TECHNICAL MEMORANDUM
OU/AEC TM09-07/80000/06-1

# RE-ASSESSMENT OF THE NECESSITY OF FLIGHT INSPECTION AS THE MEANS FOR VALIDATION OF FINAL APPROACH SEGMENT (FAS) DATA THAT DEFINE PRECISION APPROACH PROCEDURES SUPPORTED BY SATELLITE-BASED TECHNOLOGIES

This report provides an overview of the rationale used to developed WAAS and LAAS flight inspection criteria, discussion of FAS data error sources, a re-assessment of the necessity of flight inspection as the means for FAS data validation, and conclusions and recommendations regarding the necessity of FAS data block validation by flight inspection.

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# I. INTRODUCTION

Significant research and engineering work has been undertaken regarding the development, validation, and implementation of fight inspection criteria for precision instrument approach procedures supported by satellite-based technologies, particularly for both the Wide Area Augmentation System (WAAS) and Local Area Augmentation System (LAAS). WAAS is the United States of America implementation of what is referred to in international terms as a Space Based Augmentation System (SBAS). Similarly, LAAS is the United States of America implementation of a Ground Based Augmentation System (GBAS). Thus, work undertaken by the International Civil Aviation Organization (ICAO) and its member States (i.e., countries) in the areas of SBAS and GBAS system architectures is also applicable to WAAS and LAAS, respectively.

Ohio University (Ohio) conducted a study concluding in the year 1998 that developed provisional recommendations regarding the flight inspection of instrument flight procedures (IFPs) supported by WAAS with the focus on developing requirements for evaluation of the final approach segment [1]. This initial WAAS study recommended flight inspection as the means for accomplishing the following four evaluations: 1) validation of the Final Approach Segment (FAS) data used to construct or execute the approach procedure; 2) confirmation of the flyability of the procedure; 3) identification of RF interference; and, 4) verification of the obstruction environment.

A similar study was completed in the year 2000 that developed provisional recommendations regarding the flight inspection of IFPs supported by LAAS [2]. Further, these recommendations were applicable to procedures with decision altitudes of not less than 200 feet above ground level. This initial LAAS study recommended flight inspection as the means for accomplishing the following five evaluations: 1) validation of the FAS data used to construct or execute the approach procedure; 2) confirmation of the flyability of the procedure; 3) identification of RF interference; 4) verification of the obstruction environment; and, 5) confirmation that sufficient VHF Data Broadcast (VDB) signal coverage exists in operationally significant portions of the required coverage volume.

The WAAS and LAAS studies mentioned in the preceding paragraphs both recommended that the provisional criteria resulting from these initial studies be validated, refined, and revisited as additional knowledge and operational experience were gained. Accordingly, work in this area has continued during the past decade as has the vetting of the results obtained [3-11]. The Federal Aviation Administration (FAA), Aviation System Standards, tasked Ohio to conduct a study and generate a report documenting conclusions regarding the necessity of FAS data block validation by flight inspection [12].

This report provides an overview of the rationale used to developed WAAS and LAAS flight inspection criteria, discussion of FAS data error sources, a re-assessment of the necessity of flight inspection as the means for FAS data validation, and conclusions and recommendations regarding the necessity of FAS data block validation by flight inspection.

## II. OVERVIEW OF WAAS AND LAAS INSPECTION CRITERIA DEVELOPMENT

This section provides an overview of the rationale used to develop flight inspection criteria for WAAS and LAAS. The four distinct activities undertaken during initial studies are presented, as is a short discussion of the need to have insight regarding other test and qualification activities that take place prior to flight inspection of IFPs. The section concludes by outlining the flight inspection evaluations necessary for assessing the site-specific elements of an IFP and confirming navigation service availability for the IFP.

The FAA effort to develop WAAS and LAAS flight inspection criteria was initiated about a decade ago with the identification of four distinct activities to be accomplished [1,2]. In the case of both WAAS and LAAS, the first activity involved identifying those system-specific parameters that should be recorded during flight inspection of the IFPs. Once the identification of parameters was completed, the next activity was to develop candidate methodologies for assessing the data collected for these parameters, as well as specifying other evaluations to be performed (e.g., obstacle evaluation). This activity included determining tolerances and other conditions that must be satisfied for a facility or procedure to be put in service. The third activity was the development of flight inspection criteria and procedures that ensure a thorough yet efficient inspection of the service volume and IFPs. That is, how to accomplish effective, meaningful sampling of the service volume. The final activity is verification of the inspection criteria and procedures. This activity is accomplished through implementation of the criteria and procedures, which provides the opportunity to assess the technical merit of the specific parameters considered, data collection and assessment methodologies utilized, and any implementation issues that may arise during the actual application of the criteria. Additionally, revision of the criteria and procedures to improve effectiveness and efficiency should occur as operational experience is gained with a given system.

Developing effective WAAS and LAAS flight inspection criteria requires understanding what other test and qualification activities will be accomplished prior to flight inspection and the objectives of those activities. Such activities were taken into consideration when developing criteria for WAAS and LAAS [11,13, 14].

Based on the system design approval and installation qualification procedures accomplished for both WAAS and LAAS, it has been concluded that the associated flight inspection criteria are not intended to, nor required to, provide an assessment of either the ground or receiver equipment performance. Once design approval and installation procedures qualification are completed, one relies on the monitoring and built-in tests inherent to this equipment to detect and announce faults. Thus, the development of WAAS and LAAS flight inspection criteria is based on the need to assess the site-specific elements of the IFP and to confirm service availability. A more detailed discussion on this subject is presented in References 11, 13, and 14.

For the commissioning of each WAAS procedure, assessing the site-specific elements of the IFP and confirming service availability is achieved by a flight inspection that accomplishes the following four evaluations: 1) validation of the FAS data used to construct or execute the approach procedure; 2) confirmation of the flyability of the procedure; 3) identification of RF

interference; and, 4) verification of the obstruction environment. In addition, flight inspection evaluations may be required at other times [5,15].

Similarly, assessing the site-specific elements of the IFP and confirming service availability when commissioning each LAAS procedure can be achieved by a flight inspection that accomplishes the following five evaluations: 1) validation of the FAS data used to construct or execute the approach procedure; 2) confirmation of the flyability of the procedure; 3) identification of RF interference; 4) verification of the obstruction environment; and, 5) confirmation that sufficient VDB signal coverage exists in operationally significant portions of the coverage volume. As with WAAS, additional LAAS flight inspection evaluations maybe be required at other times [9,11,15].

## III. RE-ASSESSMENT OF FLIGHT INSPECTION AS THE MEANS FOR FAS DATA VALIDATION

The objective of this section is to re-examine the need for flight inspection as the means for validating the content of the FAS data used to construct and execute instrument approach procedures supported by WAAS and LAAS. This section provides an overview of FAS data elements and their use for constructing the final approach segment, examines the need for validation of FAS data elements by flight inspection, and discusses the general methodology that should be used for accomplishing the FAS data validation. Next, this section discusses the operational experience to date regarding FAS data block errors detected during the flight inspection of IFPs support by WAAS. The section closes with a short discussion regarding validation of FAS data by flight inspection as it pertains to meeting the objectives of the FAA Safety Management System (SMS).

In performing this examination, it is important to realize that both WAAS and LAAS use an earth-centered, earth-fixed (ECEF) reference system based on the WGS-84 datum instead of being source-referenced like conventional radio navigation systems [16]. Because of this, reference receiver antenna locations, runway threshold coordinates, obstacle locations, and all path point data must be accurately surveyed relative to each other. Further, if the coordinates for these items are surveyed separately by different entities, accomplished over an extended period of time, and/or obtained from differing database sources or systems, then the accuracy of the absolute coordinates becomes important [11]. In the day-to-day use of WAAS and LAAS to support IFPs, the latter condition is most always the prevailing case and thus the accuracy of the absolute coordinates is important to the quality and safety of the IFP.

Figure 1 illustrates the parameters used to define a WAAS or LAAS approach procedure. The FAS data elements are listed in Table 1 and Figure 2 shows the data entry screen for the FAS data packing tool used by the FAA to create, code, and load FAS data for each IFP. The values entered for each element are critical to the quality and safety of the IFP, and five elements are particularly relevant to the topic of this report. These five elements are located towards the bottom of Figure 2 and are: *LTP Lat, LTP Lon, LTP Ellip Ht, FPAP Lat, and FPAP Lon*. It is the values of these elements that the author believes cannot be sufficiently validated by visual inspection nor by executing the IFP in a simulator. Flight inspection is the requisite means for

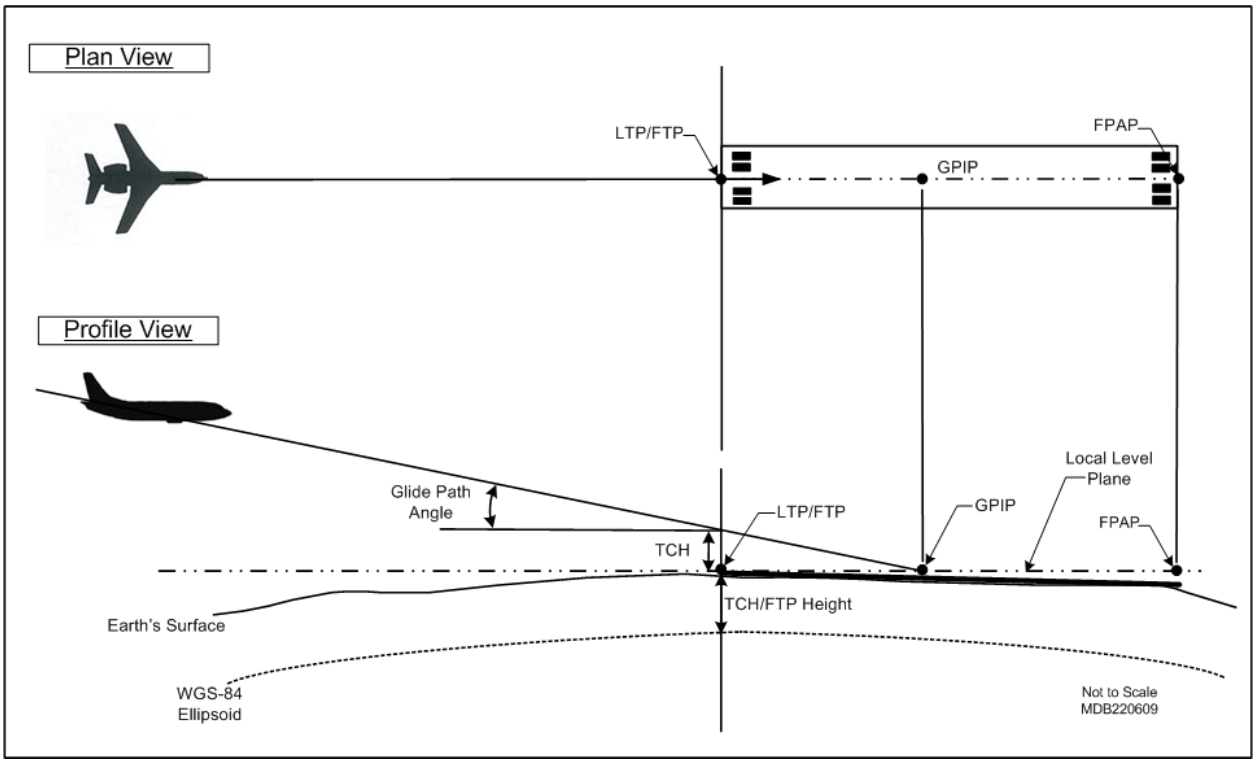


Figure 1. FAS Data Elements Defining Approach Procedure.

Table 1. Listing of CRC Protected FAS Data Elements and Associated FAS PACK Field Names.

| FAS Data Field | FAS Pack Field | FAS Data Field | FAS Pack Field |
|---|---|---|---|
| Operation type | Operation | FPAP latitude | FPAP Lat. |
| Service provider identifier | SBAS ID | FPAP longitude | FPAP Lon. |
| Airport identifier | Airport ID | Threshold crossing height (TCH) | TCH |
| Runway | Runway | TCH units selector (meters or feet) | Dropdown box adjacent to TCH field |
| Approach performance designator | Performance | Glide path angle (GPA) | GP Angle |
| Route indicator | Route | Course width at threshold | Crs Width |
| Reference path data selector | Ref. Path Sel. | Length offset | FPAP Offset |
| Reference path ID (Approach ID) | Ref. Path ID | Horizontal alert limit (HAL) | HAL |
| LTP/FTP latitude | LTP Lat. | Vertical alert limit (VAL) | VAL |
| LTP/FTP longitude | LTP Lon. | Precision approach path point data CRC remainder | CRC Code (Hex) |
| LTP/FTP ellipsoidal height | LTP Ellip. Ht. | | |

Note: CRC = Cyclic Redundancy Check

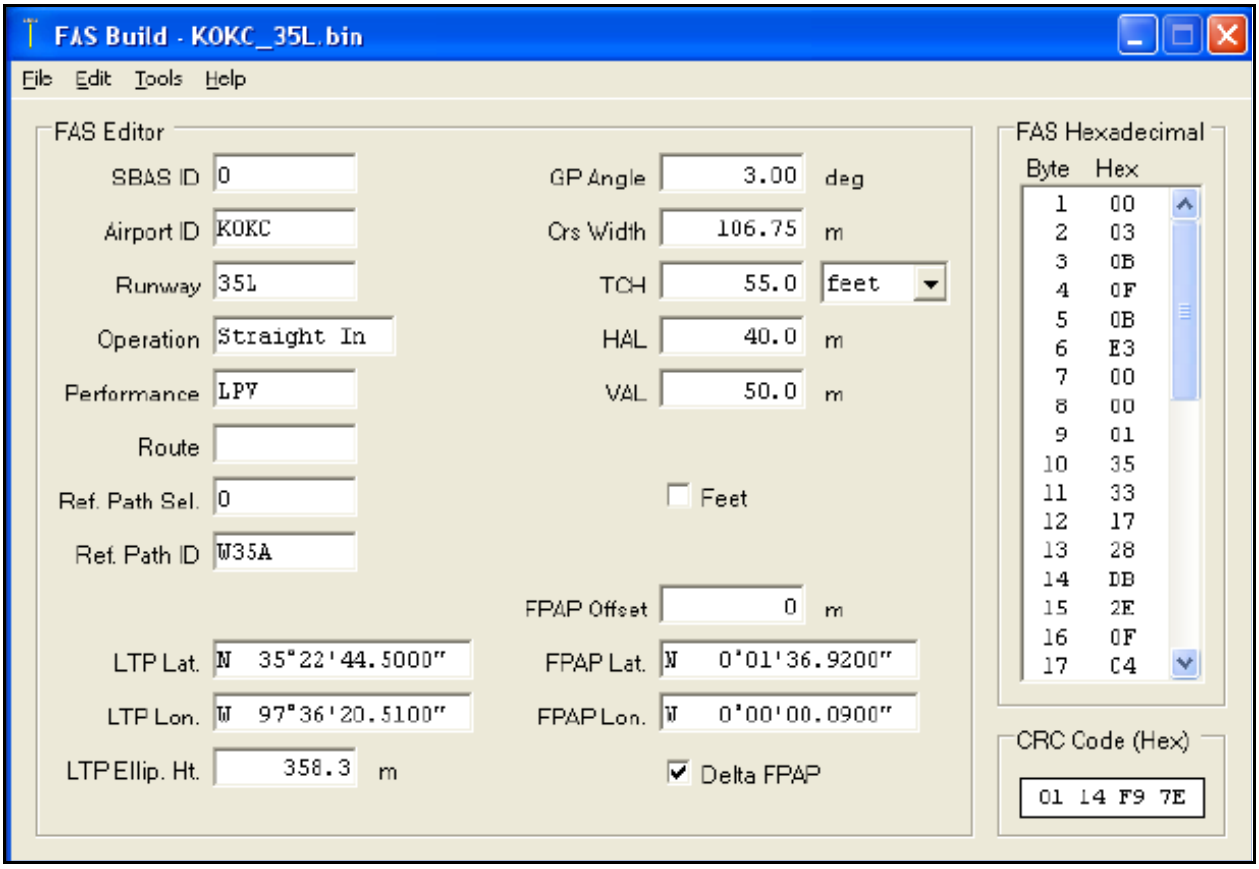


Figure 2. Data Entry Screen, FAS Data Packing Tool for AFIS (courtesy of FAA).

reliably validating these FAS data elements that cannot be validated in a simulator or through visual inspection. This opinion is most relevant to the five elements previously listed in this paragraph, since they are the site-specific elements that determine how the IFP course aligns with the physical runway surface and runway centerline, or intended course when a track other than one aligned with the runway centerline is desired. Similarly, they determine the location of the vertical path in space, thus influencing the achieved Threshold Crossing Height (TCH) and landing touchdown zone. The accuracy required for the coordinates used to define these elements is critical.

The author is hesitant to suggest flight inspection be used to directly validate the numerical values for *LTP Lat, LTP Lon, LTP Ellip Ht, FPAP Lat* and *FPAP Lon*, as this approach may not be a practical one. The approach suggested is to indirectly validate these data elements by evaluating the characteristics of the IFP that they directly influence, which are also those characteristics that have operational significance. These characteristics are: 1) the alignment of the horizontal course with the runway surface and intended procedural course, which is typically the runway center/centerline extended; 2) the achieved TCH; and, 3) the glide path angle.

Three examples will be discussed to illustrate the effects FAS data errors can have on an IFP course or glide path. Figure 3 shows the case where the coded values for the FAS data elements, particularly *LTP Lat, LTP Lon, LTP Ellip Ht, FPAP Lat,* and *FPAP* Lon, are correct. As

intended, the course is aligned with the runway centerline; the glide path achieves the desired angle, TCH and Glide-Path Interception Point (GPIP); and, obstacle clearance requirements are met. The second example is the case where the coded LTP/FTP is on the runway centerline extended, but displaced to be ahead of the landing threshold (see Figure 4). The course is aligned with the runway centerline and the glide path achieves the desired angle; however, TCH, GPIP, and obstacle clearance requirements are not satisfied. In this case, the glide path is lower than expected, thus impacting the safety of the procedure. The final example presented is the case where both the LTP/FTP and FPAP are shifted laterally compared to the runway centerline and in opposite directions (see Figure 5). The actual course is rotated angularly compared to the desired course (i.e., runway centerline). Again, this situation can cause obstacle clearance requirements not to be met, thus impacting the safety of the IFP.

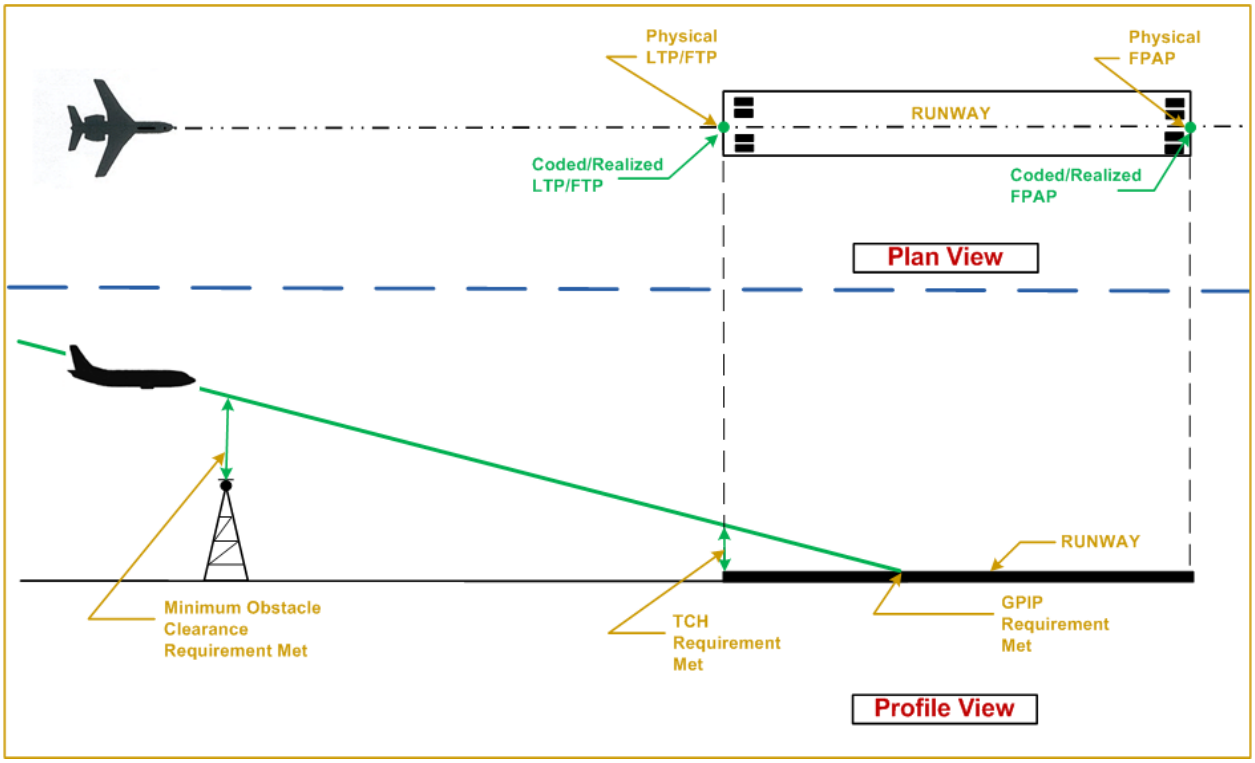

Figure 3. Illustration of IFP Course and Path with Correct FAS Data.

Subsequent to the initial Ohio studies, another national subject matter expert has independently examined the need for flight inspection of WAAS and LAAS IFPs, including validating the FAS data [7]. The conclusions and recommendations presented in Reference [7] are similar to those presented in this report. That is, flight inspection must verify the accuracy of the runway survey point, a qualitative evaluation of the designed approach is a very important safety assessment, and there is the potential for database errors to render an approach unsafe.

Similarly, international subject matter experts have examined the need for flight inspection of WAAS and LAAS IFPs. WAAS is the United States of America implementation of what is referred in international terms as a Space Based Augmentation System (SBAS). Similarly, LAAS is the United States of America implementation of a Ground Based Augmentation System (GBAS). Thus, work undertaken by the International Civil Aviation Organization (ICAO) and

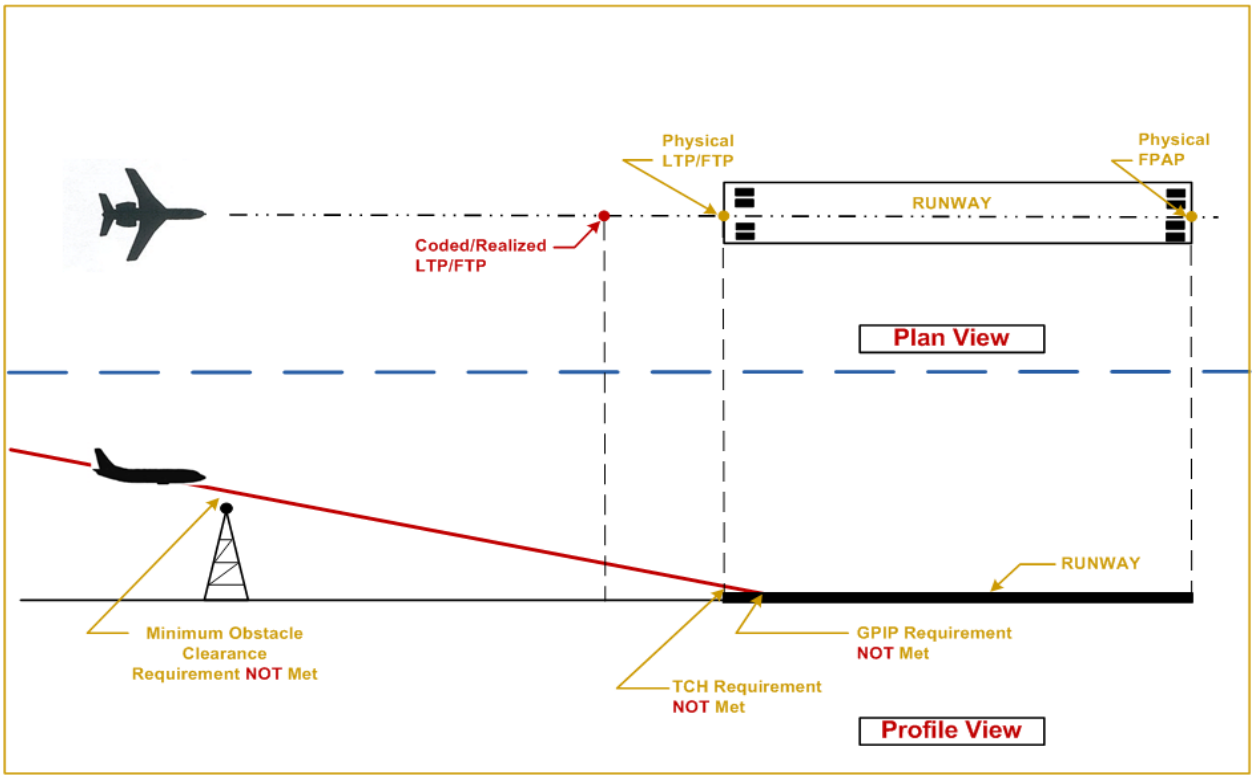


Figure 4. Illustration of IFP Course and Path with LTP/FTP Shifted Ahead of Threshold.

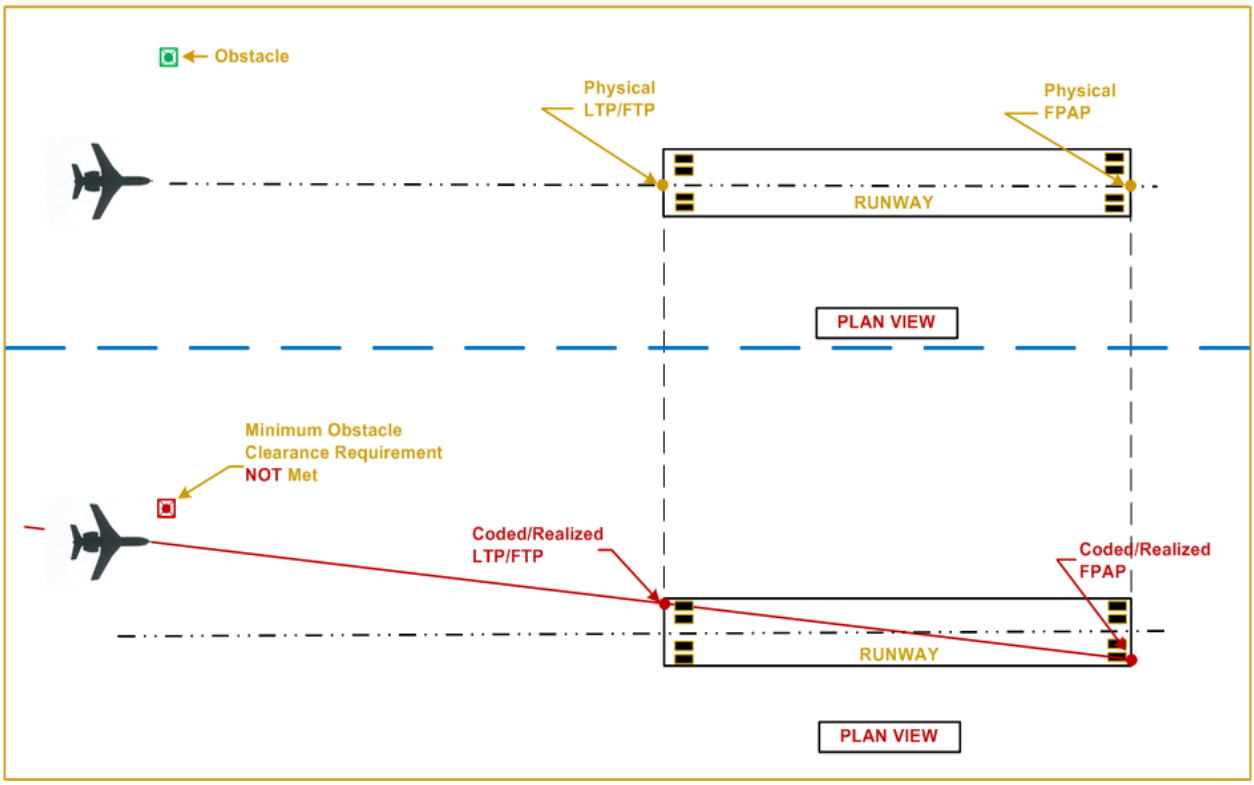


Figure 5. Illustration of IFP Course with Both LTP/FTP and FPAP Shifted Laterally of Runway Center.

its member States (i.e., countries) in the areas of SBAS and GBAS system architectures is also applicable to WAAS and LAAS, respectively. That is, recommended practices and requirements contained in international documents pertaining to flight inspection or flight testing are pertinent to the discussion undertaken in this report.

A document of interest to this discussion is the ICAO manual on testing of radio navigation aids, Document #8071 [13]. Volume II of DOC #8071, which is still under development, addresses testing of satellite-based navigation systems. The purpose of this volume is to provide general guidance on the testing and inspection of satellite-based instrument flight procedures, including non-precision and precision approach procedures. This guidance material is representative of practices existing in a number of countries. Chapter 3 provides guidance specific to SBAS (i.e., WAAS) and Chapter 4 address GBAS (i.e., LAAS). Table II-3-3, *Summary of minimum flight test requirements – SBAS procedures* and Table II-4-4, *Summary of minimum flight test requirements – GBAS procedures* both list procedure validation and FAS data as parameters. Section 5.3.7, final approach segment, states "The final approach course should deliver the aircraft to the desired point." In this case, the author feels flight inspection of the FAS data is implied since an error in this data may result in the aircraft not being delivered to the desired point in space.

The discussion at this point will focus briefly on how the author suggests the flight inspection of the FAS data should be accomplished for WAAS and LAAS IFPs. From an operational viewpoint (see Figure 1), an IFP supported by WAAS or LAAS should provide a horizontal course that is aligned with the runway centerline or desired physical track through space. Its vertical path should be of the proper slope and provide the desired threshold crossing height. The evaluations of these characteristics for an IFP supported by the Instrument Landing System (ILS) are accomplished in a quantitative, documented fashion [15]. Since the operational requirement is the same, regardless of whether the IFP is supported by WAAS, LAAS or ILS, the evaluation of these characteristics of an IFP supported by WAAS or LAAS should also be accomplished in a quantitative, documented fashion. This evaluation includes validation of the FAS data elements for WAAS-based and LAAS-based IFPs. In addition, it should be realized that there will also be evaluations performed during flight inspection that are specific to the navigation aid being used to support the particular IFP [15].

International guidance material also supports the recommendation for a documented, qualitative evaluation of the FAS data for IFPs supported by WAAS and LAAS. Doc #8071 [13], Volume II, Section 1.4.6, *Recording Keeping*, supports the suggestion presented in an earlier paragraph that flight inspection of the FAS data for WAAS and LAAS IFPs should be accomplished in a documented fashion. In addition, it is required that the data obtained be kept for a period of time sufficient to establish trends in facility performance [17]. As a minimum, Reference 17 states that the commissioning inspection data and data from the last five periodic inspections are to be retained in the facility file. PANS OPS, Volume 2, Part III, Section 2, Chapter 6 addresses requirements for qualitative quality assurance of FAS data elements [18]. It is stated therein that the $1 - (1 \times 10^{-8})$ data integrity requirement can be met by conducting flight evaluations provided that three stipulations are satisfied. These stipulations are as follows: 1) the flight evaluation occurs after the FAS data block has been defined; 2) the flight evaluation system verifies the FAS data CRC; and, 3) the flight evaluation system determines that the approach path is

acceptable based on an assessment against standardized quality assurance requirements suitable for the intended operation.

The final step in the re-assessment of flight inspection as the means for FAS data validation is to take a look at what recent operational experience suggests. A survey of FAS data block errors was undertaken by FAA Aviation System Standards as part of their ongoing quality assurance program [19 - 22]. Initially, FAS data block errors were not uncommon when IFPs were provided to flight inspection for evaluation. FAS data error sources include these general types: incorrect survey data; use of incorrect vertical datum; legacy or human induced errors in runway databases; and, FAS data block design or data entry errors. Table 2 list some examples of FAS data errors detected during the inspection of LPV IFPs [23-27]. One initial survey of pending procedures for five states chosen at random found, on average, 15% with FAS data block errors [19].

Table 2. Examples of FAS Data Errors Detected by Flight Inspection of LPV IFPs.

| Date | Procedure Identifier | Facility Identifier/RWY | Location | Unsatisfactory Condition |
|---|---|---|---|---|
| 8/14/09 | K93Y32.01 | K93Y, RWY 32 | David City, NE | Path Angle (3.14°, 3.12°, 3.14°) OT |
| 6/23/09 | KHSP25 | KHSP, RWY 25 | Hot Springs, VA | Path Angle (3.35°) OT |
| 6/18/09 | KDAY06R.01 | KDAY, RWY 06R | Dayton, OH | TCH (41’, 42’) OT |
| 6/16/09 | K74TE36 (Private Approach) | K74TE, RWY 36 | Walnut Springs, TX | Path Angle (3.19°, 3.17°) TCH (62’, 59’) OT |
| 6/16/09 | KJWY36 | KJWY, RWY 36 | Midlothian/Waxahachie, TX | Time applicability of data, associated runway stop end modification incomplete at inspection |
| 5/06/09 | KFLL27L | KFLL, RWY 27L | Ft Lauderdale, FL | Incorrect FPAP, results in incorrect bearing after FAF |
| 4/8/09 | KBKV27.01 | KBKV, RWY 27 | Brooksville, FL | Path Angle (2.88°) and TCH (73’) OT |
| 3/19/09 | K16318 | K163, RWY 18 | Mount Sterling, IL | Incorrect FPAP Latitude |
| 2/19/09 | KONX23 | KONX RWY 23 | Currituck, NC | Path Angle ( > 15°) OT |
| 4/1/08 | KIOW25 | KIOW, RWY25 | IOWA City, IA | Path Angle (3.19°) OT, time applicability of data, runway move incomplete at inspection |

OT = Out-of-Tolerance; RWY = Runway; TCH = Threshold Crossing Height; FAF = Final Approach Fix

FAA Aviation System Standards developed a FAS data evaluation tool (a.k.a., FAS PACK) that is now used to screen new WAAS LPV procedures before they are flown. Using the quality assurance metrics for the flight inspection of LPV IFPs for the cycle ending July 2, 2009 as an example [21], FAS PACK identified FAS data errors for nine of the 83 procedures screened and an additional five procedures were found to have FAS data errors during flight inspection. In total, 14 of the 83 procedures evaluated, or approximately 17%, were found to have FAS data errors in this particular example. Although the number of FAS data block errors detected during flight inspection is being reduced by screening with FAS PACK, current operational experience indicates it will not catch all FAS data errors. Further, the continued discovery of FAS data errors during flight inspection missions confirms the need for flight inspection as the means for FAS data validation.

Based on conversations with FAA Aviation System Standards personnel, the current flight inspection process has been developed to mitigate limitations identified during the initial phase of conducting inspections of IFPs supported by GPS/WAAS. These initial limitations resulted primarily from the need to implement LPV-specific training in regard to the application of the flight inspection procedures and the evaluation of the resulting data; flight inspection equipment limitations; and, the need to implement an automated process that ensures the integrity of the FAS data used during flight inspection. Under the current process, there has not been a case observed to date where an IFP was published then had to be recalled (i.e., NOTAMed out-of-service) due to a FAS data error that was not detected by flight inspection of the IFP [28].

A preliminary qualitative assessment is provided herein regarding how the validation of FAS data by flight inspection is critical in ensuring the objectives of the FAA Safety Management System (SMS) are met. The objective of this assessment is to provide an initial bound regarding the risk associated with FAS data, and then illustrate how FAS data validation by flight inspection reduces the risk. The assessment is done in terms of the relative improvement in the risk bounds; a risk bound being a plausible range of risk levels. Establishing the exact risk level requires detailed, thorough analysis that is beyond the scope of this study.

Safety risk management under the SMS process involves identifying hazards for a given system or operation, analyzing those hazards, assessing the resulting risk in a prescribed fashion, and mitigating unacceptable risks to the extent required [29]. As with most complex systems, the complete elimination of risk for IFPs is likely an unachievable goal. In accordance with SMS guidance, the process used to design, implement, validate and execute IFPs must be error or fault tolerant. Reference 29 defines an error tolerant system as a system designed and implemented in such a way that, to the maximum extent possible, errors and equipment failures do not result in an incident or accident. In the end, those charged with the responsibility of safety risk management must determine the acceptability of the level of risk remaining after all risk mitigation mechanisms and strategies have been implemented.

This determination hinges on the results of a safety analysis which assesses the risk associated with identified hazards. From Reference 29, “Risk is defined as the composite of predicted severity and likelihood of the potential effect of a hazard in the worst credible system state” (see Figure 6). As illustrated in Figure 4 and Figure 5, FAS data errors can result in TCH and/or obstacle clearance requirements not being met. For the worst system states, the author would

expect the severity classification to fall somewhere between major and catastrophic (see Figure 6). Without validation of FAS data being performed by flight inspection, the data available to the author suggests that several IFPs could be published each 56-day cycle with FAS data errors. These procedures may be flown once a week or several times daily depending on location, etc. Each approach operation would be exposed to the hazard presented by the FAS data error. However, not all of these hazards will occur during worse-cases system states (e.g., obstacle present under approach, first use of approach conducted during low-visibility conditions, etc), which is required to merit the more severe classifications. Notionally, it seems like the appropriate likelihood classification is between frequent and probable as illustrated in Figure 6.

The validation of FAS data by flight inspection does not change the severity of the hazards, but the available data does suggest that it notably decreases the likelihood. As stated previously, there has not been a case observed to date where an IFP was published then had to be recalled due to a FAS data error that was not detected by flight inspection when using the current methodology. Since the flight inspection methodology currently being implemented has been in use for about 3.5 years [30], seems the likelihood classification would be in the remote to extremely improbable range (See Figure 6).

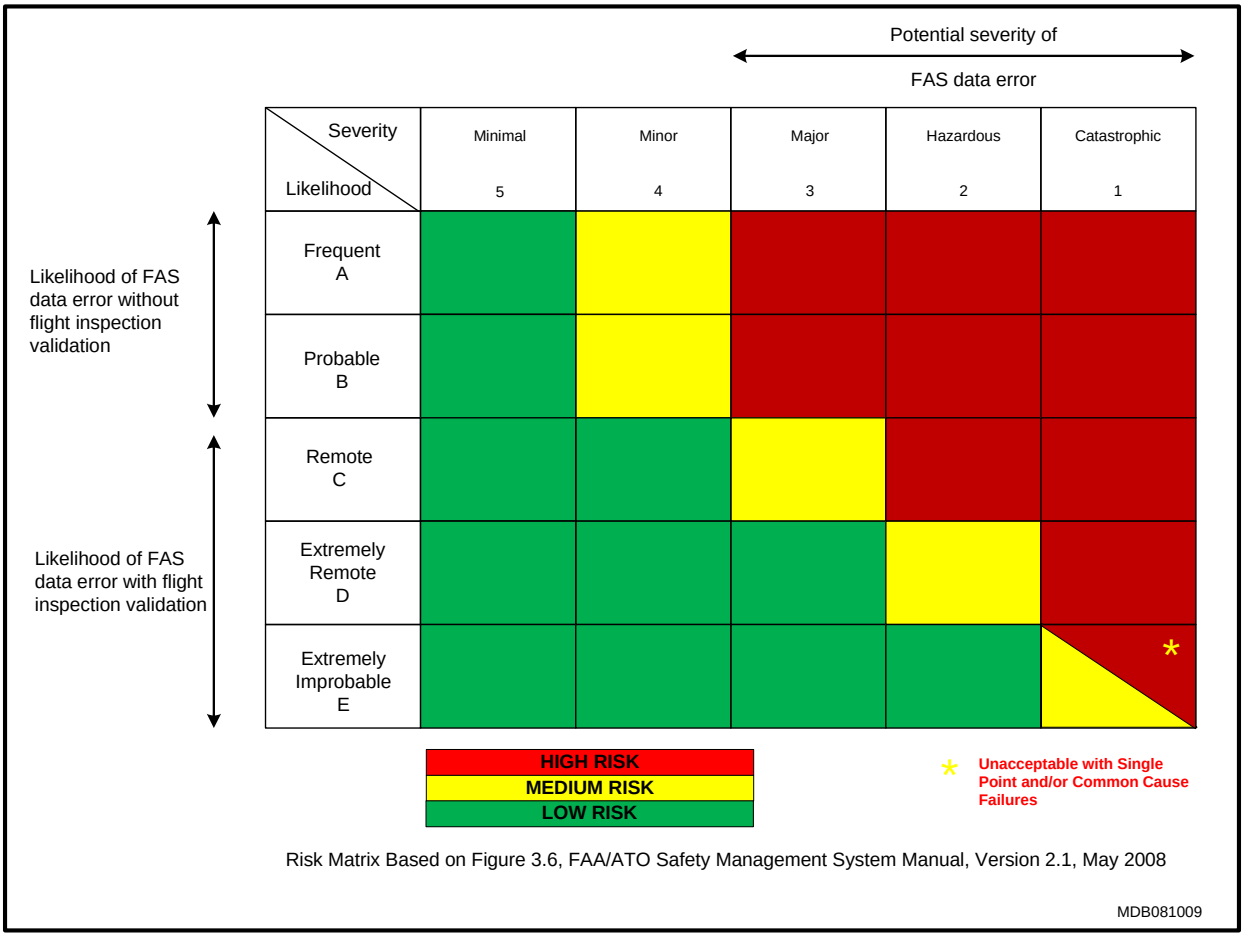


Figure 6. Preliminary Qualitative Assessment for FAS Data Errors Based on SMS Risk Assessment Matrix [29].

## IV. CONCLUSIONS AND RECOMMENDATIONS

This report provided an overview of the rationale used to developed WAAS and LAAS flight inspection criteria and a re-assessment of the necessity of flight inspection as the means for FAS data validation. This re-assessment considered previous Ohio studies, a study conducted by other subject matter experts, national and international guidance material, and operational experience gained from the flight inspection of IFPs supported by WAAS. A qualitative assessment was presented that illustrated how FAS data validation by flight inspection mitigates the risk associated with FAS data errors.

The following has been concluded based on the results of this study:

1) The discovery of FAS data errors during flight inspection missions confirms the need for flight inspection as the means for FAS data validation;

2) There are no known cases where the flight inspection of GPS/WAAS IFPs, as currently performed, failed to identify a FAS data error;

3) Flight inspection of LPV IFPs, as currently performed, is a demonstrated and effective means for validating FAS data;

4) Flight inspection is necessary as the means to validate the FAS data block elements that influence the alignment of the IFP course with the physical runway centerline or desired physical track through space, and those elements that influence the TCH achieved by the vertical path and the glide path angle;

5) The flight validation of the IFPs supported by WAAS and LAAS must be accomplished using a flight inspection system that can perform the necessary evaluations in a documented, quantitative fashion;

6) Flight inspection is necessary as the means to verify that the obstacle database information is sufficiently representative of the existing obstruction environment;

7) Flight inspection is necessary as the means to validate navigation aid service availability for each IFP;

8) FAS PACK is reducing the number of FAS data block errors detected during flight inspection; and,

9) Current operational experience with FAS PACK indicates it is not a substitute for flight inspection of the FAS data.

The recommendations offered herein pertain to the final approach segment and FAS data for IFPs supported by WAAS and LAAS, especially those with decision altitudes at or near 200 feet above ground level.

*RECOMMENDATION-1:* It is recommended that flight inspection be retained as the means for validation of the final approach segment and associated FAS data block elements for IFPs supported by WAAS and LAAS.

*RECOMMENDATION-2:* It is recommended that at least the following IFP characteristics be evaluated as a means of validating the FAS data elements defining *LTP Lat, LTP Lon, LTP Elip Ht, FPAP Lat, and FPAP Lon*.

1) Horizontal Course Characteristics:
   A) Mis-alignment type, linear or angular
   B) Measured angular alignment error in degrees (when applicable), and linear course error/offset at the physical runway threshold or decision altitude point

2) Vertical Path Characteristics
   A) Achieved/measured TCH
   B) Location ahead/after threshold of the desired/intended TCH
   C) Glide path angle

## V. ACKNOWLEDGEMENTS

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# APPENDIX: SEVERITY AND LIKELIHOOD DEFINITIONS

This appendix provides both hazard severity and likelihood definitions taken from the FAA Air Traffic Organization Safety Management System Manual [29]

**Table 3.3: Severity Definitions**

| Effect On: ↓ | Hazard Severity Classification | | | | |
|---|---|---|---|---|---|
| | **Minimal**<br>**5** | **Minor**<br>**4** | **Major**<br>**3** | **Hazardous**<br>**2** | **Catastrophic**<br>**1** |
| **ATC Services** | Conditions resulting in a minimal reduction in ATC services, or a loss of separation resulting in a Category D Runway Incursion (RI)[1], Operational Deviation (OD)[2], or Proximity Event (PE) | Conditions resulting in a slight reduction in ATC services, or a loss of separation resulting in a Category C RI[1] or Operational Error (OE)[2] | Conditions resulting in a partial loss of ATC services, or a loss of separation resulting in a Category B RI[1] or OE[2] | Conditions resulting in a total loss of ATC services, (ATC Zero) or a loss of separation resulting in a Category A RI[1] or OE[2] | Conditions resulting in a collision between aircraft, obstacles or terrain |
| **Flight Crew** | – Flightcrew receives TCAS Traffic Advisory (TA) informing of nearby traffic, or,<br>– PD where loss of airborne separation falls within the same parameters of a Category D OE [2] or PE<br>– Minimal effect on operation of aircraft | – Potential for Pilot Deviation (PD) due to TCAS Preventive Resolution Advisory (PRA) advising crew not to deviate from present vertical profile or,<br>– PD where loss of airborne separation falls within the same parameters of Category C (OE) [2]<br>*or*<br>– Reduction of functional capability of aircraft but does not impact overall safety (e.g., normal procedures as per AFM) | – PD due to response to TCAS Corrective Resolution Advisory (CRA) issued advising crew to take vertical action to avoid developing conflict with traffic or,<br>– PD where loss of airborne separation falls within the same parameters of a Category B OE [2] or,<br>– Reduction in safety margin or functional capability of the aircraft, requiring crew to follow abnormal procedures as per AFM | – Near mid-air collision (NMAC) results due to proximity of less than 500 feet from another aircraft or a report is filed by pilot or flight crew member that a collision hazard existed between two or more aircraft<br><br>– Reduction in safety margin and functional capability of the aircraft requiring crew to follow emergency procedures as per AFM | – Conditions resulting in a mid-air collision (MAC) or impact with obstacle or terrain resulting in hull loss, multiple fatalities, or fatal injury |

| Effect On: ↓ | Hazard Severity Classification | | | | |
|---|---|---|---|---|---|
| | **Minimal**<br>**5** | **Minor**<br>**4** | **Major**<br>**3** | **Hazardous**<br>**2** | **Catastrophic**<br>**1** |
| **Flying Public** | – Minimal injury or discomfort to passenger(s) | – Physical discomfort to passenger(s) (e.g., extreme braking action; clear air turbulence causing unexpected movement of aircraft causing injuries to one or two passengers out of their seats)<br>– Minor[3] injury to greater than zero to less or equal to 10% of passengers | – Physical distress on passengers (e.g., abrupt evasive action; severe turbulence causing unexpected aircraft movements)<br>– Minor[3] injury to greater than 10% of passengers | Serious[4] injury to passenger(s) | Fatalities, or fatal[5] injury to passenger(s) |

1 – As defined in the 2005 Runway Safety Report
2 – As defined in FAA Order 7210.56, *Air Traffic Quality Assurance*, and Notice JO 7210.663, *Operational Error Reporting, Investigation, and Severity Policies*
3 – Minor Injury - Any injury that is neither fatal nor serious.
4 – Serious Injury - Any injury which: (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns, or any burns affecting more than 5 percent of the body surface.
5 – Fatal Injury - Any injury that results in death within 30 days of the accident.

a. Data are expressed as a measure of quality
b. Data are subjective
c. Data allow for examination of subjects that can often not be expressed with numbers but by expert judgment

**Table 3.4: Likelihood Definitions**

| | NAS Systems & ATC Operational | NAS Systems | | ATC Operational | | Flight Procedures |
|---|---|---|---|---|---|---|
| | Quantitative | Qualitative | | | | |
| | | Individual Item/System | ATC Service/ NAS Level System | Per Facility | NAS-wide | |
| **Frequent A** | Probability of occurrence per operation/operational hour is equal to or greater than $1x10^{-3}$ | Expected to occur about once every 3 months for an item | Continuously experienced in the system | Expected to occur more than once per week | Expected to occur more than every 1-2 days | Probability of occurrence per operation/operational hour is equal to or greater than $1x10^{-5}$ |
| **Probable B** | Probability of occurrence per operation/operational hour is less than $1x10^{-3}$, but equal to or greater than $1x10^{-5}$ | Expected to occur about once per year for an item | Expected to occur frequently in the system | Expected to occur about once every month | Expected to occur about several times per month | |
| **Remote C** | Probability of occurrence per operation/operational hour is less than or equal to $1x10^{-5}$ but equal to or greater than $1x10^{-7}$ | Expected to occur several times in the life cycle of an item | Expected to occur numerous times in system life cycle | Expected to occur about once every year | Expected to occur about once every few months | Probability of occurrence per operation/operational hour is less than or equal to $1x10^{-5}$ but equal to or greater than $1x10^{-7}$ |
| **Extremely Remote D** | Probability of occurrence per operation/operational hour is less than or equal to $1x10^{-7}$ but equal to or greater than $1x10^{-9}$ | Unlikely to occur, but possible in an item's life cycle | Expected to occur several times in the system life cycle | Expected to occur about once every 10-100 years | Expected to occur about once every 3 years | Probability of occurrence per operation/operational hour is less than or equal to $1x10^{-7}$ but equal to or greater than $1x10^{-9}$ |
| **Extremely Improbable E** | Probability of occurrence per operation/operational hour is less than $1x10^{-9}$ | So unlikely that it can be assumed that it will not occur in an item's life cycle | Unlikely to occur, but possible in system life cycle | Expected to occur less than once every 100 years | Expected to occur less than once every 30 years | Probability of occurrence per operation/operational hour is less than $1x10^{-9}$ |