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Benefits of EGNOS and Galileo for aviation in French Airspace

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ABSTRACT

The purpose of this paper is to provide the reader with an overview of the issues relating to the introduction and the large-scale deployment of vertical guidance for aRea NAVigation approaches (RNAV). The first RNAV approaches using the GPS navigation system are operational in France since the end of 2004. These approaches, known as the "conventional" or "non-precision" type, do not require the use of vertical guidance. And yet, over the last few years, a consensus at ICAO and within the worldwide aeronautical community has been observed to ultimately replace or complete non-precision approaches by RNAV approaches that systematically include guidance in a vertical plane. Actually, it has been clearly demonstrated that vertical guidance is effective in preventing CFIT (Controlled Flight Into Terrain) type accidents. In this article, various technologies are presented that could help ensure this guidance on the vertical plane in area navigation, then the interest for the European GNSS EGNOS system in this context is explained. Finally, the policy of the main aircraft manufacturers, the FAA, Eurocontrol and the French civil aviation authorities is considered with regard to RNAV and GNSS approaches.

Figure 1. EGNOS Architecture

I. INTEREST OF VERTICAL GUIDANCE. SOME REMINDERS ON GNSS AND OTHER TECHNOLOGIES FOR VERTICAL GUIDANCE OF APPROACH AND INSTRUMENT LANDING PROCEDURES.

1.1. The early stages of GNSS.

The recommendations of the worldwide aeronautical community during the 10th Air Navigation Conference in 1991, followed by those of the ICAO council in February 1994, approving the conclusions of the FANS (Future Air Navigation Systems) committee, helped launch satellite navigation. In October 1994, a letter was sent by the United States government to ICAO offering, without collecting direct costs, a positioning system for civil aviation. Then, in June 1996, a letter was sent by the Russian federation proposing a similar service for GLONASS.
These letters provided the decisive impetus for ICAO to undertake standardisation work for GNSS, with the objective of defining GNSS systems that could be used during all phases of flight, ranging from ocean navigation to Category III precision landings.
Following these decisions, the work by the GNSS Panel expert group enabled ICAO, in November 2002, to publish GNSS standards covering all phases of flight up to Category I approaches in Annex 10 of the Chicago Convention. It was decided to limit the standards to Category I applications in this first version of GNSS standards as the definition and validation work for GNSS standards had shown that with current GPS or GLONASS signals (single frequency), it was very difficult to ensure a performance level such as the one required for ILS or Category II/III MLS.
In order to ensure the levels required in terms of precision, integrity, continuity of service and availability of GNSS for various phases of flight, the ICAO GNSS standards define different architectures to augment the basic constellations (GPS and GLONASS):

• ABAS (Airborne Based Augmentation System)
• GBAS (Ground Based AugmentationSystem)
• SBAS (Satellite Based AugmentationSystem)

Their main characteristics of these different augmentations are introduced in table 1.

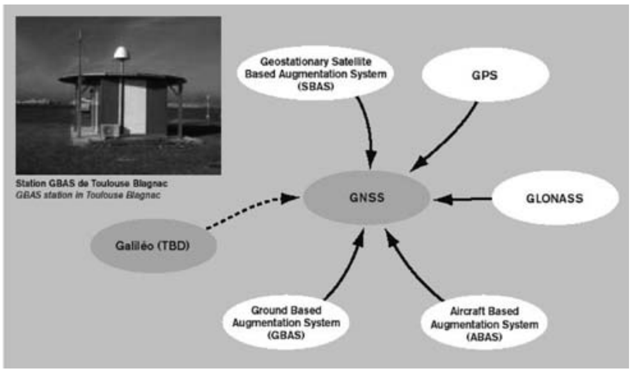

Figure 2. ICAO GNSS

Airborne Based Augmentation systems

The GNSS ABAS systems use only redundant elements that are within the GPS constellation, for example the multiplicity of distance measurements to various satellites, or the combination of GNSS measurements with those of other navigation sensors, such as the inertial surveying systems, to develop integrity control.
This integrity control is crucial for GNSS as, according to the failure characteristics permitted in the ICAO standards, GPS satellites may lead to major position errors over periods of several hours. The simplest type of ABAS augmentation is traditionally RAIM (Receiver Autonomous Integrity Monitoring). This uses the redundancies of a number of measurements greater than four - a minimum number to develop a position measurement. This is the algorithm that is generally implemented for GNSS receivers in general aviation or a part of business aviation.
For aircraft with an inertial system, it is possible to use the additional properties of GNSS and the inertia to combine their measurements and develop an integrity control. It must be noted that unlike other augmentations of the GBAS and SBAS type, ABAS augmentation does not improve positioning accuracy. As a result, considering the requirements of Annex 10 for operations using GNSS, the use of ABAS systems is limited at best to non-precision approaches.

Ground Based Augmentation Systems

To carry out Category I precision approach operations, a certain number of measurement errors in signals transmitted by GNSS satellites need to be eliminated, trajectory tracking and clock errors in particular, as well as errors caused by propagation through the ionosphere.
The most standard method is based on a technique known as local area differential corrections, where a control station at an airport for example, enables the precise measurement of these errors and then relays them to a user so that he can eliminate them from his own measurement.
The ICAO GBAS standard is based on this technique through the use of a data link in the VHF frequency band of ILS - VOR systems (108 - 118 MHz). The other elements transmitted through this VHF link are

integrity data of various satellites in view, as well as the database used for the final approach segment. For a GBAS station, the coverage is about thirty kilometres. Thus, typically an approach area associated with an airport and a single GBAS station can provide approaches to all runways of that airport.
The most recent ICAO standards provide for the possibility to interconnect GBAS stations to form a network broadcasting large-scale differential corrections, such a system being identified more accurately by the acronym GRAS (Ground Regional Augmentation System).

Satellite Based Augmentation System
Like GBAS, the SBAS transmits differential corrections and integrity messages for navigation satellites that are within sight of a station network, typically deployed for an entire continent. Depending on the architecture of the system and the required performance level, 20 to 35 stations may be required to cover a continent.
There are three important differences compared to GBAS. First of all, the frequency band of the data link is identical to that of the GPS signals (about 1575 MHz), which allows the use of standard input Radio Frequency parts of GPS receivers. Next, the use of geostationary satellites enables messages to be broadcast over very wide areas. Finally, positioning measurements on these geostationary satellites can also be made, as if they were GPS satellites. This has the effect of increasing by as much, the number of navigation satellites in sight.
Considering the limitation of the number of ground-based control stations to control deployment and operation costs, it is thought that the best performance level that can currently be attained by the SBAS GNSS corresponds to APV I or II performance approaches, which are presented in greater detail later in this article.

Table 1. Main characteristics of GNSS ABAS, SBAS and GBAS

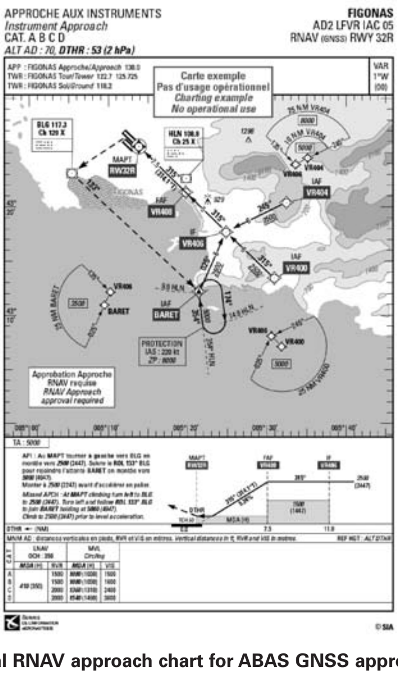

Figure 3. Typical RNAV approach chart for ABAS GNSS approaches showing minima for NPA/GPS (LNAV)

1.2. The problems of vertical guidance.

Along with the definition of GNSS at ICAO, many studies have shown that, in the field of approaches, it is crucial to reduce the accident rate caused by CFITs (Controlled Flight Into Terrain), as these represent a significant percentage of all accidents. In particular, a statistical study by the Flight Safety Foundation, published in 2001, helped quantify that, on an average, the risk of a serious incident or accident is 7 to 8 times higher on a non precision approach than on a precision approach, the increase in the risk factor being mainly due to the absence of vertical guidance.

Besides, it should be recalled that the worst accident that occurred in France during the last decade corroborated these analyses (the Mont Saint Odile accident in Strasbourg): it was a case of CFIT on a non precision approach, without vertical guidance. And yet, for obvious economic reasons, it was not possible for ICAO to recommend states to deploy precision approach systems on a major scale (ILS Cat I or GNSS GBAS Cat I) at airports to ensure vertical guidance for all runways.
Further, the most important point to improve safety is the presence of stabilised vertical guidance, but does not necessarily require a precision level comparable to ILS. Therefore, ICAO pragmatically decided introduce a new category of area navigation approaches (RNAV) in the classification of approaches in Annex 6 at the Chicago Convention: the APV (APproach with Vertical guidance).
This intermediate category between non precision approaches and precision approaches was designed to allow the use of precision systems inferior to ILS while at the same time ensuring stabilised vertical guidance.

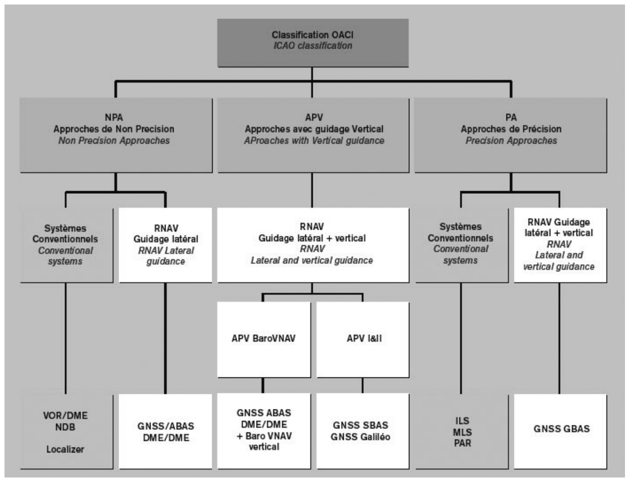

Figure 4. ICAO classification for approaches and different navigation systems.

1.2. An initial response to the need to deploy large-scale vertical guidance, the BaroVNAV systems.

Long before ICAO defined GNSS and APV approaches, the major aeronautical manufacturers were aware of the risks induced by complex trajectories in the vertical plane of certain non-precision approach procedures. This particularly concerned approaches using a series of level flight and descent phases with the aim of avoiding certain obstacles.
They therefore decided to design navigation systems in the vertical plane based on a barometric sensor which, processed by the flight management system (FMS), indicated deviations to the pilot in relation to a continuous and stabilised glide slope. The initial objective of these navigation systems in the vertical plane, traditionally known as BaroVNAV (Barometric Vertical Navigation), was to enable a final approach in a continuous descent at a constant slope up to the operational minima of non precision approaches.
In the United States in particular, where there are many non precision runways and therefore a strong exposure to the risk mentioned above, the FAA decided to certify and operationally approve these first navigation applications in the vertical plane with the BaroVNAV systems, through a circular issued in 1988 (AC 20-129. Airworthiness approval of Vertical navigation Systems for use in the U.S. National Airspace System, NAS, and Alaska).
It is important to note that the use of BaroVNAV systems such as those defined in this circular were authorised only as an advisory, with the crew continually controlling its navigation in the vertical plane in relation to information from the altimeter. The first operational applications of the BaroVNAV systems thus began at the end of the 1980s and were aimed at improving the safety of non-precision approaches, for equipped users, mainly wide body aircraft. This type of BaroVNAV operation is approved by the French civil aviation authorities.

1.4. BaroVNAV APV, the second stage in the use of BaroVNAV systems?

1.4.1 Standardisation work for APV/BaroVNAV procedures

The use of BaroVNAV systems might have remained limited to the specific operational context of non-precision approaches. However, the fleet was well-equipped at the end of the 1990s (it can be estimated today that 80 % of aircraft landing at Roissy are equipped with BaroVNAV systems) and it was tempting to propose specific design criteria in the vertical plane for procedures based on the use of these same BaroVNAV systems, meeting the new category of approaches defined by ICAO, the APVs (APproach with Vertical guidance).

ICAO's OCP (Obstacle Clearance Panel) thus began working on this subject, and the first design criteria for APV procedures were published in ICAO's PANS-OPS documents with an effective date of November 2001. However, the obstacle assessment surfaces chosen for these new procedures had initially been defined very cautiously, and the associated minima were quite high, at times even higher than those for existing non-precision approach procedures.

The OCP therefore worked on new criteria that were more efficient, approved recently by ICAO with an effective date of November 2004. The OCP also proposed that the minima corresponding to APV/ BaroVNAV approaches be identified on approach sheets by the term LNAV/VNAV (Lateral Navigation/Vertical Navigation), while the non precision approach minima were identified just by the term LNAV.

The lateral guidance of these APV/BaroVNAV approach procedures can be ensured by certain already standardised area navigation systems (RNAV) for manoeuvres in the horizontal plane in non-precision approaches. In particular, these are systems such as GNSS with ABAS augmentation, or RNAV DME/DME area navigation systems.

Although the fleet is relatively well-equipped, the implementation of APV BaroVNAV procedures by states currently remains a controversial subject. In the context of non precision approaches, the use of BaroVNAV systems to improve safety without changing the operational minima does not seem to pose any major problems. However the use of these BaroVNAV systems to take advantage of more efficient minima, in particular with a reduction of obstacle clearance, was recently questioned by some states, including France.

1.4.2. Difficulties resulting from the operational approval of APV/BaroVNAV by states

There are several reasons for these difficulties. First of all, the main certification regulation today is still the US circular of 1988 mentioned above, according an advisory status to BaroVNAV airborne systems and most baroVNAV systems existing today have been certified versus this document. However, the APV/BaroVNAV approaches are designed as approaches calling for a primary navigation system, with specific requirements and French aircraft certification experts are not able today to certify the new APV baroVNAV versus AC 20 129. Furthermore the required certification criteria to support the new ICAO APV BaroVNAV are not easy to assess.

Another key issue, is related to the integrity of navigation databases, and their corruption by FMS that do not have the required safety levels, which can have disastrous consequences. Also, for all other types of approaches with vertical guidance standardised by ICAO (ILS, MLS, GBAS, SBAS, etc.), there exists a possibility of cross-checking the approach slope of the system transmitting the vertical guidance with the altitude or the barometric height when passing a particular point on the ground during approach. This procedure is important because it helps verify that there is no major error (known as "blunder" error), either on the approach slope of the radio-electric guidance system, or the altimeter setting on which the pilot must rely in order to identify operational minima.

In the past there were numerous examples where this crosschecking procedure helped detect variations in the ILS approach slope caused, for example, by large quantities of snow, a change in the nature of the ground (vegetation, humidity, etc.). There were even errors in the pilot's altimeter settings, a frequent case being an oversight of a change in the QNE 1013 setting to QNH at the transition altitude.

For APV/Baro-VNAV approaches, the barometer is the common source of information for vertical guidance and altimetry. Therefore the possibility of a common failure mode exists, for example a blunder error in altimetry settings may simultaneously affect the approach slope and the operational minima, without the possibility of crosschecking. For this purpose, the ICAO PANS OPS document on the procedures for crews indicates the necessity to implement supplementary systems to limit the impact of blunder errors in ground or airborne altimeter settings on safety. But no standardised methods exist today and some states, including France, feel that more work needs to be done by ICAO.

For these reasons, the PANS OPS APV/BaroVNAV criteria are not included in the French national regulation for approaches, and the difficulties mentioned above will have to be resolved before considering them.

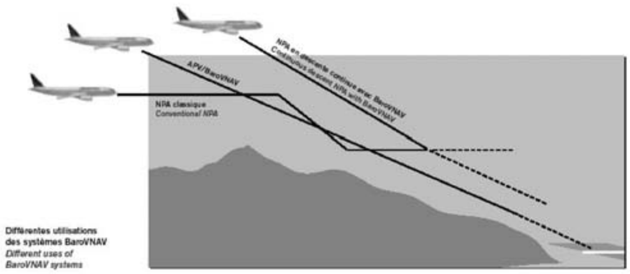

Figure 5. Different uses of BaroVNAV systems.

1.5. GNSS APV, safe and efficient approaches

1.5.1 The main characteristics of APV I - II

Unlike APV/BaroVNAV, the standardisation of GNSS GBAS and SBAS systems by ICAO and the EUROCAE/RTCA airborne equipment industry has included from the beginning the main characteristics of precision approaches, as provided today by ILS.

During the definition of requirements applicable to various GNSS systems, two new performance levels were defined: the approach levels for vertical guidance APV-I and APV-II. Although these performance levels are currently independent of a specific GNSS augmentation, it has been verified that GNSS with large-scale coverage, particularly the augmentations by SBAS geostationary satellites, are compatible with APV I or II.

As an indication, the SBAS system that covers the United States (WAAS) today has a performance level compatible with APV-I, whereas the European EGNOS system, as well as the future Galileo system, were defined to provide APV-II performance level. These APV-I and APV-II requirements were derived from the requirements applicable to Category I, except for those relating to vertical guidance which require, in 95% of cases, a precision of 20 m for APV-I, and a precision of 8 m for APV-II instead of the 6 m required for Cat-I.

It is noteworthy that all other requirements (precision, integrity, continuity of service) are identical to those required for Category I, particularly those relating to lateral guidance. For this reason, at one time it was planned to classify these performance levels as precision approaches, of a category lower than Category I but, when the ICAO classification was extended to APVs, it seemed simpler to use this new class of approaches.

Another important characteristic of SBAS APV-I or II approaches is the standardisation of a data block protecting the entire database required for the final approach segment by a CRC (Cyclic Redundancy Check). This ensures that the SBAS database has a guaranteed high level of integrity during its routing from the information provider to the user and can not be corrupted without detection by the avionics, unlike the databases used for non-precision RNAV and APV/BaroVNAV approaches.

Further, the "ILS look-alike" operational concept was chosen for SBAS approaches by ICAO and the RTCA standardisation committee. In practice, this means that the SBS APV approaches will be very similar to ILS approaches for pilots. This led to the FAA defining this new type of GNSS approaches as LPV approaches, which stands for Localizer Precision with Vertical guidance.

By using the APV-I and II performance characteristics described in Annex 10 and the ILS Look-alike operational concept, the ICAO OCP (Obstacle Clearance Panel) recently defined the design criteria for approach procedures with APV I and II vertical guidance using the SBAS. These will be applicable as from November 2006. The minima corresponding to these APV I or II approaches will be identified on approach sheets by the term LPV (Localizer Precision with Vertical guidance), which has been explained above.

To summarise, the main characteristic of GNSS approaches based on the APVI and II performance levels is therefore to provide geometrical guidance independent of the altimeter, comparable to that provided by an ILS. With the only difference being the lower precision in vertical guidance, it was decided to limit at this stage the minima at 250 ft instead of 200 ft for Cat. I.

1.5.2 Difficulties relating to the equipment-rate for fleets

These technical characteristics are very interesting in practice, as they enable the States to plan for the introduction of vertical guidance with much better safety conditions than those provided by the BaroVNAV systems and improve accessibility to airports due to the possible low minima. The DGAC study presented below confirms this.

Furthermore, unlike the BaroVNAV systems that are reserved for certain aircraft equipped with FMS, the SBAS receivers have been standardised so that they can be installed on all kinds of aircraft, ranging from single-engine aircraft of general aviation to four-jet engine aircraft equipped with Multimode receivers (MMR).

The 11th ICAO Conference on Air Navigation held in September 2003 validated these potential benefits of APV GNSS approaches by recommending the deployment of approaches using the APV-I performance level all over the world, by first using the SBAS GNSS systems. Similarly, the new Approach & Landing Strategy of ICAO Annex 10 (Recommended standards and practices for Aeronautical Telecommunication systems - Volume I, Radio navigation systems), that will come into effect in November 2005, indicates that the worldwide strategy consists in "encouraging operations with APV, particularly those that include GNSS vertical guidance, to improve safety and accessibility".

The main problem that arises today to achieve these operational benefits is linked to the equipment-rate of fleets. As for any new technology, a transition phase to upgrade the airborne equipment is required. For a user equipped with an ABAS GNSS receiver, a minimum of one software update is required to decode the signals from SBAS geostationary satellites. However, to implement the designed APV I or II approaches, as for precision approaches, a higher safety level is needed for the software and refresh rates for data output from the receivers than the one generally required for ABAS receivers. Consequently, a new card is needed, as well as a specific certification of the SBAS function in the multi-mode receiver (MMR) of all equipped aircraft.

At this point, it should also be mentioned that, within the community of users, there is some confusion regarding the common name under the acronym "APV" of APV/baroVNAV approaches and APV I or II GNSS approaches. The aircraft manufacturers and airline companies that have equipped their fleets with baroVNAV systems are inclined, for obvious reasons of investment return, to try and maximise the use of existing airborne systems rather than install new ones.

As explained above, the characteristics of APV/baroVNAV and APV I or II GNSS are in fact very different. However, the aeronautical community is not necessarily very aware of this, and up to now a certain opposition can be observed to the equipping with SBAS sensors by users that are equipped with baroVNAV sensors today. For all these reasons, the upgrading of the user fleet will take time, and it is important to remain proactive while developing APV I or II procedures in order to create a positive dynamic. This is currently the strategy of FAA as well as that of the French civil aviation authorities.

Figure 6. GARMIN receiver compatible with I&II approaches.

1.5.3. GNSS APV, looking ahead

It should not be forgotten that the GNSS APVs are not limited to SBAS. Indeed, the SBAS systems, particularly EGNOS and WAAS, are the first GNSS to have been designed to ensure approaches with vertical guidance meeting the APV-I or II requirements, but other GNSS systems may also eventually provide these performance levels.

For example, there is a new augmentation system with extended coverage, designed as an interconnected network of GBAS stations, which may be operational in Australia in a few years' time - GRAS (Ground Regional Augmentation System). Similarly, the European Galileo constellation project is currently designed to be compatible with APV-II, with a global coverage associated with this level of service.

The work undertaken today at ICAO, in the United States and in Europe to operationally implement the APV I or II SBAS will thus also benefit from the implementation of APV I or II, which could be ensured by other GNSS augmentations. It is for this reason, among others, that the European Commission decided to include EGNOS in the Galileo programme, as it was felt that the operational implementation of APV EGNOS would help the commissioning of APV Galileo, by several years.

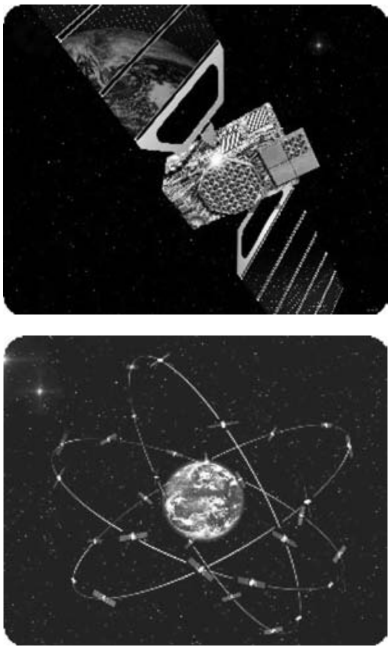

Figure 7. Galileo satellite and Galileo constellation

2.WORK OF THE DGAC APV GROUP

Considering the elements introduced earlier, the French Civil Aviation Air Navigation Directorate (DNA), during the "Navigation Strategy" meeting on 14th May 2002, confirmed its support for the European GNSS Navigation Overlay Service (EGNOS) project and its use for APV approaches meeting the APV- I or II performance levels.

In order to study the operational benefits relating to the improvement in safety and accessibility to airports and to promote the new approaches with vertical guidance (APV) that may be provided by EGNOS, the DNA entrusted STNA with the organisation of a working group on the APV I or II procedures. This working group included experts from different departments of the Direction Générale de l’Aviation Civile (DNA, STNA, SIA, SFACT, ENAC and DAC-SE) as well as from DIRCAM. Eurocontrol and ASECNA also contributed to the activities of the group. This work led to the publication of a report in March 2004 (DGAC study on the operational benefits of APV EGNOS approaches in France - report by the DGAC group, V 2.0 dated 30th March 2004).

Initially, the DGAC APV working group established a list of about twenty French aerodromes for which the APV EGNOS procedures would be potentially useful for resolving operational problems existing today. This was not a definitive or complete list of French airfields where the APV EGNOS procedures could eventually be published, but it represented a

selection of IFR aerodromes in France for which setting up APV procedures would help improve the existing situation in relation to various operational criteria.
The airports chosen for the study were very varied: airports with high traffic density (e.g.: Roissy Charles de Gaulle), medium-sized airports (e.g. Lille) or airports with low traffic. Some overseas airfields, such as Fort de France which may, over a longer period, be covered by an extension of WAAS, or an extension of EGNOS towards Africa (St Denis de la Réunion) were also studied. The study of advantages for the aerodromes concerned was undertaken in collaboration with the Centre-East, North, North-East, West, South and South-West DACs, the West Indies-Guyana Civil Aviation Regional Directorate and the Reunion Island Civil Aviation Department as well as with Paris Airports. The operational objective to be achieved for each of the aerodromes was identified, and in particular the following:

- Lowering the slope on final approach
- Creating a direct approach that does not currently exist with standard navigation resources
- Improving the procedure by proposing vertical guidance - improving safety - and lowering the Obstacle Clearance Height(OCH).
- Proposing a procedure with vertical guidance and low obstacle clearance height(OCH) as a back-up for ILS
- Proposing a procedure with vertical guidance and low obstacle clearance height(OCH) at aerodromes that handle commercial activities
- Improving lateral guidance and proposing vertical guidance in order to satisfy environmental requirements.

In addition to the accomplishment of these operational objectives, a performance analysis of APV EGNOS procedures was carried out. It was agreed that this analysis would be done by calculating the Obstacle Clearance Height (OCH) parameter that represents the minimum height above the threshold level at which an interrupted approach procedure must be initiated in order to respect the obstacle clearance criteria. It was determined by taking into account all obstacles that exceed the obstacle evaluation areas of the APV procedure.
The results of the study showed that the APV EGNOS not only improves the operational context during approach (introduction of GNSS vertical guidance, limiting the slope, introduction of a direct approach, etc.) but can also lead to a lowering of the required minima due to the reduction in the obstacle clearance height (OCH).
Secondly, the group examined all elements required for defining procedures to operationally implement APV EGNOS approaches. The main points discussed covered: the certification of ground and airborne systems, ground infrastructure requirements at aerodromes, aeronautical information relating to the EGNOS system, and the integrity of navigation databases. This work, coordinated with DGAC experts with diverse and complementary skills, helped build up a high level of expertise in France on the new subject of APV. This, in particular, helped positively fuel discussions in this domain within the Eurocontrol and ICAO groups.
The actions recommended by the DGAC APV group on these points were examined by the DNA in September 2004 and they were validated and incorporated in the steering committee's task programme for implementation RNAV approaches. The presidency of the steering committee is ensured by the Safety Directorate and the Directorate of French Air Navigation Services since January 2005.

3. SUMMARY: A FEW POINTS FOR CONSIDERATION

3.1 The current position of the main aircraft manufacturers on APV and GNSS SBAS

Over the last decade, Airbus and Boeing have opted to invest in GNSS ABAS technologies (Airborne Based Augmentation System - with BaroVNAV) and GBAS (Ground Based Augmentation System). This has naturally led the aeronautical industry to strongly promote these two systems, particularly to ICAO, as well as to Eurocontrol and the FAA.
As mentioned above, the use of GNSS ABAS with vertical navigation of the BaroVNAV type presents a definite potential improvement in the safety of non-precision approaches. However, the extension of the use of BaroVNAV systems in an operational APV context, particularly aimed at reducing the clearance margins to attain lower operational minima, raises many questions relating to the safety of these approaches.
Resolving these questions and addressing certification issues will take time, considering the great disparity in systems currently deployed. Furthermore, the GBAS which seemed to have a bright future as the designated successor of ILS about ten years ago, is currently affected by a conjunction of several factors:

- There is still a high density of conventional Cat I systems, particularly ILS, and their dismantling is not envisaged in the near future,
- If the ILS are maintained, the APV I or II SBAS is today an efficient system that is supplementary to and competes with the GBAS system, as Galileo will be tomorrow,
- The Cat I GBAS was the first step towards Cat II/III GBAS, but there are some doubts about the planning of Cat II/III (international implementation of GBAS Cat II/III is not currently envisaged prior to 2015) and its future architecture.

It is therefore not certain whether the clients of Airbus and Boeing will be able to take full advantage of the benefits promised by the two technologies - ABAS BaroVNAV and GBAS - at least in the foreseeable future.
On the other hand, the SBAS signals have been IFR approved in the United States since 2003 and should be approved in 2006/2007 in Europe. Other SBAS projects are being developed: the coverage of WAAS has been extended to Canada and Mexico, MSAS in Japan, GAGAN in India, extension of EGNOS in Africa, etc. In spite of all these elements, Boeing still seems to oppose SBAS by justifying that APV BaroVNAV provides an equivalent performance level. As already explained in this article, this point of view is not shared by the DGAC experts. Airbus, for its part, has launched a study to identify the potential advantages of SBAS and assess the impact of integrating SBAS into the MMR multi-mode receiver, but is not at this stage very active on this subject.
If the integration of SBAS receivers on board general aviation and business aviation is relatively simple to implement, it is now quite possible that, considering the delay involved, the integration of the SBAS on board wide-body aircraft may be done mainly with the migration of current GPS sensors to new generation sensors that will be multi-constellation (Galileo/GPS) and multi-frequency while including basic SBAS function. This will ensure increased dependability and improved performance levels. These new generation sensors are currently being studied by Eurocae Working Group 62 (in coordination with the RTCA group SC 159) and the first standards are planned for 2007/2008. However the risk of this strategy is that the date of APV operational validation of Galileo services is quite difficult to estimate now, and could well slip a several years after 2010.

3.2. The current position of main European service providers on SBAS

The main European aviation navigation service providers coordinated their position on the subject of GNSS approaches in 2004 when these activities were being defined in the Navigation domain of Eurocontrol. The views that were submitted to Eurocontrol are similar to those stated in this article, i.e. a special interest in implementing APV EGNOS approaches as a supplement to ILS.

3.3. Deployment of SBAS (WAAS) approaches in the United States

The setting up of approaches using GPS (with a GNSS ABAS type augmentation) is an old story in the United States, as the first approaches were published in 1994. Today, most IFR rated runways have a non-precision GNSS approach, i.e. about 3,300 runways - which is a considerable number. About 700 of these runways are also equipped with the possibility of a APV/BaroVNAV approach, with reduced minima. (Note that the United States uses specific procedure design criteria different from those of ICAO's PANS OPS, and the problems raised by APV BaroVNAV introduction in Europe as discussed here are different than in the US).
The WAAS system was approved for IFR use by the FAA in June 2003. There are currently about 200 procedures based on the APV I performance level provided by WAAS, with an objective of 300 procedures publication per year, starting in fiscal year 2006. The ultimate goal is to cover all capable US runways, with WAAS vertical guidance and

approach minima close to 250 ft. The FAA also approved the use of WAAS receivers to build 700 existing APV/BaroVNAV approaches, with minima close to 350 ft. In the United States, general aviation today is the community of users that is most concerned by these new approaches, with WAAS helping improve the safety and accessibility to airports by efficient vertical guidance and a reduced airborne installation cost.

Figure 8. Typical RNAV approach chart showing minima for APV-I with SBAS (LPV), APV/BaroVNAV (LNAV/VNAV) and NPA/GPS (LNAV)

3.4. The deployment of SBAS (EGNOS) approaches in France and in Europe

Activities aimed at the deployment of GNSS approaches in Europe have, until now, been rather limited in comparison with the United States in particular. This may be explained by the high density of conventional means in Europe, thus a lesser need for RNAV than in America and due to economic reasons relating to the Eurocontrol organisation, which, in the past, included two separate GNSS and Navigation entities. In 2003/2004, the merging of these two domains and the consideration of directions desired by the main European service providers helped make progress on these subjects.

This resulted particularly in the definition of ECIP (European Convergence and Implementation Plan) type convergence objectives for the 2005 plan, concerning the various possible types of GNSS approaches (NPA, APV, and Cat I). Furthermore, the European commission decided in 2004 to finance 50 % of Eurocontrol's activities relating to the preparation and operational implementation of APV EGNOS, through a TEN (Trans European Networks) contract coming into effect in 2005, for a period of three years. The activities identified by the DGAC APV EGNOS group were included in this project, as well as activities relating to the certification of EGNOS and promotion initiatives for users (e.g. for regional airlines).

In France, the strategy approved today by the new French Civil Aviation Service Provider (DSNA) for implementing approaches based on area navigation (RNAV) GNSS and the introduction of APV vertical guidance relies on two stages:

- Initially, non-precision approaches based on GNSS ABAS for lateral guidance will be published. Vertical guidance may advised by BaroVNAV systems for equipped aircraft, up to the minima of non-precision approaches. The first procedure was issued in Lille at the end of 2004, andt will be followed by about forty procedures at selected airfields in Metropolitan France and overseas territories.
- Secondly, APV approaches will be introduced for all users with APV I or II EGNOS, which will help improve safety and minima in relation to non-precision approaches (NPA). This second step is conditioned to the existence of a stable EGNOS system.

Concerning the alternative systems supporting RNAV vertical guidance, as long as the questions relating to the certification and safety of APV/BaroVNAV approaches indicated in this article are open, this type of approach is not likely to be authorised within French airspace. A GBAS Cat I is currently deployed at Toulouse-Blagnac airport to enable Airbus certifications. The deployment of other GBAS stations is not currently planned in metropolitan France, while it could be introduced in some overseas territories (outside SBAS coverage).

ABAS : Airborne Based Augmentation System
APV : APproach with Vertical guidance
ASECNA : Agence pour la sécurité de la navication aérienne en Afrique
ASQF : Assurance Specific Qualification Facility
BaroVNAV : Barometric Vertical NAVigation
CFIT : Controlled Flight Into Terrain
CRC : Cyclic Redundancy Check
DAC : Direction de l'Aviation Civile
DGAC : Direction Générale de l'Aviation Civile
DIRCAM : DIRection de la Circulation Aérienne Militaire
DNA : Direction de la Navigation Aérienne
DME : Distance Measuring Equipment
EGNOS : European GNSS Navigation Overlay Service
ENAC : Ecole nationale de l'Aviation Civile
EWAN : EGNOS Wide Area Network
FAA : Federal Aviation Administration
FANS : Future Air navigation Systems
FMS : Flight Management System
GBAS : Ground Based Augmentation System
GNSS : Global Navigation Satellite System
GPS : Global Positioning System
GRAS : Ground Regional Augmentation System
ILS : Instrument Landing System
LNAV : Lateral NAVigation
LNAV/VNAV : Lateral and Vertical NAVigation
MCC : Master Control Center
MLS : Microwave Landing System
MMR : Multi Mode Receiver
NLES : Navigation Land Earth Station
OACI - ICAO : Organisation de l'Aviation Civile Internationale - International Civil Aviation Organisation
OCH : Obstacle Clearance Height
PACF : Performance Assessment and Check-Out Facility
PANS OPS : Procedures for Air Navigation Systems Operations
PAR : Precision Approach Radar
RNAV : aRea NAVigation
RIMS : Ranging and Integrity Monitoring Station
SBAS : Satellite Based Augmentation System
SIA : Service de l'Information Aéronautique
SFACT : Service de la Formation Aéronautique et du Contrôle Technique
STNA : Service Technique de la Navigation Aérienne
VOR : VHF Omni Range
WAAS : Wide Area Augmentation System