DEVELOPMENT OF APPROACH PROCEDURE DESIGN CRITERIA FOR SYSTEMS BASED ON GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) WITH GROUND BASED AUGMENTATION SYSTEM (GBAS)

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ABSTRACT

This paper gives an overview of a research project currently conducted at the Institute of Aeronautics and Astronautics of the Technical University of Berlin in close cooperation with the German Air Traffic Control (DFS). Furthermore the project is integrated with the ICAO Obstacle Clearance Panel work on the development of a supplement for the ICAO Doc. 8168 (ICAO PANS-OPS) containing approach procedure design criteria for systems based on Global Navigation Satellite System (GNSS) with Ground Based Augmentation System (GBAS). Four different methods for the development of GBAS approach procedure design criteria are presented. The methods are to be judged on the basis of a Utility Value Analysis to give a recommendation on the preferable method.

1 MOTIVATION

In order to use GNSS for approaches, the related procedure design criteria must be derived from mathematical models. Approach procedure design criteria used for the now standard Instrument Landing System (ILS) are based on the ICAO Collision Risk Model (CRM) specifically developed for ILS facilities. The utilization of this model for GNSS is limited due to different principles of position determination of the navigation system components. ILS as well as conventional navigation methods is based on the measurement of angles. GNSS uses pseudo ranges for determination of position. Thus the nature of error is completely different.

Currently the implementation of technical GNSS specifications into the ICAO Annex 10 is conducted. GNSS procedure design criteria to be developed simultaneously should be reflected in a supplement to ICAO Doc. 8168 (ICAO PANS-OPS). The research project described in this paper supports development of appropriate criteria for GNSS GBAS approach procedures.

Four different methods for the development of GBAS approach procedure design criteria are presented:

- ILS equivalence method
- RNP method (RNP – Required Navigation Performance)
- Advancement of the ILS CRM
- Development of a new GBAS CRM

The methods and possible sub methods are to be judged on the basis of a Utility Value Analysis for an objectives hierarchy set up before. It is foreseeable that some methods need to be developed in parallel, in order to fulfill the different objectives different times.

2 INTRODUCTION

2.1 The Definition of ILS Procedure Design Criteria by Obstacle Assessment Surfaces

Approach and departure flight procedures are specified in order to guarantee the safety and effectiveness of operations also in instrument flight conditions. The criteria for the construction of these procedures are published in ICAO Doc. 8168 Procedures for Air Navigation Services – Aircraft Operations (ICAO PANS-OPS) Volume 2.

Today ILS is the most common landing aid for precision approaches although it has some shortcomings e.g. that straight approaches are possible only and each landing direction of a runway needs an separate ILS. Furthermore the use of ILS as navigation aid for departure and missed approach procedures is only limited possible. The protected airspace for the precision segment of ILS approaches has an angulare shape. The reason for that is that both the error values of ILS ground facilities and the pilot navigational error increase with increasing distance from navigational aid. The latter error results from the on board display of the nominal flight path.

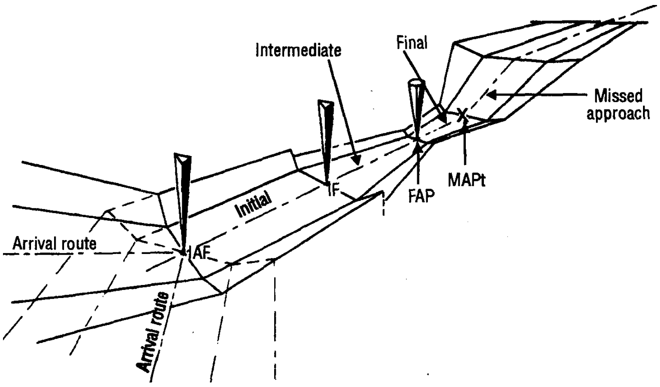

Fig. 1: Segments of an instrument approach according to ICAO PANS-OPS (Ref.: [4])

The protected airspace for the precision segment of ILS approaches, depicted in Fig. 2, is formed by so-called Obstacle Assessment Surfaces (OAS). The OAS consist of six sloping surfaces (W, X, Y and Z) and a horizontal surface (A). The dimensions of the OAS depend on various operational conditions. The related parameters of the OAS surface equations can be derived from the attachments of ICAO PANS-OPS. However these parameters are valid only for so-called standard conditions. In the case of deviations from these conditions the parameters need to be corrected.

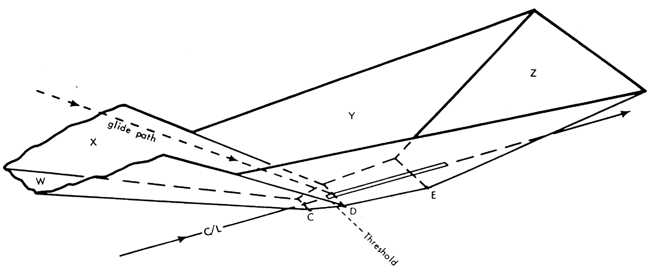

Fig. 2: Protected airspace for precision segment of ILS approaches – Obstacle Assessment Surfaces according to ICAO PANS-OPS (Ref.: [4])

The OAS system finds broad application and is recognized world-wide although the correct determination of the OAS is not very simple, particularly since different OAS apply to different operating categories[1]. Furthermore a fitting in is necessary into the surrounding protected airspace due to the range limitation of the OAS[2].

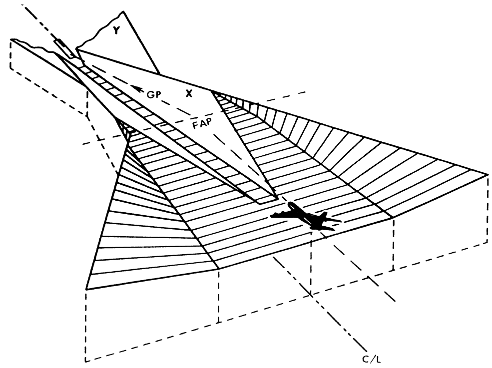

Fig. 3: Interface between OAS and surrounding protected airspace (Ref.: [4])

2.2 Derivation of ILS Obstacle Assessment Surfaces from the ILS Collision Risk Model

The system of ILS OAS was derived from the ILS CRM, which is a computer program that computes a collision probability with individual objects or a set of objects per approach. The basic idea is to use the probabilities for lateral and vertical deviation from nominal flight path of an approaching aircraft. With these deviations and a given maximum permissible collision risk (corresponding to the Target Level of Safety – TLS) it is possible to calculate airspaces which are to be kept free from objects, in order not to exceed the given TLS (according to ICAO 10^{-7} per approach). This airspace has a funnel-like shape around the nominal flight path with elliptical cross sections (see Fig. 4).

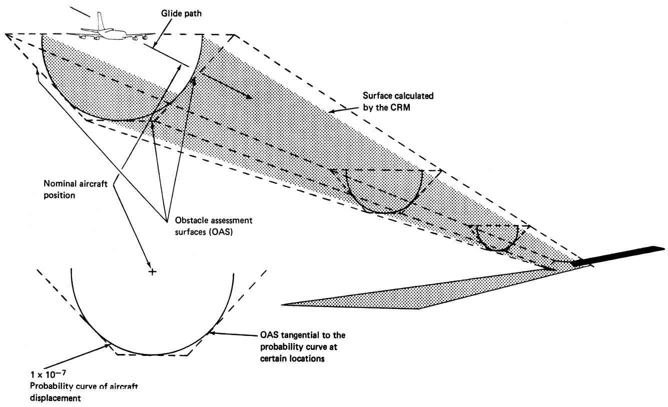

Fig. 4: Derivation of ILS OAS from the ILS CRM (Ref.: [3])

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[1] Different surfaces for CAT I, CAT II Flight Director, CAT III Autopilot to be used depending on operational parameters and possible corrections.

[2] The surface system is only valid for the precision approach segment which includes the final approach segment and the initial and intermediate missed approach segment. The surfaces for CAT I terminate at a height of 300m above threshold, for CAT II at 150m above threshold. The X and W surface for CAT I are extended up to the Final Approach Point (FAP). Further restrictions apply to glide path angel etc.

The OAS are derived from this by defining flat surfaces which surround this funnel very tightly and in the same time are easy to construct by the procedure designer. Since the deviations from the nominal flight path are affected by various parameters the OAS must be defined with regard to these parameters as well.

2.3 Satellite Based Navigation Systems

Various improvements are expected with the use of GNSS, as for example:

- High-integrity, high-reliability, all-weather navigation services worldwide
- Cost savings from reduction or non-implementation of ground-based navigation aids
- Provision of non-precision approach/precision approach capabilities at presently non-equipped airports

To overcome inherent system limitations and to meet the performance requirements (accuracy, integrity, availability and continuity of service) for all phases of flight, satellite signals require varying degrees of augmentation. These augmentations are classified in three broad categories: aircraft-based (ABAS), ground-based (GBAS), and satellite-based (SBAS). With these augmentations a considerably reduction of the total position error can be achieved (see following table):

GPS segment	Error source	GPS with SA[1) 2)]	DGPS[1)]
Space segment	Satellite clock	3,0	0
	Ephemeris data	1,0	0
	Selective Availability	32,3	0
	Miscellaneous	0,5	0
Control segment	Prediction of Ephemeris data	4,2	0
	Miscellaneous	0,9	0
User segment	Ionosphere	5,0	0
	Troposphere	1,5	0
	Receiver measurement	1,5	2,1
	Multipath	2,5	2,5
	Interference	0,5	0,5
Total system	Root Sum Square (UERE)	33,3	3,3

[1)] Values represent standard deviations in m
[2)] SA was terminated in 2000

Table 1: Error budgets for the measurement of pseudo ranges using GPS in SPS mode (Ref.: [10])

The augmentation of GBAS systems should only be used up to a maximum distance of 20 NM.

3 DEFINITION OF A OBJECTIVES HIERARCHY

Based on the previous chapters now the process of the development of procedure design criteria for satellite-based approaches should be explained.

The principal purpose is the creation of procedure design criteria for GBAS approaches. The selection of the suitable proceeding and the methods, which lead to the objective optimally, should be based on a Utility Value Analysis. For this the principal purpose is arranged into different sub objectives, which are for the example:

- "Have a solution as soon as possible"
- "Minimum expenditure"
- "Compatibility with existing standards"
- "Good acceptance"
- "Flexibility in the applicability"
- "Optimum use of the navigation advantages of GBAS – Exact consideration of the effects resulting from the GBAS guidance in the missed approach segment"
- "Optimum use of the navigation advantages of GBAS – Linearization within the approach range"
- "Realistic representation of reality"
- "Flyability for the pilot"
- "Introduction of the procedure CAT I with FD"
- "Easy software implementation"
- "Possibility of application for curved approaches"

After weighting the sub objectives different methods can be evaluated using this objectives hierarchy. With this a justified selection of the method, which brings the biggest value, can be conducted.

3.1 Example Sub Objective: "Optimum Use of the Navigation Advantages of GBAS – Linearization within the Approach Range"

The ILS measures the Difference in Depth of Modulation to calculate the deviation between actual and nominal position. This value is a scale for the angular displacement from the nominal flight path and is displayed in the cockpit. A result of this position determination is that equal absolute deviations from nominal position cause increasing deflections in the ILS display for decreasing distances between transmitter and receiver antenna. Thus the sensitivity of the display improves during the process of the approach caused by the systems architecture. If multimode receivers are used to employ GBAS as landing aid this changing sensitivity is artificially produced, so that no differences between ILS and GBAS are recognizable for the pilot. Thus it should be avoided that the pilot cannot use the well-trained ILS routines for GBAS approaches, which would happen if the navigational displays would react unusually from his point of view. Thereby however a big potential of GBAS is given away.

A relatively small linearized range in the beginning of the Final Approach could already lead to a substantial reduction of the dependency of operations on close parallel runways. Studies need to be conducted to clarify if pilots can fly GBAS approaches, which do not have the angular character of the ILS. Given this information a weighting of this objective is possible.

3.2 Example Sub Objective: "Introduction of the Procedure CAT I with FD"

At present only ILS procedure design criteria for CAT I are available, which consider manual flight. With the development of GBAS procedure design criteria CAT I approaches using Flight Director or even Autopilot are to be pursued. The reason for this is the knowledge that the contribution of the Flight Technical Error (FTE) to the Total System Error is bigger than the contribution of Navigation System Error (NSE) and the FTE can be reduced only by employment of Flight Director or Autopilot.

4 METHODS TO ACHIEVE THE OBJECTIVES

In the following different methods are discussed, which can fulfill the defined objectives hierarchy. These methods are:

- ILS equivalence method
- RNP method
- Derivation of OAS from an advanced ILS CRM
- Derivation of OAS from a completely new GBAS CRM

Every method is discussed under the aspects of the objectives hierarchy defined above.

At the end a degree of fulfillment of the objectives hierarchy can be assigned to every single of the possible methods with the help of the Utility Value Analysis. This value can be used to support the selection of the method to be preferred.

4.1 ILS Equivalence Method

The idea of the ILS equivalence method is to demonstrate that GBAS CAT I approaches are at least as good as ILS CAT I approaches. This means the GBAS total system error (TSE) is inside the ILS protected airspace. With this information it is possible to use the existing ILS approach procedure design criteria for GBAS.

Currently flight trials are conducted to demonstrate that the GBAS TSE is less than the ILS TSE. Further data will be collected in additional GBAS flight trials (FAA Technical Center Atlantic City, Oklahoma City University, DERA und Airbus), which can be used for validation as well. Therewith are reasonable amount of flight trials data will be available for all aircraft speed categories.

The following table shows the results of an evaluation of flight trials data from 21 approaches of the FAA:

	Distance from Threshold	ILS CRM [1)]	TSE [1)]	FTE [1)]	NSE [1)]
Vertical	1200 m	5,8	4,1	4,0	0,5
	4200 m	13,6	9,8	10,5	0,6
	7800 m	27,4	20,7	20,5	0,6
Lateral	1200 m	20,8[2)]	9,8	9,6	0,5
	4200 m	45,6[2)]	22,5	21,5	0,5
	7800 m	85,7[2)]	37,0	36,3	0,9

[1)] Values represent standard deviations in m
[2)] normalized

Table 2: FAA evaluation results on GBAS flight trials compared with ILS CRM values (Ref.: [8])

The analysis of the flight trials data has been done for a 2σ (95,5%) probability range so far. In order to proof the Target Level of Safety of $1\text{-}10^{-7}$ per approach probability ranges up to 6σ are to be examined. Due to the reason, that the large number of needed flight trials, to fulfill statistical significance, cannot be conducted, the following options are conceivable:

- Pinpoint the added safety margin for ILS CAT I approaches and comparison with the real ILS FTE in order to conclude dimensions of the safety margin to be added.
- Mathematical method of the so-called "tail extrapolation".
- Build up of a model and simulation of the approaches.

The expenditure of the options has to be estimated. The existing ILS criteria can be used for GBAS if one of the options indicate that the procedure design criteria for ILS CAT I protect GBAS CAT I approaches appropriately.

Presumably the development of the ILS equivalence method requires a small expenditure only. This needs to be considered when evaluating this method by using the objectives hierarchy. The method fulfills the following sub objectives optimally: "Have a solution as soon as possible", "Minimum expenditure", "Compatibility with existing standards". However the fulfillment of the sub objective "Realistic representation of reality" is not optimally given. That means that GBAS OAS developed with this method have the same angular shape as ILS OAS, which results from the ILS assumption, that with decreasing distance from the threshold the NSE decreases as well. As this assumption is not valid for GBAS a huge optimization potential is given away, which is inherent in the use of GBAS. Also curved approaches cannot be considered. With an adequate weighting of the sub objectives this alternative could be the best compromise in reaching the sub objectives.

4.2 RNP Method

The objective of this method is to adopt the en-route RNP concept to precision approaches. This means to set up specific standards for specific procedures in specific airspaces, which have to be fulfilled by each aircraft regardless which navigational aids are used.

The All Weather Operations Panel (AWOP) of the ICAO developed the "Draft Manual on Required Navigation Performance (RNP) for Approach, Landing and Departure Operations" in the year 1996, which describes the development of RNP values on basis of the ILS specifications. The FAA evaluated its GBAS flight trials also as comparison to these RNP specifications. The following table shows the results of the 21 CAT I approaches mentioned above (RNP 0.02/40) for a height of 200ft (60m) above threshold:

		RNP[1)]	GBAS[1)]
Vertical	NSE	4,4	2,1
	FTE	11,4	8,1
	TSE	12,2	8,8
Lateral	NSE	18,2	1,8
	FTE	39,5	15,8
	TSE	43,5	18,9

[1)] Values represent standard deviations in m

Table 3: FAA evaluation results on error components for GBAS flight trials compared with RNP values (Ref.: [8])

This method needs to be discussed in particular under the aspect of the feasibility. At present still no certification regulations are existent for RNP approaches. This leads to a not sufficient fulfillment of the sub objective "Compatibility with existing standards". The sub objectives "Have a solution as soon as possible" and "Minimum expenditure" is surely well attainable. The fulfillment of the sub objective "Realistic representation of reality" will not be that easy due to the requirement that the standards should be achievable without regard to the navigational aids used (e.g. ILS, GBAS, MLS). Hence the angular funnel effect of ILS has to be considered when designing procedure criteria. Also the sub objective "Good acceptance" will be difficult to fulfill since this method questions not only the valid regulations used today but also the general concept behind it.

4.3 Derivation of OAS from an Advanced ILS CRM

This method uses the computation principle of the collision probability from the ILS CRM. To build the GBAS CRM only the unusable elements of the ILS CRM need to be exchanged. From the new GBAS CRM the corresponding GBAS OAS can be derived. To get started with this the ILS CRM needs to be analyzed and the applicability of the system elements for GBAS needs to be examined. The following figure gives an overview of the system elements:

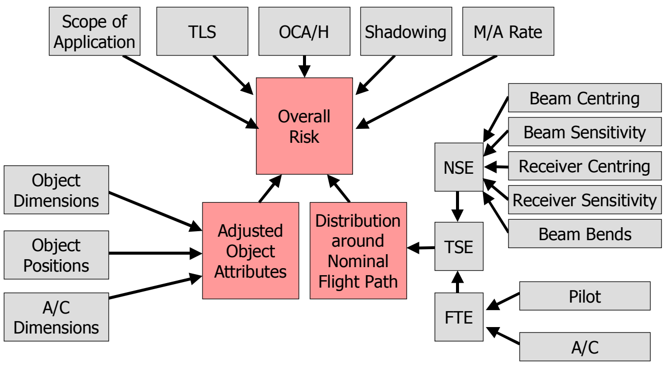

Fig. 5: System elements of the ILS CRM (own figure)

To decide which system elements of ILS CRM can be maintained and which need to be exchanged for GBAS CRM a sensitivity analysis needs to be conducted. With this the contribution of each system element to the overall risk should be derived so that system elements can be identified which differ on the one hand strongly from the characteristics of ILS and have on the other hand a substantial contribution to the overall accuracy of the model. Thus several sub methods can be derived which show a different accuracy at different expenditure. Exemplarily the following problem is described: The introduction of GBAS influences the Navigation System Error (NSE) in particular.

However this contributes only a small fraction of the Total System Error (TSE). One sub method could be to model the NSE as exactly as possible at big expenditure in the GBAS CRM. Another sub method could be to estimate the NSE only in favor of the reduction of the expenditure. Finally adequate threshold values for the contribution of system elements to the overall risk need to be established and suitable sub methods need to be selected by means of the Utility Value Analysis.

In the following some system elements of the ILS CRM are examined for their applicability for GBAS CRM to give some examples. With the knowledge about the needed adjustments of the system elements and the related expenditure this option can be evaluated by means of the Utility Value Analysis. Examples for the advantages of this option are the direct comparability of ILS and GBAS, the preservation of the skeletal structure of the CRM. A substantial disadvantage is the missing possibility to implement curved approaches in the model.

4.3.1 Probability Distribution around the Nominal Flight Path

The probability distribution around the nominal flight path was derived from a mathematical model. The specific values for lateral and vertical deviation from nominal flight path of the different aircraft categories are placed in tables. The ILS model was derived from the following single models:

- An ILS approach model for the description of the approach distributions, which was validated with data collected in a data collection program. The following ILS-specific failure distributions were considered:
  - Beam Centering Error
  - Beam Sensitivity
  - Receiver Centering Error
  - Receiver Sensitivity
  - Beam Bends
  - Piloting Performance
- A model of the vertical flight path component during missed approach, which is based on the aircraft's aerodynamic characteristics and was validated by measurements. This model calculates the value of the height loss, which occurs after initiation of a missed approach (see ICAO PANS-OPS Height Loss / Altimeter Margin).
- A lateral missed approach model, which was derived from flight simulations and real data.

The lateral and vertical probability density functions calculated with the ILS approach model are described with so-called Burgerhout functions. Due to the perfectly different error components of the NSE these probability density functions cannot be used for GBAS and must be determined completely new. The FTE depends strongly on the cockpit display and therefore no big change is expected if the nowadays-usual multimode receiver is in use. Studies need to be conducted on the ability of the pilots to fly linearized GBAS approaches. Only then it will be possible to determine the need to change the probability density functions and thus the contribution to the risk computation can be determined and different sub methods can be evaluated using the Utility Value Analysis.

4.3.2 Object Modeling

Each object that should be considered in the ILS CRM is represented by one ore more vertical spikes or rectangles perpendicular to the approach/missed approach path. As the risk calculation in the ILS CRM implies standard conditions certain modeling rules must be observed. The smallest absolute distance to the threshold should be fed in as coordinate of an object. When modeling an object as a group of spikes the smallest distance perpendicular to the approach/missed approach path between the spikes should not exceed the wingspan of the related aircraft category. The longitudinal distance should not exceed 100m. The height of the highest point of an object should be fed in as the object height.

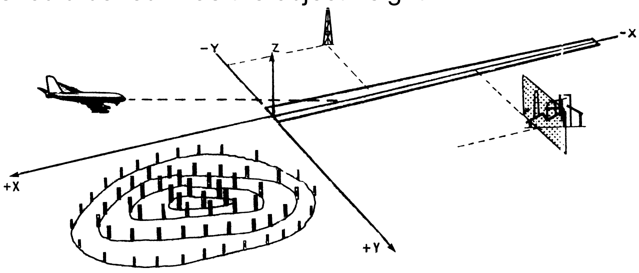

Fig. 6: Object modeling in the ILS CRM (Ref.: [5])

The ILS CRM internally adjusts the object dimensions based on the standard conditions. The dimensions of the aircraft category are added to the object dimensions. Furthermore the flight path is considered as a line.

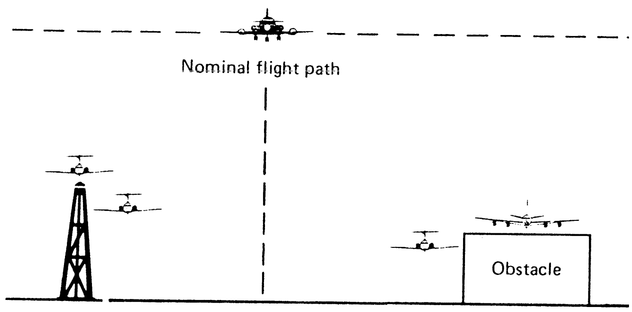

Fig. 7: Dimensions of aircrafts and objects for risk calculation (Ref.: [5])

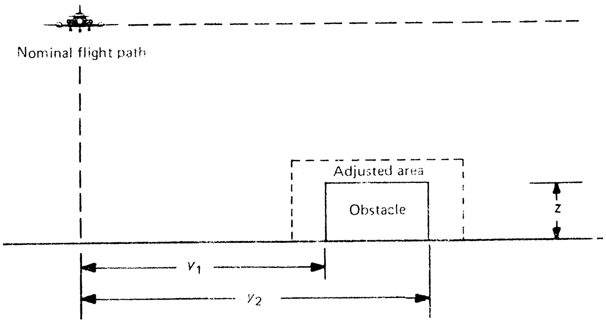

Fig. 8: Adjustment of object dimensions based on aircraft dimensions (Ref.: [5])

The object modeling of the ILS CRM can be maintained for GBAS CRM. However changes are possible e.g. enhancement of user-friendliness by an easier input of the objects. The question of the realization of this "change of beauty" has to be judged by means of the Utility Value Analysis.

4.3.3 Risk Calculation

To compute the collision risk for an approaching airplane with one or more objects the ILS CRM calculates the probability of being within the adjusted object contours with the airplane's centerline. Also the Obstacle Clearance Altitude / Height (OCA/H) can be determined for a given Target Level of Safety of $1 \cdot 10^{-7}$ per approach.

The principle of these two possibilities – "Risk Calculation" and "Minimum OCA/H" – should be maintained also in the GBAS CRM. That's why the following two sub system elements are examined for applicability.

Missed approach rate

The Target Level of Safety is valid for a single approach. Since most approaches lead to a landing and not to a missed approach, a weighting of the collision risk for objects in the missed approach area is necessary by looking at the missed approach rate for the determination of the collision probability per approach. The ILS missed approach rate of 1% was determined on basis of a data collection.

The method of weighting the collision risk for objects in the missed approach area with the help of the missed approach rate can be adopted for GBAS CRM. The value of the missed approach rate for GBAS needs to be revised by looking at the real missed approach rates of the recent years. Furthermore a study on the Initial Missed Approach Performance needs to be conducted that discusses whether the differentiation of "Approach Obstacle" and "Missed Approach Obstacle" is also valid for GBAS.

Shadowing

The shadowing describes the interdependence of objects in the process of calculating the collision risk. The overall collision risk would be overestimated if it would be calculated simply by adding the single collision risks of the individual objects. To prevent this the ILS CRM uses the method of shadowing. Shadowed objects – or parts of it – are not considered when calculating the overall collision risk.

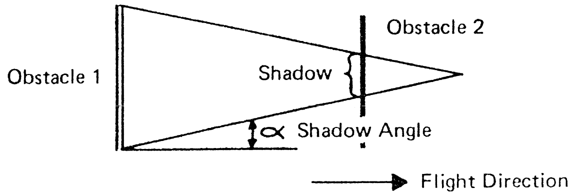

Fig. 9: Principle of shadowing (Ref.: [5])

In other words: If an aircraft passed an object safely during an approach it can be assumed that this aircraft cannot fly into a certain area subsequently. The lateral shadow angle for ILS is approximately 5° for the approach and approximately 14° for the missed approach. The different values are based on the fact that ILS supplies guidance during approach and not during missed approach. For GBAS also during missed approach guidance is available. This together with the assumption that pilots are able to navigate during missed approach leads to the conclusion that the shadowing routines for missed approach of ILS CRM need to be revised for GBAS. The expenditure needs to be estimated. To implement this in the software a case differentiation is necessary for ILS and GBAS. A new source code needs to be developed.

4.4 Derivation of OAS from a completely new GBAS CRM

For this method, which is based on a completely new CRM, it is necessary to define the exact structure of such a new CRM and to identify all dependencies within the model.

This method guarantees that no limitations exist, which would be apparent with the ILS CRM. All benefits from modern technology and the current developments can be implemented. This is especially reflected in the fulfillment of the sub objective "Flexibility in the applicability" and in particular in the "Possibility of application for curved approaches".

In this chapter the possible architectures and contents of a new GBAS CRM are discussed and the associated expenditure is specified. Afterwards this has to be evaluated using the Utility Value Analysis.

4.4.1 Identification of System Elements

The system elements and their interdependences have to be identified. Fig. 10 represents these.

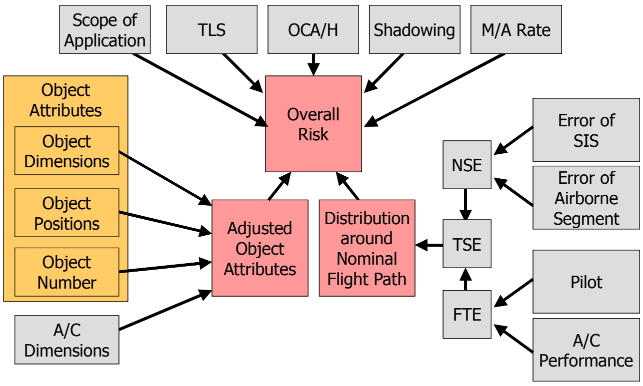

Fig. 10: System elements of a GBAS CRM (own figure)

4.4.2 Proceeding

This method is very complex and necessitates very much time, experience and international cooperation. It is helpful to bring all existing models together, which could become part of a new GBAS CRM. In particular institutions with big know-how such as Boeing, DERA, DFS, EUROCONTROL, FAA etc. must agree on the use of common models for wind, autopilot, flight director, pilot, airplanes etc., so that the sub objective "Good acceptance" is fulfilled as well as possible. An international agreement must be obtained on a common model to be used for the determination of the distribution functions (Probability Density Functions, PDFs). Hence the parameter variations used in Monte Carlo Simulations for aircraft certification by FAA and JAA have to be considered.

After definition of the operational procedures (category, use of Flight Director/ Autopilot) Monte Carlo Simulations are to be conducted with the coordinated parameter variation. It is essential to conduct flight trials also for verification reasons.

4.4.3 Estimation of Expenditure

The biggest effort will be the determination of the Probability Density Functions. The developing effort for a new software frame for GBAS CRM depends on whether it should be "two or three dimensional". With a three-dimensional GBAS CRM also curved approaches could be examined. The requirements for the PDFs are given with this information too. Additional effort arises from various other tasks like determination of the height loss values and determination of the correlations between FTE and NSE and/or for vertical and lateral distribution. All the other system elements of the GBAS CRM must be modeled as well like object modeling and shadowing.

ILS and GBAS CRM must be compared in order to judge the quality of the GBAS CRM. Conduction of flight trials is essential in order to adjust and validate GBAS CRM.

4.4.4 Determination of the Utility Value

The exact specification of the development expenditure is necessary for the Utility Value Analysis since it will be expected to be the main negative argument for this method beside time consumption. Examples for the advantages are:

- GBAS CRM can be used for optimal validating of the ILS equivalence method.
- The model can be used for the subsequent extension for CAT II/III.
- Curved approaches can be examined.

5 SELECTION OF THE OPTIMAL APPROACH

It is possible that a combination of the different methods turns out as the optimal way. If it is recognized that a sub objective is not compatible with a certain method, it is possible to put the weight of a sub objective into perspective. This can be done in different ways: If the sub objective "Minimum expenditure" should prove as the critical, the method could still be considered with additional expenditure assuming all other sub objectives are fulfilled well. Or if the sub objective "Have a solution as soon as possible" should prove as the critical, the following consideration could apply: usage of the ILS equivalence method to have a solution in time and put this sub objective into perspective and simultaneous development of other methods utilizing the time attained.

6 DERIVATION OF GBAS OAS

From the GBAS CRM, which could be an advanced ILS CRM or a completely new GBAS CRM, the OAS have to be derived. Different possible designs have to be discussed in order to select the optimal method by means of a Utility Value Analysis.

For this an objectives hierarchy is to be set up first. The sub objectives have to be weighted. Different possible designs of the OAS are to be pointed out. In doing so the methods used for ILS represent a possible way to. All possibilities are to be discussed and rated by the objectives hierarchy (Utility Value Analysis). Finally the optimal method is to be selected for use and implemented in the appropriate ICAO documents (e.g. ICAO PANS OPS).

The development of different possible OAS designs is the main focus of the studies still to be done. For example the OAS for straight ILS approaches consists of seven flat surfaces (principle of the "secondary areas"). Due to the overall availability of computers for procedure design nowadays, the introduction of a "third area" or even a "fourth are" could be considered apart from the "secondary area". Even the application of surfaces with a cylinder or cone shape can be considered. It has to be analyzed systematically, which possibilities could be offered and could be brought into line with the objective criteria.

7 SUMMARY

The development of procedure design criteria for GBAS has to be done as soon as possible. Four reasonable development methods are available:

- ILS equivalence method
- RNP method (RNP – Required Navigation Performance)
- Advancement of the ILS CRM
- Development of a new GBAS CRM

The generation of a suitable proposal for a solution has to be accomplished with the application of a Utility Value Analysis. For this an objectives hierarchy has to be set up and the individual sub objectives have to be weighted. After estimation of the development expenditure for each individual method the respective Utility Value can be derived which can be the basis for decision-making. The following should be considered:

- The ILS equivalence method seems to bring a short-term solution. However it is very inaccurate and neglects the advantages of GBAS completely.
- The RNP method would specify procedure design criteria regardless of the used navigation systems. This method is not yet feasible since RNP approaches are not yet possible due to certification reasons.
- The advancement of the ILS CRM seems to bring the most accepted solution as it has proven its reliability over many years for ILS. However it will be limited in the applicability and expandability for future approaches (e.g. curved approaches).
- The development of a new GBAS CRM appears to be the solution, which is extremely exact, flexible and user-friendly. However this method will be very time consuming and complex with the necessity of international coordination, co-operation and acceptance.

It is expected that some methods will be developed in parallel in order to implement GBAS approach procedure design criteria on the one hand as soon as possible and on the other hand in medium term to realize criteria, which allow for the GBAS specific advantages and will be accepted world-wide. Only a new GBAS model and GBAS CRM will be capable to cover future approach characteristics that might come up on a long-term basis.

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