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ENHANCING THE DEVELOPMENT OF A PARTICULAR NETWORK OF AERODROMES BY USING EGNOS

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Abstract

Major improvements and new challenges will arise from the availability of new Global Navigation Satellite Systems (GNSS) in the next decades. In particular, Satellite Based Augmentation systems (SBAS) meet the high accuracy, integrity and continuity levels required for safe critical applications, such as civil aviation radionavigation. The European SBAS contribution is called EGNOS (Global Navigation Overlay Service) which after more than six years of system development is expected to be ready for the final certification phase by the end of 2005.

Conventional air radionavigation in continental airspace uses ground based navigation aids. Consequently, the system is inflexible regarding the en-route structure and airport departure or approach procedures. In addition, these facilities have a significant cost and an expensive maintenance program which small airports or aerodromes cannot afford. On the other hand, EGNOS will provide improved procedures at almost no cost for the airport authority in locations where instrumental navigation is poor or even not existing.

This work contains a feasibility study of new EGNOS departure and approach procedures in small aerodromes where currently instrumental radionavigation is not possible. Particularly, the study focuses on the regional aerodrome network of Catalonia (Spain), whose characteristics are varied enough to make the benefits of the study representative. For instance, opportunities for new users such as fire extinguishing and rescue services as well as potential business development (like small regional passenger or cargo operators) are pointed out. In addition, this study remarks safety, environmental and operational advantages that satellite navigation will provide to civil aviation.

1 Introduction

The whole society is being largely influenced with the introduction of the Global Navigation Satellite Systems (GNSS). Although the American Global Positioning System (GPS) was first initialized in early 80's, widely used civilian applications became popular in last decade, in conjunction with new miniaturized and embedded electronics and high computer processor speeds. Thus, plenty of disciplines are currently beneficiating with GNSS technologies such as land vehicle navigation and tracking, marine applications, spacecraft attitude control, precise time and time interval measurement applications, surveying applications, geodesy, orbit determination, etc. [1].

However, in civil aviation GNSS systems are still playing a secondary role. Civil air transport is considered as a safety of life application and all systems involved must verify very high and strict levels of performance. In this context GPS or GLONASS. Satellite navigation systems do not meet these requirements and can not be used in all phases of flight as primary means of navigation. One of the major drawbacks is the lack of *integrity*, which is defined as the ability of the system to provide timely and valid warnings to the user if it is not functioning properly. In addition, for some critical flight phases (such as approaches) these systems may suffer from poor *accuracy* or *availability* too [2]. In this context, some solutions have been recently developed in order to overcome the problems of the stand alone use of GPS or GLONASS navigation. With a generic name of *Augmentation Systems* these solutions provide GPS and GLONASS users with an extra set of information in order to enhance the whole system performances and achieve the strict requirements for using them in civil aviation.

There are three different types of augmentation systems, basically distinguished in function of the source which is providing this extra set of information: *Airborne Based Augmentation Systems (ABAS)*, *Ground Based Augmentation Systems (GBAS)* and *Satellite Based Augmentation Systems (SBAS)*. At present, SBAS systems are the ones which are in a most advanced phase of development and certification. The first one being developed, and currently operational is the American *Wide Area Augmentation System (WAAS)* followed by the*European Geostationary Navigation Overlay Service (EGNOS)* (expected to be fully operational in 2006) and the Japanese *MTSAT Space Augmentation System (MSAS)* (still under development). Recently, the Indian government has announced the future development of its own SBAS system: the *GPS and GEO Augmented Navigation (GAGAN)* [3].

The role of navigation instruments is to assess the pilot of an aircraft to follow certain routes, which have been designed to drive the aircraft safely from one point to another even with bad or zero visibility conditions. During last decades, navigation in continental airspace has been based on the use of radionavigation aids spread widely in the territory resulting in non efficient and inflexible routes. This is the main cause of flight delays (due to bottle necks in some high overflown aids), environmental and noise issues and non-economically optimal routes for airline operators. With the introduction of computerized avionics and on-board system integration new solutions arose and the first step into new navigation techniques was introduced with the *Area Navigation (RNAV)*. This concept defines new routes between arbitrary points that do not need to be placed over any radionavigation aid, providing more airspace capacity and flexibility. In Europe, the RNAV introduction is settled as an objective for all phases of flight. In this context, EUROCONTROL (the European organization for the safety of air navigation [4]) has defined RNAV concept and satellite navigation systems as the key enablers for future improvements in terms of safety, efficiency and/or economy of flight, provided that their implementation is based on a fully co-ordinated, harmonized, evolutionary and flexible planning process [5], [6].

One particular, and important, flight phase is the approach procedure. The *Instrumental Landing System (ILS)* is, at present, the conventional system most extended and widely used for this purpose. Despite its good performances for low visibility approaches, only important airports can afford the cost of installing and maintaining such a system. In addition, because of its inherent technology, all ILS approaches must be defined as straight segments aligned with the landing runway, being this sometimes a problem due to nearby orography or due to environmental reasons. New satellite navigation systems will override those ILS drawbacks and it will be possible to define more flexible approach procedures at almost no cost. Specifically, with SBAS systems, a new type of *Approach with Vertical Guidance (APV)* is at present in standarition process.

This paper describes a feasibility study of new EGNOS APV approach procedures in small aerodromes where currently instrumental radionavigation is not possible. In particular a specific APV procedure in Igualada-Odena aerodrome, which is one of the regional aerodrome network of Catalonia (Spain), has been performed in order to show the advantages of this kind of navigation. Some background on aircraft navigation and instrumental procedure design is given first in this document. Then the state of the art in APV approaches is presented as well as the situation of the general aviation in Catalonia. Finally the Igualada-Odena APV procedure is described.

2 Background on aircraft navigation

Air navigation is the process of directing an aircraft from a certain point to another by means of the own pilot ability or by using different kinds of navigation instruments. In civil aviation there are two main ways to navigate and it is said that an aircraft is evolving accordingly to certain flight rules:

- Visual Flight Rules (VFR)
- Instrumental Flight Rules (IFR)

VFR navigation is based on visual references which the pilot picks from the outside, such as rivers, mountains, roads, etc. In this type of navigation almost no instruments are used and, if used, they are always as complementary means. Therefore, VFR navigation is strictly bond to certain favorable meteorologic conditions (measured in terms of visibility and minimum separation between aircraft and clouds) and, as a consequence, its use is almost completely restricted to private or leisure aviation. On the other hand, an aircraft flying under IFR rules uses several navigation instruments which provide the pilot with information for following its trajectory or navigation route with no need for external visual references. The route to be followed can not be any trajectory, but one which has been previously studied by the competent authorities in air traffic management, and conveniently published to let it be known by the users of the air space. Particularly, these trajectories are called procedures (for airport departure, arrival or approach maneuvers) or airways (for the cruise phase). The design of procedures and airways guarantees obstacle clearance (above mountains, buildings...) by means of a secure enough flight altitude, as well as the minimum separation between aircrafts using different procedures or airways in the same zone, and finally, it helps managing and directing the air traffic flow in a better way in congested areas.

2.1 Conventional radionavigation systems

Most of the navigation instruments and equipment which support IFR flights use the radiofrequency technology and this is why they are called radionavigation instruments (or equipments). There are several different radionavigation systems and the most used world-wide are the *Non Directional Beacon (NDB)*, the *VHF Omnidirectional Ranger (VOR)*, the *Distance Measurement Equipment (DME)*, the *Instrumental Landing System (ILS)* and the *Microwave Landing System (MLS)*. It is out of the scope of this document to describe those systems, which are often called as *conventional radionavigation systems* and for further details one can refer to [7]. Essentially, these systems can be treated as different radiobeacons which give to the user (the pilot) relevant information about his relative position to the beacon (which depending on the beacon can be relative distance or relative bearing) enabling the definition of different flight procedures.

Among all these systems ILS and MLS should be highlighted. Both systems, compared to the other conventional ones, are designed only for supporting the final approach phase in a given runway. Another important characteristic is that they are the only ones providing the aircraft with vertical guidance in addition to the lateral information.

2.2 Satellite radionavigation systems

The generic term Global Navigation Satellite System (GNSS) include all the systems which allow for the positioning of an aircraft by means of signals received from navigation satellites, as well as the possible (current or future) augmentations to be applied on these systems. So, GNSS stands for a great variety of elements, which basically consist of global constellations of satellites (for instance, GPS, GLONASS and the future Galileo) and the necessary augmentations for them to guarantee the strict security requirements of aeronautical applications.

The two main GPS augmentation systems (currently undergoing the implementation phase), are the Satellite and the Ground Based Augmentation System (SBAS and GBAS respectively). In Europe, the augmentation system SBAS is called EGNOS (European Geostationary Navigation Overlay Service), while in the USA, the equivalent system is called WAAS (Wide Area Augmentation System). More information concerning European satellite navigation program can be found, for instance, in [8] or [9].

2.2.1 SBAS

An SBAS system provides integrity data and differential corrections on the GPS or GLONASS signals, as well as additional positioning signals, broadcast by Geostationary satellites in order to cover relatively wide areas (continental scale). SBAS systems are composed of some common elements:

- **Reference stations network** monitoring continuously all satellite signals.

- **One or more master stations** collecting and processing data provided by the reference stations and generating the SBAS messages, which contain differential corrections and integrity information.
- **Uplink stations** which transmit SBAS messages to Geostationary satellites
- **Satellite transponders** broadcasting SBAS messages an giving extra ranging signals

3 Fundamentals on instrumental procedure design

Conventional navigation, which is based on overflying a set of radionavigation aids, has shown some limitations in last years due to the increase of air traffic. Area Navigation (RNAV) was first introduced in Europe by April 1998 and is considered as a vitally important contribution to the development of an optimal en-route operating environment in European airspace. Aircraft equiped with suitable systems can fly RNAV routes, which are defined beetwen arbitrary waypoints that do not necessarily have to be placed over radionavigation aids as it happens with conventional navigation. This technique is possible thanks to new on-board automated systems that continuously calculates aircraft's position from navigation input data coming from conventional facilities (such as VOR-DME or DME-DME information) or even GNSS measurements.

3.1 Conventional approach procedures

The final phase of an aircraft arriving into an airport is known as the *approach phase.* Conventional approaches have been always divided in two groups:

- **Non Precision Approaches (NPA)**: An instrumental approach procedure when only lateral guidance is provided.
- **Precision Approaches (PA)**: An instrumental approach procedure using lateral and vertical guidance.

Different radionavigation systems can be used to define non precision approaches such as NDBs, VORs, DMEs. Precision approaches can only be designed using ILS or MLS systems because of the need for the vertical guidance.

All instrumental approaches have the so called *landing minimums* which have been established for each approach at a given airport and can vary from runway to runway. Factors which affect these minimums include the type of approach equipment installed, equipment on board the aircraft, runway lighting, aircraft landing airspeed and obstacles in the approach or missed approach paths. Approach landing minimums contain both minimum visibility[1] and minimum altitude requirements that are needed to finish the approach and land into the airport. If those minimum requirements are not meet pilot must execute a missed approach procedure.

In non precision approaches altitude requirements are specified with a *minimum descent altitude (MDA)* which the pilot must remain until the *missed approach point (MAPt)* is reached. After the MAPt the pilot must continue the approach visually or execute a missed approach.

On the other hand, precision approaches, since they are providing vertical guidance, specify only a *decision height or altitude (DH or DA)* where the decision of continue the approach visually or start the missed approach procedure must be taken. If standard equipment is used and no penalizing obstacles are found in the approach path, there exist three types of landing categories in function of the precision approach equipment performances and related values are given in table 1.

3.2 APV approaches

Although RNAV navigation is more flexible and efficient it gives only lateral guidance, so only non precision approaches can be defined using that concept. In order to overcome that drawback, in November 2002 a new approach definition was adopted in addition to the existing Non Precision Approaches and Precision Approaches. The new approach procedure is known as *APproach with Vertical Guidance (APV)* which is defined by an instrument procedure which utilizes lateral and vertical guidance but does not meet the requirements

[1]Visibility is measured in terms of the *Runway Visibility Range (RVR)*

Category	DA/DH	RVR	Flying mode
CAT I	DA $\geq 200\,ft$ above terrain	$> 800\,m$	Manual or automatic flight
CAT II	DH $\geq 100\,ft$	$> 400\,m$	Manual or automatic flight
CAT III	DH ranging from $100\,ft$ to $0\,ft$	$< 400\,m$	Automatic flight

Table 1: Landing categories for conventional precision approaches

established for precision approach and landing operations. APV approaches can be achieved using RNAV systems (giving lateral guidance) in conjunction with vertical guidance provided by a barometric source. Nevertheless APV approaches give a significant difference when navigation information is provided by GNSS systems, which provide directly lateral and vertical guidance (such as an SBAS system).

Table 2 shows different APV approach performances in function of the system employed. Figures of *Navigation System Error (NSE)*, *Flight Technical Error (FTE)* and *Total System Error (TSE)* are given. TSE is the global error figure taking into account the navigation aid error (NSE) plus the error due to piloting deviations (FTE).

It should be noted that APV-I and APV-II approaches, based on GNSS systems are the ones offering better performances, similar to those required to execute an ILS CAT-I approach. The main difference remains on less vertical guidance accuracy for APV approaches compared with ILS ones. To summarize, the main advantages of APV approaches, compared with Non Precision Approaches, are:

- Low cost implementation
- Lower angle of descent during final approach
- Lower operation minimas
- Safety improvement due to provided vertical guidance
- More accurate lateral guidance
- More flexibility when designing the projected ground procedure:
  - Environmental improvement
  - Possibility to design procedures in mountainous areas
  - Better air space management

In front of Precision Approaches, APV advantages are mainly the low cost of implementing the procedure (ILS or MLS systems are much more expensive and for instance APV SBAS approaches does not need any facility to be installed on ground) and the flexibility in the trajectory. On the other hand, APV approaches does not meet the accuracy required for CAT-I, CAT-II and CAT-III operations which are required in very degraded meteorological conditions.

4 State of the art in APV approaches

The official and standardized methodology to design any given procedure is published by the *International Civil Aviation Organization (ICAO)* in the Volume II of the document *8168. Procedures for Air Navigation Services - Aircraft Operations* [10]. It provides basic guidelines to States or organizations in charge of designing instrument flight procedures. The corresponding material specifically designated to flight operators, including flight crews can be found in Volume I of the same publication [11].

At present only RNAV depart and approach procedures are published, enabling therefore only non precision approaches if SBAS navigation is used. However some draft material from the *Obstacle Clearance Panel (OCP)* meetings is available. The OCP is the ICAO technical group of qualified experts in charge of defining the standards published in *Doc 8168* and eventually propose amendments or recommendations. OCP fourteenth meeting was mainly devoted to define the rationale for the new SBAS APV Obstacle Clearance criteria. These criteria is based on a ILS accuracy equivalency method and is justified in [12]. Therefore new ap-

Types of APV approaches		
Equipment type	**Lateral Performances**	**Vertical performances**
Lateral: RNAV (DME/DME) Vertical: BARO-VNAV	NSE: not defined TSE: 0.3 NM	NSE: not defined FTE: equivalent to a non-precision approach (246 ft)
Lateral: RNAV (GNSS) Vertical: BARO-VNAV	NSE: 220 m (95%) TSE: 0.3 NM	NSE: not defined FTE: equivalent to a non-precision approach (246 ft)
Lateral: RNP Vertical: BARO-VNAV	Variable in function of RNP	NSE: not defined FTE: equivalent to a non-precision approach (246 ft)
GNSS with APV-I performances	NSE and TSE equivalent to an ILS LLZ	NSE: 20 m (95%) 50 m (limit) FTE: equivalent to an ILS GS
GNSS with APV-II performances	NSE and TSE equivalent to an ILS LLZ	NSE: 8 m (95%) 20 m (limit) FTE: equivalent to an ILS GS

Table 2: Different types of APV approaches

proach procedures such as APV will adopt the *ILS-look alike* concept, giving to the pilot equivalent indications of aircraft vertical and lateral deviations in the same fashion that is done with the ILS system. On the other hand, document [13] contains the SBAS APV approach criteria proposed to be included in the future in *Doc 8168*.

Meanwhile, EUROCONTROL has financed the development of an utility capable of calculating the using the provisional criteria proposed in different OCP. this utility [14] allows the automatic assessment for the required Obstacle Clearance Criteria in the final approach phase of an APV procedure.

5 General aviation in Catalonia

Catalonia is located in the north-east of the Iberian Peninsula and covers an area of approximately 32.000 square kilometers, with a population slightly above six million people. It is one of the autonomous communities of Spain, having its own governing body: the *Generalitat de Catalunya*.

Catalan Airport's plan document [15] describes the general guidelines for adequate zoning, planing and development of the whole airport sector in the Catalan region. In a first part, this plan gives a sector diagnosis listing the current airport facilities in Catalonia and pointing out the principal opportunities and menaces. The second part includes several recommendations in order to achieve the final airport network, which is divided in five different levels or sub-networks in function of the airport/aerodrome size and installed facilities.

Regarding the first document of the Catalan Airport's plan, where the situation of the aeronautic sector is analyzed, the following important conclusions are driven:

- Commercial aviation health is considered acceptable, if major future plans for main country airports such as Barcelona, Girona and Reus airports are taken into account. However, regular commercial services should be developed in other airports.
- On the other hand, general aviation is in a seri-

ously worrying situation due to its underdevelopment. In addition, it is stated that this kind of aviation constitutes the base of the whole aeronautic sector.

General aviation is defined as all those aerial activities with the exception of passenger or cargo transport. Thence, we can identify four main sectors in general aviation:

- Aerotaxi (business aviation)
- Air works activities (such as public services, aerial photography, etc.)
- Private and sportive aviation
- Aeronautics outreach and training

One of the major issues that is currently stopping the development of general aviation in secondary Catalan aerodromes is the lack of IFR procedures that would enable all weather operations. If no satellite navigation methods were available, but an IFR procedure was to be implanted in some aerodrome or airport, conventional procedures (precision or not precision) would have to be designed. In either case, the installation of a ground-based equipment, such as radio aids, would be required. This would unavoidably lead to a considerable economic investment, being much bigger for precision than for not precision procedures. Consequently, the implementation of RNAV and/or APV procedures in the Catalan network of airports, especially in secondary aerodromes, would yield remarkable improvements. Not only would it provide particular aerodromes with currently inexisting IFR procedures, but it would do it with practically no investment infrastructures. Obviously, some on board equipment would have to be adapted to the new navigation and IFR method, but this is not a serious drawback, inasmuch as it is a necessary expense when implementing conventional methods as well.

6 Case of study: the Igualada-Odena aerodrome

A joint cooperation between the *Politechnic University of Catalonia (UPC)* and the firm *PILDO Labs* enabled the design of an experimental APV procedure, using draft material published in [13] in a particular aerodrome of the Catalan regional aerodrome network. In particular, the *Igualada-Odena* aerodrome, which is considered at present as a sports aviation aerodrome, was selected. This field is located at 3 km east of Igualada town, which is at about 50km km to Barcelona (Spain). Figure 1 shows a picture of the aerodrome, and table 3 contains aerodrodrome's specific data.

Geographic coordinates of the aerodrome reference point
Latitude $N\,41^o\,39'^o, 16.01''$ Longitude $E\,1^{oo}, 35'\,2.27''$
UTM coordinates of the aerodrome reference point (UTM-31)
X 387.934 Y 4.604.664
Elevation of the aerodrome reference point
elevation 330 m
Magnetic declination, date and annual variation
$3^o\,08'$ - 01/01/86 - -7.9

Table 3: Situation of the Igualada-Odena aerodrome

Figure 1: View of the Igualada-Odenaś aerodrome

The aerodrome has a main asphalt runway (denominated as 15-35) with a length of 900 meters by 15 meters wide. This kind of runway is suitable for small to medium aircraft devoted to general aviation and/or regional transportation. Only few visual aids are available, such as basic runway marks and wind socks. In addition, at present, no IFR operations are defined in the aerodrome and the closest conventional radionavigation facility is Sabadell VOR (SLL) which is located at more than 50 km from the field. Therefore, it is almost impossible to define IFR procedures in the aerodrome except those based on GNSS navigation.

Finally, just point out that the aerodrome have some facilities, such as a

refueling service, a small control tower (even if currently no control

services are available), fire extinguishing facilities and various types of hangars. In addition there is enough free space next to the runway which will permit the construction of an aircraft apron or even a little passenger or cargo terminal. Thence, the airport has the minimum infrastructure in order to enable general aviation activities but on the other hand it has the handicap that no IFR operations can be defined due to the lack of radionavigation infrastructure nearby. With only VFR operations it is very difficult to establish any general aviation activity due to the impossibility to operate in the aerodrome during degraded weather conditions. So, therefore almost no general aviation activities are based in Igualada-Odena, except from those devoted to private or sportive aviation. This is why this particular scenario was chosen in order to demonstrate the benefits that APV procedures, based on SBAS navigation, could offer.

7 The APV procedure in Igualada-Odena

Obstacle clearance is the primary safety consideration in developing instrument procedures. Each segment in a procedure has an associated protection area. Normally this area is symmetrical on both sides of the intended track and specific obstacle clearance must be provided in the area. The specific width of the areas and the minimum obstacle clearance altitude vary in function of the type o procedure (depart, arrival, approach, en route...) or even in function of the nature of the segment considered (for example an initial or intermediate segment in an approach procedure) and in function of the sensor being used for flying the procedure (VOR, DME, GNSS...).

Special attention must be given in designing final approach procedures where a value of the *Obstacle Clearance Altitude or Height (OCA/H)* may be computed in order to assess the publication of the Minimum Descend Altitude (MDA) for non precision approaches or de Decision Altitude/Height (DA/H) for precision approaches. In other words, the OCA/H is the lowest altitude or the lowest height above the elevation of the relevant runway threshold of the acrodrome used in establishing compliance with appropriate obstacle clearance criteria.

For the Igualada-Odena aerodrome the EGNOS based APV-RNAV procedure approach was designed following current RNAV guidelines [16] and draft criteria published by the ICAO Obstacle Clearance Panel [13]. Despite the great advantages of such procedure in front of existing ones in the aerodrome the obstacle clearance altitude (OCA) obtained was still too high due to obstacles located in the approach path. A refined procedure using, for instance, curved approach criteria may help to improve significantly the OCA. Figure 2 show the vertical profile obtained for the APV procedure in Igualada-Odena aerodrome.

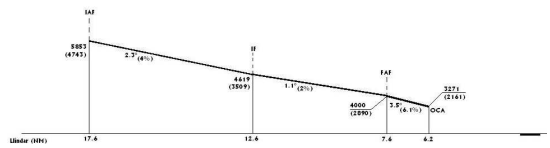

Figure 2: Vertical profile of the APV procedure in Igualada-Odena aerodrome

The procedure was completed by designing the intermediate and initial segments, as well as omnidirectional arrivals sectorization, where the FAA's[2] Terminal Arrival Area (TAA) concept was adopted. The TAA is usually divided into three sectors in function of the arrival direction: straight-in, left base and right base. If necessary, these may be sub-divided by step-down arcs with different minimum altitudes. The final TAA for Igualada-Odena used this kind of sectorization in the straight in area because of the presence of high mountainous area in the north of the aerodrome. Thus a a Terminal arrival altitude of almost 2700 m was imposed in the outer part of the straight in sector and a step down arc 10 NM from the initial approach fix was allowed to a minimum altitude of 1800 m. Left and

[2]Federal Aeronautics Administration

right base areas had a minimum altitude of 1800 m as well. Figure 3 shows the obtained procedure and the Terminal Arrival Area designed.

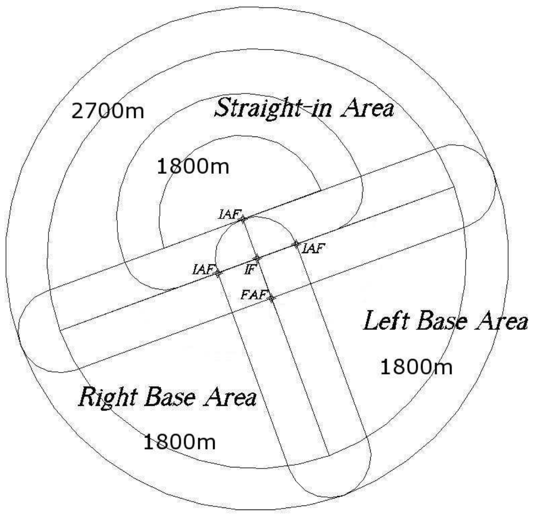

Figure 3: Terminal Arrival Area

8 Conclusions

This paper gives an overview of the future utilization of SBAS systems in civil aviation. In particular, new navigation concepts such as RNAV navigation or APV approaches are presented. Furthermore the advantages of using this kind of technology in general aviation are highlighted, such as security enhancements in aerodromes (IFR procedures are more secure than VFR ones) and the possibility of all-weather operations. Thus, SBAS IFR operations will be one of the key enablers for boosting the implantation of new regional and general aviation activities (aerial works, specialized cargo, pilot and crew formation...) in secondary airports, which can not afford the expensive cost of conventional navigation means. It should be underlined here that these improvements are fully compatible with environmental preserving measures and sustained development criteria, due to its high level of flexibility as well as the intelligent uses which can be derived of such navigation procedures.

In this work, a feasibility study of new EGNOS APV approach procedures in a particular aerodrome of the Catalan network is performed and an experimental APV approach and a Terminal Arrival Area is designed. Despite being the results very encouraging the obstacle clearance height obtained for the designed procedure is a bit high due to obstacles located in the surrounding areas. Further work may deal with the design of curved approaches which are in fact possible using SBAS navigation, but are still in preliminary certification phase.

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References

[1] Bradford W. Parkinson and James J. Spilker, editors. *Global Positioning System: Theory and Applications*, volume 2 of *Progress in astronautics and aeronautics. Volume 164*. American Institute of Aeronautics and Astronautics Inc., Washington DC (USA), 1996.

[2] International Civil Aviation Organisation (ICAO), Montreal (Canada). *Annex 10 to the Convention on International Civil Aviation - AERONAUTICAL TELECOMMUNICATIONS - Volume I, Radionavigation Aids*, 5 edition, July 1996.

[3] K.N. Suryanarayana Rao and S. Pal. The indian SBAS system - GAGAN. In *India-United States Conference on Space Science, Applications, and Commerce*, Bangalore (India), June 2004. AIAA.

[4] http://www.eurocontrol.int

[5] http://www.ecacnav.com/navigation_strategy.htm

[6] http://www.eurocontrol.int/corporate/public/standard_page/cb_atm_strategy.html

[7] Myron Kayton and Walter R. Fried. *Avionics - Navigation Systems*. John Willey and Sons. Inc., London (UK), 2 edition, 1997.

[8] R. Lucas, P. Lo Galbo, M.L. de Mateo, A. Steciw, and E. Ashford. The ESA contribution to the european satellite navigation programme. *Acta Astronautica*, 38(4-8):605–611, April 1996.

[9] Javier Ventura-Travesset, P. Michel, and L. Gauthier. Architecture, mission and signal processing aspects of the EGNOS system: the first european implementation of GNSS. In *7th International Workshop on Digital Signal Processing Techniques for Space Communications*, Sesimbra (Portugal), October 2001.

[10] International Civil Aviation Organisation (ICAO), Montreal (Canada). *Procedures for Air Navigation Services - Aircraft Operations (PANS-OPS) - Volume II, Construction of Visual and Instrument Flight Procedures*, 4 edition, 1993. Doc. 8168-OPS/611.

[11] International Civil Aviation Organisation (ICAO), Montreal (Canada). *Procedures for Air Navigation Services - Aircraft Operations (PANS-OPS) - Volume I, Flight Procedures*, 4 edition, 1993. Doc. 8168-OPS/611.

[12] Edward Bailey and Barry Billmann. Rationale for SBAS APV approach obstacle clearance criteria. Obstacle Clearance Panel. Fourteenth meeting, International Civil Aviation Organisation (ICAO), Montreal (Canada), March 2005.

[13] Edward Bailey. Area nevigation (RNAV) approach procedures for SBAS GNSS receivers. Obstacle Clearance Panel. Fourteenth meeting, International Civil Aviation Organisation (ICAO), Montreal (Canada), March 2005.

[14] École Nationale de l'Aviation Civile (ENAC), Toulouse (France). *APV1 Minima estimator tool. User guide. Version 1.02*, April 2004.

[15] Generalitat de Catalunya. Departament de política territorial i obres públiques, Barcelona (Spain). *Pla d'Aeroports de Catalunya*, 2003. Llei 19/2000 de 29 de desembre.

[16] EUROCONTROL. *Guidance Material for the Design of Terminal Procedures for Area Navigation (DME/DME, B-GNSS, Baro-VNAV and RNP-RNAV)*, 3 edition, March 2003.