME's) to establish validity as was conducted for the mid-latitude certification of GBAS [3].

The focus of this paper is aimed at moving through the safety design process of GBAS to attain system certification and operational implementation, therefore, two pillars of SMS, safety risk management and safety assurance, have direct application. The SMS provides several excellent control processes and tools that will be utilized to lay the foundation for system certification to include; Hazard Control, Failure Mode Effects Analysis (FMEA), Fault Tree Analysis (FTA),

FHA, and PSSA. Given the above assumptions, the safety case will focus on the GGF. The goal of effort will be to identify hazards within the GGF and quantify the hazards. However, a number of hazards present in satellite based systems like GBAS (e.g. satellite failures, ionosphere environmental conditions) present unique challenges. The nature of threats to satellite based systems requires a deep understanding of the system architecture to ensure they are correctly understood and that the appropriate amount of risk is assigned. Additional analysis and documentation is required to quantify the risk posed by these hazards, their interdependencies, and the effect certain mitigations have on reducing their overall risk to particular operations.

The primary process for identifying threats to the system is identification of sources of Hazardous Misleading Information (HMI) and documenting mitigations to its effect to ensure compliance. HMI analysis provides the additional documentation to link the system design to the required safety performance parameters. A high-level understanding of a system's components, its inter-design dependencies and the performance of specific hazard mitigations (e.g. satellite failure monitors) is a key step toward building the safety case. The HMI analysis will be applied to the safety case activities described below to ensure hazards are identified and mitigated [5]. The safety case will provide a detailed description of the system safety methodology to be performed to ensure SARPs compliance and overall system safety. The safety case is comprised of two primary activities: The FHA and the PSSA. The FHA and PSSA are both living documents used during the process to aid in identification of and tracking control of system hazards. The FHA supports generation of system safety requirements that are included in the System Segment Specification (SSS) and supports architecture definition that is contained in the System/Subsystem Design Description (SSDD). The PSSA is used as a validation tool to determine whether it is reasonable to expect that the proposed architecture will comply with system safety requirements. The PSSA is also used to allocate the system safety requirements to lower levels [14]. These allocated safety requirements are captured in applicable requirements documents. The safety activities accomplish the following:

1. Identification and control planning for system hazards (FHA, PSSA)
2. Identification of system safety requirements (FHA, PSSA)
3. Allocation of system safety requirements (PSSA)
4. Assurance that the system architecture can reasonably be expected to meet system safety requirements (PSSA).

The purpose of the following sections is to define the methodology for allocation of those safety requirements. Identification of hazards: DO-178B, DO-254, and DO-264 all contain hazard classifications, which identify hazards associated with airborne and air traffic services. Table 1 identifies hazards associated with the airborne segment as defined in DO-178B and DO-254.

Table 1

*Hazard Classifications/Development Assurance Levels*

Hazard Class	Hazard Classifications	Development Assurance Level
I	Catastrophic	Level A
II	Hazardous/Severe-Major	Level B
III	Major	Level C
IV	Minor	Level D
V	No Effect	Level E

Assessment of GGF hazards relative to air traffic services is based on criteria from DO-264. These criteria are described as follows:

- Catastrophic - Total loss of separation.
- Hazardous/Severe-Major - Large reduction in separation or a total loss of air traffic control for a significant period of time.
- Major - Significant reduction in separation or significant reduction in air traffic control capability.
- Minor - Slight reduction in separation or slight reduction in air traffic control capability. Significant increase in air traffic controller workload.
- No Effect - Slight increase in air traffic controller workload.

The hazard classifications will also be used in the FHA [9]. The design assurance level of the GGF system is driven by the most severe system hazard, which is a loss of integrity. A loss of integrity is a hazardous/severe-major hazard that corresponds with a design assurance level of “B” in accordance with DO-178B (Software Considerations in Airborne Systems and Equipment Certification) and DO-254 (Design Assurance Guidance for Airborne Electronic Hardware) [13]. The safety case will be based on assumption that loss of integrity is the most severe system hazard GBAS will encounter in low-latitudes [6].

**5.1 Loss of Integrity**

The transmission of hazardously misleading data to the aircraft, undetected by the ground facility (loss of integrity), is a safety issue when the aircraft is using the system for either a Category I Precision Approach or Differential Correction Positioning Service (DCPS). Precision Approach Misleading Information (PAMI) is defined as information that, when processed by a fault-free receiver compliant with RTCA DO-253A and DO-246B, results in an out-of-tolerance lateral or vertical relative position error [13]. An out-of-tolerance lateral or vertical relative position error

is defined as an error that exceeds both the Category I precision approach protection level and the ephemeris error position bound. A severe increase in pilot workload would result, as the pilot would be outside the approach corridor as depicted in Figure 2 and might not be aware of the position error until decision height is reached. At the decision height the pilot may not be in a position to transition to visual approach rules, initiate a missed approach, or adequately clear an obstacle [3].

### **Identify System/Functional Hazards**

The system and each individual function are evaluated to identify potential hazards due to failure conditions. The failure sources that are considered include:

1. Loss of function.
2. Other malfunctions such as erroneous output.
3. A failure or malfunction of another system (loss of primary power, satellite fault).
4. External events (operator actions).

Both single and multiple failure conditions must be considered to complete the hazard list. Functions that include inherent redundancy, such as the Reference Receiver and Power functions, must consider multiple failure conditions. During this step, hazards associated with the functional failure must be characterized and documented in the System Safety Program Plan [6].

### **Analyse Hazards**

Each of the identified hazards must be analysed to determine the following:

- System effect
- Hazard classification
- Verification method.
- Mitigation requirements.

The system effects for each hazard are determined based on their effect on the aircraft. The system effects are categorized and the hazard classifications are assigned based on the hazard classifications defined in Table 1. The hazard classifications also use the system-level hazards and classifications and are summarized as follows:

1. Loss of Approach Service Integrity (Level B – Hazardous/Severe-Major)
2. Loss of DCPS Service Integrity (Level B – Hazardous/Severe-Major)
3. Loss of GGF Continuity (Level D – Minor, or Level C – Major)
4. Loss of GGF Availability (Level D – Minor).

Mitigation requirements are not used in determination of system effects and hazard classifications. Once the hazards have been identified and classified, the next step is to determine

the verification methods. Each hazard must be evaluated and a determination made as to how the system will address each hazard to meet the system safety requirements. This step is where system, architectural, and operational requirements, which may include mitigation strategies, are identified. Subsequent safety analyses that will be used to validate and verify system safety compliance are also identified here. Critical hazards, (integrity and continuity), will typically be analysed in the PSSA and verify safety compliance in the SSA.

### **Summarize Analysis Results**

This step is largely a documentation task, but is important to ensure usefulness of the FHA results. The output from this step identify the primary FHA output and are listed as follows:

- Failure Modes, Effects, and Hazard Classification
- System/Function Hazard Class Summary
- System Safety Requirements
  - Architectural Requirements
  - Operational Requirements
  - System Monitor Requirements
- Verification Methods.

The PSSA will use the FHA data to ensure that all hazards are properly considered in the analysis. The hazard classification for the overall system, as well as for each function, will be identified based on the highest level of hazard each can cause. System safety requirements will include quantitative safety requirements for all failure effects that affect system safety. The results of the FHA, particularly the derived safety requirements, are also used in development of the system architecture described in the SSDD [6].

The primary outputs from the FHA are definition of safety requirements and identification of failure modes, effects, and hazard classifications. The FHA will validate safety requirements identified in the system specification as well as additional safety requirements such as functional level hardware design assurance levels and software development levels. However, one of the assumptions of this safety case is that no major re-designs will be required. This assumption is valid because the system is operating in low-latitude regions, but its current availability does not meet the ICAO requirement. Availability is not a safety issue, but rather a service issue.

### **5.3 Safety Requirements**

Safety requirements for the GBAS ground system are contained at section 4 of this document. In addition, complete safety requirements for en-route through CAT-I are contained in Table 2.

Table 2

*GBAS Navigational Precision Expectations*

Typical Operation	Accuracy Horizontal 95%	Accuracy Vertical 95%	Integrity	Time-to-Alert	Continuity	Availability
En-route	3.7 km (2.0 NM)	N/A	$1-1 \times 10^{-7}/h$	5 min	$1-1 \times 10^{-4}/h$ to $1-1 \times 10^{-8}/h$	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1-1 \times 10^{-7}/h$	15 s	$1-1 \times 10^{-4}/h$ to $1-1 \times 10^{-8}/h$	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach, Departure	220 m (720 ft.)	N/A	$1-1 \times 10^{-7}/h$	10 s	$1-1 \times 10^{-4}/h$ to $1-1 \times 10^{-8}/h$	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft.)	20 m (66 ft.)	$1-2 \times 10^{-7}/h$ in any approach	10 s	$1-8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft.)	8.0 m (26 ft.)	$1-2 \times 10^{-7}/h$ in any approach	6 s	$1-8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Category I precision approach	16.0 m (52 ft.)	6.0 m to 4.0 m (20 ft. to 13 ft.)	$1-2 \times 10^{-7}/h$ in any approach	6 s	$1-8 \times 10^{-6}$ per 15 s	0.99 to 0.99999

*Note.* Extracted from Guide for Ground Based Augmentation System Implementation [9]

### a) Derived Safety Requirements

The primary inputs to the PSSA are safety and operational requirements from the System Segment Specification, the architectural definition from the System/Subsystem Design Description document, and failure modes, effects, and hazard classifications from the FHA. The PSSA activity will use Fault Tree Analysis (FTA) techniques to derive lower level requirements [6]. Upon completion of the PSSA, the team will conduct a review of the fault trees with all stakeholders to ensure completion and accuracy of the assessment.

- GGF Continuity – The GGF specification identifies two sources by which GGF continuity could be lost. The first, loss of VDB transmission continuity, is caused if valid VDB transmissions are lost for 3 seconds or longer in any 15-second interval. The

second, reference receiver and ground integrity monitor continuity loss is caused if the number of ranging sources (satellites) is reduced below 3 within the reception mask in any 15-second interval [3].

- Approach Integrity Risk – Overall this risk can be defined as the probability of transmission of erroneously misleading data for a period of 3 seconds or longer without detection and annunciation in any 150-second interval [3].
- Positioning Service Integrity Risk – Overall this risk can be defined as the probability of transmission of erroneously misleading data for a period of 3 seconds or longer without detection and annunciation during any 1-hour period [3].

## **6. Execution**

Execution of the safety case will revolve around HMI analysis of system threats identified as a result of development of the FHA and PSSA as they pertain to low-latitude GBAS operations. The core of an HMI analysis is a series of assertions that, when taken together and shown to be true, completely define the integrity proof [3]. The basic procedure for completing HMI analysis is to validate (in some fashion) this series of assertions. There are three basic techniques for validation, a formal mathematical proof, data driven analysis, and the consensus engineering judgment of a group of subject matter experts (SMEs) [3]. Each of these methods has limitations however; the combination of the three methodologies is generally accepted as an appropriate and recognized standard. A given HMI analysis can be categorized as one of two types based on the specific issue it addresses. The first type is System Safety Parameters (SSPs). These are parameters that make an algorithm or an analysis sufficiently conservative for integrity purposes. SSPs generate inputs to the relevant system prototype or to other HMI analyses. The second type is “HMI bounding analysis”, where data output from a prototype (or some other system or algorithm simulator) is utilized to verify the statistical properties of the system outputs. In this case, the team will utilize the actual certified system output operating in a low-latitude environment.

There are two fundamental design paradigms for satellite-based systems utilized to validate integrity requirements, namely a monitor-then-calculate approach or a calculate-then-monitor approach. Note that distinct monitors in the system may employ either or both approaches. A monitor-then-calculate design basically means that measurements are performed by the system and then the monitor examines and tests the measurements for reasonability and accuracy. Once a set of measurements (and other input data) is deemed “trusted”, i.e., acceptable for use “as is” in determining corrections, corrections are then calculated. This is inherently different from a calculate-then-monitor approach, which first performs the correction calculations and then monitors the corrections for reliability and accuracy to ascertain “trust” or confidence in the corrections data [2].

The GBAS low-latitude safety case will utilize both approaches. The monitor-then-calculate approach will be applied to signal input to the GGF in and around the immediate vicinity of the airport. This will allow an independent data collection and calculation in the GGF environment which will be accomplished through installation of a network of four reference receivers on the airport proper and an additional three reference receivers outside the airport boundary on extended final out to and including the final approach fix. The calculate-then-monitor approach will entail utilization of a certified commercial aircraft (GOL 737-800), equipped with GBAS avionics, collecting flight data off the GGF. The approach data will be collected and stored on the aircraft and downloaded after each flight. Flight data will be collected during daylight and under visual flight rules only as flights will be revenue-generating flights. As previously stated, this approach will be utilized to collect data for each of the scenarios below under the assumption that each one is a separate effort.

It is important to clarify that there are two main aspects to be considered: availability (performance requirement) and integrity (safety requirement). Although they are related, they represent different aspects, and sometimes they compete between them. The main objective is to ensure (to prove) safety and then check the resulting availability. There are basically three main approaches for proving safety:

- Collecting and analyzing real/historical GBAS data: Currently there is very little historical data directly related actual GBAS operation in low latitudes. Therefore, this data is necessarily applicable to proving GBAS safety. This must be a significant consideration for the safety case since we are under low solar activity (near solar minimum).
- Performing lab tests: For the purposes of safety case development it is not viable to model the iono and satellite environment in order to perform valid tests for GBAS safety performance.
- Engineering analyses: Engineering analyses comprise simulations, formal methods, design reviews, analytical assessment based on expert judgement, etc. This is the approach taken for the mid latitude certification and is understood to be the best approach.

The following approach for demonstrating safety (integrity) related to ionospheric threats is described in the mid latitude HMI documents and will be applied to the low latitude process:

1. Data will be collected from GPS stations (RBMC and their reference stations in Rio) to validate / modify the mid latitude threat model.
2. Statistical distributions of the gradients will be developed and split into probability classes (ranges) of gradients for each range.
3. Aircraft approach procedure simulation scenarios will be developed with a variety of parameters (satellite geometry, bubble size, bubble speed, bubble direction, gradient, etc).

For each of these parameters, the distributions for the gradient probability ranges developed in item 2 will be applied.

4. Monte Carlo simulations, with millions of different conditions based on the above probabilities, will be run and the resulting vertical error distributions analysed and plotted in a histogram.
5. A gaussian distribution will be plotted for the sigma\_vig of 25.5 (the highest sigma\_vig tolerable according to ICAO), considering the integrity requirement ( $10e-7$ ), which must demonstrate bounding of the vertical errors is enough to ensure the integrity requirement is met.

Data will be analysed and the SMEs will provide guidance on the viability of aggregating one or more of the scenarios to achieve the required safety margins. A brief synopsis of each scenario follows:

- **Adjustment of the VAL:** The current VAL for GBAS is 10m for a CAT I approach. The VAL for the Wide Area Augmentation System (WAAS) is 35m for CAT I approaches. Adjustment of the VAL will most likely provide the highest level of safety margin if analysis supports the increase [1].
- **Use of a far-field monitor:** A far-field monitor will enable early notification to the GGF of impending ionospheric events thereby allowing the GGF to remove effected satellites from the position solution or send a Do Not Use message to the aircraft prior to the aircraft reaching the final approach fix (FAF). While this may affect availability of the system, the benefit in safety is much greater because it allows the user to transition to another type of approach prior to the FAF and/or greatly reduce the probability of an out-of-tolerance lateral or vertical relative position error as defined in DO-253A and DO-246B [1].
- **Correlation between scintillation and gradients:** The ability to correlate these two ionospheric events will provide the system with the ability to make assumptions concerning the level of events and its ability to maintain service or deny service. Scintillation is a very common occurrence in low-latitudes and if a certain level of scintillation can be correlated to gradients those events can be bounded by the system to eliminate the possibility of an out-of-tolerance event [1].

## 7. Implementation

Given the low latitude threat model is complete and falls outside the boundaries of the mid latitude model, GBAS should not be approved for operations in low latitudes until a safety case has been completed. In order to reduce risk, it is recommended the safety case focus on a limited operational approval (daytime operations) to ensure safety margins can be maintained, additional

operational GBAS data can be collected, and better understanding of low latitude ionospheric anomalies can be attained. In this way the approval processes can be accomplished to establish an operational baseline for low latitude operations. This is similar to the approach taken by India (Chennai) and the UK (St. Helena Island). As data is collected by the GBAS monitoring stations the threat model can be updated to provide optimum capability for low latitude GBAS operations.

### **Interim Operational Approval**

- Conduct safety case for limited low latitude operations
- Based on findings – grant interim operational approval for revenue service during hours of low ionospheric activity
  - GLS & RNAV/VNAV minima
- Develop Service Provider, airline regulator and ICAO requirements for training (crews, ATC, etc.), documentation (SDA), GBAS CONOPS, flight procedures, etc.
- Conduct approval process for limited operations

## **8. Conclusion**

Global harmonization is one of the highest priorities for the FAA and ICAO. These priorities are embodied in the FAA's NextGen and ICAO's ASBU programs to promote standardization and enhance safety for global airline operations. Additionally, airlines operate to destinations around the world and demand global technology standardization before training and equipping with new technology. CAT-I/II/III operations around the world are presently supported by ILS, however, the forecasts of increased global air traffic will create major operational constraints at all airports, in particular in low visibility conditions with challenging arrival capacity demands. Application of SMS processes to GBAS certification in low-latitudes will ensure a structured and measured FHA process is followed to identify, analyse, and mitigate hazards. The identified hazards then flow into the PSSA process to map hazards to system and safety requirements [11].

GBAS is an important, cost-effective, and highly adaptable component to be applied toward the realization of a truly gate-to-gate navigation system and implementation of NextGen/ASBU technologies. Therefore, development of a viable safety case for low-latitude GBAS operations is critical to NextGen/ASBU implementation, global harmonization, and standardization. The above SMS centric approach to safety case development will ensure adequate safety margins are maintained and implementation of GBAS is realized.

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