

**POTENTIAL BENEFITS OF
DEPLOYING A GROUND BASED
AUGMENTATION SYSTEM (GBAS) AT
STOCKHOLM ARLANDA AIRPORT**

Pre-Project Report

Review

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List of Abbreviations

Abbreviation	Description
AAL	Augmented Approaches to Land
ABAS	Aircraft Based Augmentation System
ACC	Area Control Centre
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATCC	Air Traffic Control Center
ATCO	Air Traffic Controller
ATM	Air Traffic Management
CAA	Civil Aviation Authority
CAT I	Category I
CAT II	Category II
CAT III	Category III
CNS	Communication, Navigation, Surveillance
DS	Double Slope
DSU	Declaration of Suitability for Use
EC	European Commission
EFVS	Enhanced Flight Vision System
ENRI	Electronic Navigation Research Institute
EU	European Union
FAS	Final Approach Segment
FMC	Flight Management Computer
GAST	GBAS Approach Service Type
GBAS	Ground Based Augmentation System
GLONASS	Globalnaja Navigatsionnaja Sputnikovaja Sistema
GLS	GBAS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
G/S	Glide Slope
HMI	Human-Machine Interface
IGS	Increased Glide Slope

Airport
Stockholm Arlanda Airport
Swedavia ATM

 Prepared by
The GBAS Project Group
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Reference

Abbreviation	Description
ILS	Instrument Landing System
ICAO	International Civil Aviation Organization
KPA	Key Performance Area
MRAP	Multiple Runway Aiming Points
NM	Nautical Mile (1 NM=1,852 km)
NSA	National Supervisory Authority
NPA	Non-Precision Approach
OFZ	Obstacle Free Zone
OSED	Operational Services & Environment Description
PA	Precision Approach
PANS-OPS	ICAO Procedures for Air Navigation Services – Aircraft Operations
RF	Radius to Fix
RNAV	Area Navigation
RNP	Required Navigation Performance
RNP AR	Required Navigation Performance – Authorization Required
PBN	Performance Based Navigation
SARPs	Standards and Recommended Practices
SESAR	Single European Sky ATM Research
SBAS	Satellite Based Augmentation System
SFO	San Francisco International Airport
SIS	Signal in Space
SVGS	Synthetic Vision Guidance System
TAP	Terminal Area Path
TMA	Terminal Maneuvering Area
ToD	Top of Descent
VDB	VHF Data Broadcast
VHF	Very High Frequency
xLS	x Landing System

EXECUTIVE SUMMARY

This report is part of a pre-project study to investigate the possible benefits and the road to implementation for GBAS operations at Stockholm Arlanda Airport. The report was created jointly by Swedavia, Indra Navia, LFV and Novair. The project members have extensive competence in the areas of airport operations, Air Traffic Control, flight operations, environmental issues, international legislation and national regulations as well as technical aspects of the GBAS system.

The study describes how GBAS functions and how GBAS operations relate to current operations. It describes a number of different applications of GBAS that can be used to improve air traffic management. A number of similar efforts in Europe and the USA are described. It goes on to explain how GBAS operations can be approved and implemented on a generic level.

A site where it is feasible to position a GBAS ground station at Stockholm Arlanda Airport has been identified and an implementation project to progress towards implementations has been examined. The study proposes that a GBAS installation be implemented at Stockholm Arlanda Airport in a stepwise manner in order to provide full GBAS operations at the airport which fully exploit the potential benefits identified in this report.

The most promising GBAS benefits that can be expected for Stockholm Arlanda Airport are primarily those that can reduce noise in specific areas using curved approaches, variable approach angles and/or multiple runway aiming points.

From an ATC perspective it is deemed feasible to commence GBAS validation flights during periods of low traffic intensity in the coming years. However, performing curved operation in combination with GBAS in higher traffic intensity, mixed with traffic using straight-in approaches will be challenging.

Airline operators find that an implementation of GBAS approach procedures and even more advanced GBAS procedures at Stockholm Arlanda Airport can be considered feasible, valuable and necessary. They see that the limiting factor will be the aircraft equipage rate which is nevertheless assumed to increase if incentives are clearly visible.

GBAS technology is still under development and the market is still to be considered as immature. However, through testing and studies in the framework of SESAR, GBAS technology has shown the capability to also provide a number of operational benefits which are well worth further investigation.

1 INTRODUCTION

GBAS – an acronym for Ground Based Augmentation System – is a system enabling Precision Approaches (PA) to an airport that could be used instead of the commonly used Instrument Landing System (ILS). GBAS augments available satellite signals and transmits corrections to the approaching aircraft in order to improve the accuracy of, and provide integrity for, aircraft satellite navigational position.

It is technically possible to combine a GBAS Landing System (GLS, aircraft on-board flight guidance system) in the latter phase of flight with satellite based arrival and approach routes to avoid overflying noise sensitive areas. GBAS can support increased usability of curved approach procedures. In addition, the technology supports lower operating minima, compared to traditional curved approaches. GBAS therefore enables operations under lower visibility conditions. The GBAS technology also has the potential to provide greater flexibility in using variable approach path angles compared to today's ILS approaches, which potentially could help decreasing the noise levels on ground. If so, and to what extent, needs to be further analyzed.

This report is part of a pre-project study, carried out jointly by Swedavia (Anette Näs), Indra Navia (Linda Lavik, Hugo Moen, Sven Sethfors), LFV (Lars Rappich) and Novair (Andreas Linnér) providing competence in the areas of airport operations, Air Traffic Control, flight operations, environmental issues, international legislation and national regulations as well as technical aspects of the GBAS system.

1.1 Background

The background and rationale of this pre-project study is that a historic ban of straight-in approaches¹ to runway 01R at Stockholm Arlanda Airport was replaced by a court decision in 2014. This stated that the central parts of Upplands Väsby (a town south of Arlanda) should be avoided when approaching runway 01R, whenever feasible and that non straight-in approaches (curved approach paths) should be used when possible, considering the weather conditions, maintaining airport capacity and operating within ATM and safety regulations. The Airport Operator – Swedavia – is, according to the court decision, required to continuously work on noise reduction measures in order to relieve noise exposure around the airport and to develop a system that allows for curved approaches to runway 01R, see Figure 1.

¹ A straight-in approach is flown along the extended centre axis of the landing runway.

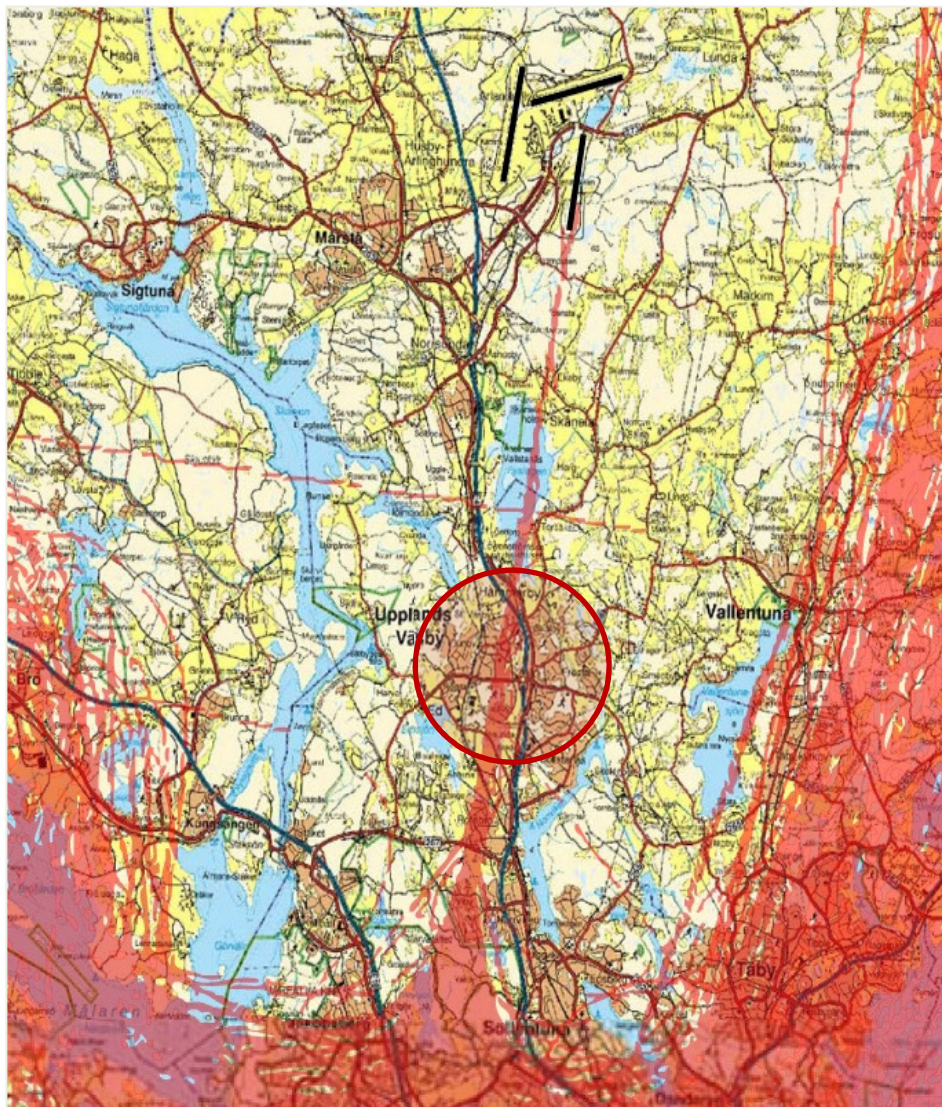


Figure 1: Straight-in ILS-approaches to Runway 01R at Stockholm Arlanda Airport overflying Upplands Väsby.

Aviation noise is an issue that almost all airports have to address. Potential solutions for either avoiding overflight of populated areas or for lowering the noise exposure are to a large extent generic and might be implemented at any airport. For an airport of Arlanda's complexity and traffic intensity, the challenges in finding a solution that could be put into operation are of course higher.

In current operations at Stockholm Arlanda Airport, straight-in Precision Approaches (PA) are predominately used. These are performed by using a ground based navigation system, called Instrument Landing System (ILS) which gives lateral and vertical guidance for the aircraft and the flight crew. Precision Approaches are further divided into three different Categories (CAT), denoted CAT I, CAT II and CAT III, distinguishing between the level of precision available in reduced visibility conditions.

Curved approaches are typically linked to non-linear lateral trajectories, followed by a straight segment during the final approach phase, i.e. just prior to landing. Today, there are curved approaches available to Runway 01R and Runway 26 at Stockholm Arlanda Airport. Curved Approaches are not Precision Approaches and therefore have higher operating minima. They belong to an approach category known as Approach Procedures with Vertical Guidance (APV).

An Instrument Approach is composed of four different segments:

1. Initial Approach Segment

This provides a method to align the aircraft with the intermediate or final approach segment and to permit descent during the alignment. It begins at an Initial Approach Fix (IAF) and ends at the Intermediate Fix (IF).

2. Intermediate Approach Segment

Positions the aircraft for the final descent towards the runway. Begins at IF and ends at Final Approach Fix/Point (FAF/FAP). Usually aligned within 30° of the Final Approach Segment.

3. Final Approach Segment

Final descent towards the runway. Begins either at FAF/FAP and ends either upon landing or if conducting a Missed Approach Procedure (MAP).

4. Missed Approach Segment

In case the approach must be discontinued. Begins where the approach is discontinued and ends at a point where the initial or en-route segment begins.

1.2 Scope

This pre-study aims to provide an overview of the possible benefits of operating a GBAS station at Stockholm Arlanda Airport. A site survey that was conducted suggests the appropriate site for a GBAS station installation, focusing on enabling a decrease in noise exposure when Runway 01R is in use for arrivals. The study states the preconditions necessary for a fully operational test installation at Stockholm Arlanda Airport and identifies which steps should be taken to gain the potential benefits of a GBAS station.

The study identifies areas where further research is needed; taking into account results from the recently finished European SESAR 1 program, and its associated Projects 6.8.5 and 6.8.8. The proposed next steps at Stockholm Arlanda Airport are also aligned with activities in the ongoing SESAR 2020 projects.

1.3 Summary of Results

A local siting study has been performed in the context of this pre-project. A site where it is feasible to position a GBAS ground station has been identified (Section 6.2), and an implementation project is proposed as a follow up to this pre-project. It is proposed that a GBAS installation should be implemented at Stockholm Arlanda Airport in a stepwise manner in parallel with the operational

considerations and assessments that are required in order to provide a full GBAS operation at the airport that exploits the potential benefits identified in this report.

GBAS benefits from a general point of view are discussed in Sections 3 and 4. The most promising benefits that can be expected for Stockholm Arlanda Airport are primarily those that can reduce noise in specific areas, more specifically curved approaches, variable approach angles and multiple runway aiming points. In the longer term, introducing GBAS may replace aging technologies and non-optimal approach procedures for some runways – such as runway 08 – at Stockholm Arlanda Airport.

From an ATC perspective it is deemed feasible to commence GBAS validation flights during periods of low traffic intensity (off-peak) in the coming years. However, performing curved operations using GBAS during higher traffic intensity straight-in approaches is challenging and highly dependent on a number of factors (see Section 5.2).

The exploration of GBAS including both straight-in GBAS approach procedures and enhanced, more advanced GBAS procedures at Stockholm Arlanda Airport is considered feasible, valuable and necessary by the airline operators. As indicated later in this report, the move from ILS procedures will most likely be seamless and is not expected to introduce any drastically increased needs of training, safety considerations etc. for airlines. The limiting factor will be the aircraft equipage rate. However this rate is assumed to increase if incentives such as enhanced procedures and increased accessibility to the airport are clearly visible.

GBAS technology is still under development and the market is still to be considered as immature when it comes to manufacturers, European certification organizations and aircraft equipage. GBAS technology has, however, through testing and studies in the frame of SESAR, shown the capability to also provide a number of operational benefits such as avoidance of overflying noise sensitive areas and flexible approaches.

2 SATELLITE NAVIGATION

This section gives a brief background of how air navigation has developed over the years. The aim is to give the reader an understanding of why satellite navigation has become the primary means to facilitate a safe, efficient and sustainable operation, including the rationale behind using augmented satellite systems, such as GBAS.

2.1 Historic Background

Air navigation has changed dramatically since the first flight. In the very beginning, visual references on the ground were the only means to navigate, which meant that flights were fully dependent on visual conditions. In the U.S. in the early 1920s, lighted beacons in combination with arrows on the ground, were used to facilitate a more robust operation for the airmail service (“Transcontinental Airway System”).

The next and very important step was the introduction of radio beacons transmitting radio signals. Aircraft could then receive the radio signals and navigate towards the beacon by displaying deviations to/from the signal on an instrument onboard. The limitation of flying only in good weather and visibility was hence decreased. This is today known as “conventional navigation”.

Further development and ground installations enabled radio beacons to be linked together in various networks, forming specific routes that aircraft could follow. The precursor of today’s world-wide airway system was born.

Further development of airway system(s) has been focused on enhancing the use of radio beacons by linking them together more efficiently. Initially, aircraft had to fly from beacon to beacon (point-to-point) to be able to navigate to their final destinations. This has been modernized over the years by identifying crossing points (“waypoints”) by latitude and longitude within the route network and thereby defining a route structure that does not require point-to-point navigation, but where a change in direction instead can be made at these specific points. For example, today it is not necessary to actually overfly a specific radio beacon. This is known as Area Navigation (RNAV). Initial steps within RNAV did not have on-board requirements of identifying deviations from the intended route, meaning the aircraft could drift off while approaching a new waypoint without any alert, hence increased separation between aircraft was needed. The development of on-board RNAV systems – for modern aircraft – today includes a requirement of on-board monitoring and alerting if any deviation from the intended route is discovered. This is known as Required Navigation Performance (RNP), i.e. where an airspace, route, approach etc. is defined as RNP (instead of RNAV) there is a requirement of on-board monitoring and alerting for aircraft operating within this context.

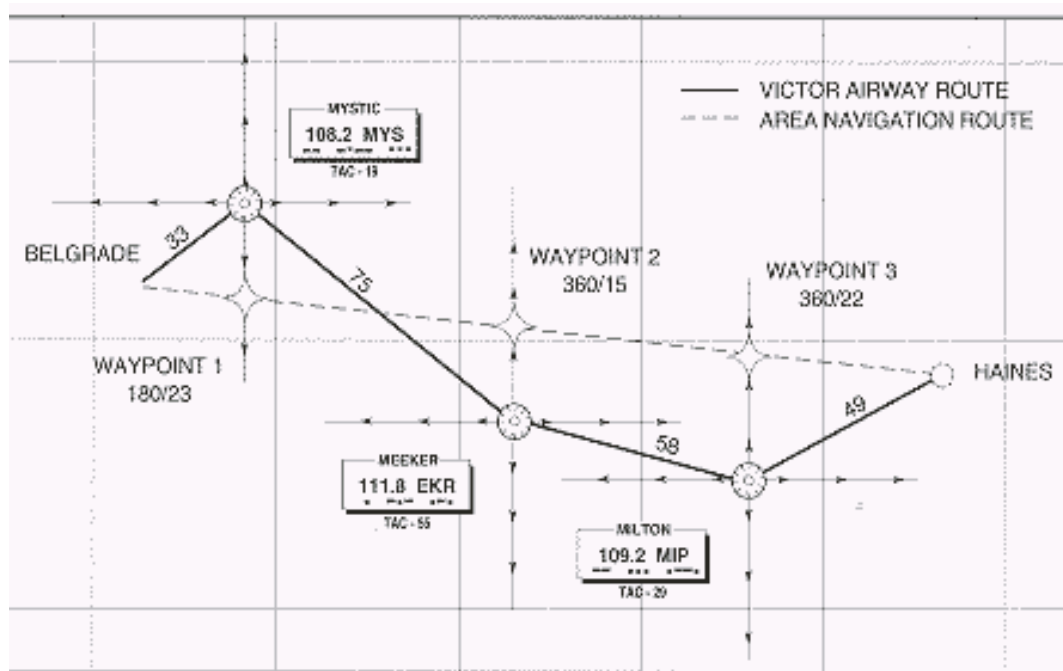


Figure 2 Area navigation (RNAV) route

Ground-based radio beacons still play an important role to maintain the established and global route network. However, the ground-based network was initially developed with the aim to enable navigation without visual references, and not necessarily to enhance airspace capacity. Furthermore, as radio beacons are ground based, there are obvious constraints and limitations in terms of surrounding environment. Therefore, being dependent on this type of infrastructure, the airway system cannot be fully optimized. Radio coverage (signal transmission) is normally also limited by line-of-sight, meaning the aircraft cannot conduct the flight too far from a radio beacon before the signal is lost, if navigating point-to-point (i.e. beacon to beacon).

In addition to the costly preservation and maintenance of radio beacons, the infrastructural limitations have driven air navigation towards satellite-based navigation as the primary mean to facilitate a more optimized and capacity efficient airspace.

2.2 Satellite-Based Air Navigation System

A satellite navigation system is a system of satellites providing geo-spatial positioning, which is the technical term for a specific location on or above the earth in three dimensions. A satellite navigation system receiver can be used to determine latitude, longitude, altitude, velocity and time information. The satellites broadcast a signal containing orbital data and the exact time the signal is transmitted. The receiver compares the time of broadcast encoded in the transmission with the time of reception, thereby measuring the time difference and hence the distance can be calculated.

By calculating distance from several satellites at the same time, the receiver can use triangulation to determine its location. To establish position accuracy, the receiver needs to be able to track a minimum of four satellites (latitude, longitude, altitude and time). However, the more satellites the receiver can track, the better the location accuracy will become.

Basic triangulation is not very complicated; however all navigation systems have inaccuracies inherent in them. Typical sources of inaccuracies in satellite navigation systems are errors in satellite clocks and orbital parameters as well as signal propagation errors such as deflection in the ionosphere and troposphere. This is one reason why ground and space based augmentation systems are used (GBAS or SBAS respectively).

The main reason for applying augmentation systems in the most critical phases of flight is integrity. The integrity of a navigation system is the probability that the navigator can actually rely on the information provided. None of today's satellite navigation systems have, on their own, the integrity required by ICAO for the most critical phases of flight (approach and landing). The most important task of the augmentation system is therefore to detect any potential errors in the satellite system that the augmentation system will be unable to compensate for, and warn the aircraft system.

2.3 Global Navigation Satellite System – GNSS

The term GNSS refers to a constellation of satellites providing signals from space transmitting positioning and timing data (as described in Section 2.2 above). By definition, GNSS provides global coverage. There are a few different satellite systems included in the term GNSS that are in operation today, and several more systems are under development.

GPS

US NAVSTAR Global Positioning System (GPS) is the primary GNSS in use today. It was developed by the US military in the 1970s and was fully operational in the 1990s. GPS contains 31 satellites covering the entire globe.

GLONASS

GLONASS (Globalnaja Navigatsionnaja Sputnikovaja Sistema) is the Russian GPS equivalent operational with global coverage since 2011. Commercial products with possibilities to receive GLONASS signals have been on the market since 2011-2012. Normally, these products also include GPS receivers.

GALILEO

Europe is in the process of launching its own independent and global GNSS, Galileo. Fully developed, the system will consist of 24 operational satellites with 6 additional as back-up. System completion is scheduled for 2020. Galileo will be interoperable with GPS and GLONASS and as it will provide dual frequencies as standard (enabling higher redundancy and robustness to ionospheric disturbances compared to single frequency transmission) the system will deliver real-time positioning with very high precision (accuracy within a meter).

BeiDOU-2

China has indicated plans to complete the entire second generation Beidou Navigation Satellite System (BDS or BeiDou-2, formerly known as COMPASS), by expanding current regional (Asia-Pacific) service into global coverage by 2020. A 16 satellite regional version (covering Asia and Pacific area) was completed by December 2012.

Additional GNSS

There are other GNSS in development throughout the world, however only for regional coverage at this point (e.g. India, Japan, Australia etc.) and therefore not addressed in this report.

Table 1 – GNSS summary

	Number of satellites	Owner	Precision	Status
US NAVSTAR Global Positioning System	31	USA	±5m	Fully operational since 1991
GLONASS	24	Russia	±4.5-7.4m	Operational since 2012
Galileo	24 + 6	EU	±1m	Scheduled for 2020
BEIDOU-2	Currently 16, planned 35	China	±10m	Planned operational by 2020

3 GBAS

As described in Section 2.2, using only GNSS will provide accuracy and integrity to provide horizontal positioning for most parts of the flight, i.e. en-route and part of the departure and arrival. However, during approach and landing, especially in low visibility conditions, standalone GNSS is not sufficient to facilitate the required accuracy and integrity within the required limits. Therefore additional systems to enhance and augment GNSS are required. Ground Based Augmentation System (GBAS) is such a system. GBAS is expected to provide airport operations in any weather condition. In addition, it has a great potential of enhancing departure and approach procedures well beyond today's traditional airspace configuration.

3.1 General

GBAS is a high integrity concept based on differential GNSS system where the GBAS station, located at the airport, transmits differential corrections to incoming aircraft. The concept is currently standardized for GPS, but will be expanded to augment other GNSS systems in the future. Based on corrections from the GBAS station and the GNSS signal received directly from the satellite system, the aircraft is able to achieve a higher accuracy, availability and continuity than via traditional GNSS systems.



Figure 3 Illustration of the GBAS System.

In addition to the differential corrections, the GBAS station also sends Final Approach Segment Data (FAS Data) to the aircraft. The FAS data provides the landing path for the actual approach path used by an incoming aircraft. One GBAS ground station is able to transmit up to 48 different FAS data packages at

the same time, and is therefore able to serve several runway ends at an airport simultaneously.

GBAS used as a PA landing system is not dependent upon large antenna arrays at the end of each runway like the ILS. GBAS only requires reception of GNSS data and transmission of data messages. The GBAS station can therefore be placed in any area of the airport that is practically possible. Since just one GBAS station is necessary to cover several runway ends, less infrastructure is needed at the airport, which reduces the need for periodic flight calibration as well as maintenance cost compared to a traditional ILS solution for the same runways.

Due to the nature of the system, the integrity and accuracy of the signal is not dependent on the environment.

GBAS is categorized in several Approach Service Types, so called GAST categories. Each category has its own characteristics as shown in Table 3 below.

Table 1: GBAS Approach Service Type (GAST) characteristics.

GBAS System	Capable Category	Frequency	GNSS Systems	Approvals
GAST C	CAT I	Single	GPS	FAA approved
GAST D	CAT I to CAT III	Single	GPS	2021/2022 SARPS ² approved
GAST F	CAT I to CAT III	Multi	GPS+ Galileo	2030+

The terms CAT I, CAT II and CAT III are ICAO defined terms associated with PAs that categorize the minimum visibility for a specific runway in which aircraft are allowed to land. The Category of a specific operation is determined by several elements, including runway equipage, airport procedures, aircraft equipage and flight crew training. CAT I operations require a certain visibility at the runway when the aircraft is at 200 ft above ground. CAT III is the most demanding operation, and can be used during much lower visibility, and only in the horizontal dimension for deceleration on the runway after landing as well as for taxiing. The current standards cover operations up to and including CAT IIIB, which does not cover taxiing.

3.2 GBAS Characteristics

The GBAS characteristics described below are compared to the ILS system which is the dominant PAs used today.

² Standards and Recommended Practices, see Section 3.3.

2.5°	230	3425	4650	170	3050	4650	120	1900	4600
3.0°	200	2800	3850	160	2675	3850	110	2100	3800
3.5°	180	2375	3250	140	2275	3250	105	1900	3250
4.0°	160	2075	2850	130	2000	2850	100	1725	2800
4.5°	140	1925	2550	120	1800	2550	90	1675	2450
5.0°	130	1650	2250	110	1600	2250	85	1550	2200
5.5°	120	1525	2000	100	1475	2000	85	1475	1950
6.0°	110	1375	1950	100	1375	1850	80	1350	1800

When operating GBAS, the obstacle free zone determines the point at which landing clearance can be given to an approaching aircraft. Therefore, other flight operations determine required separation, not sensitive areas.

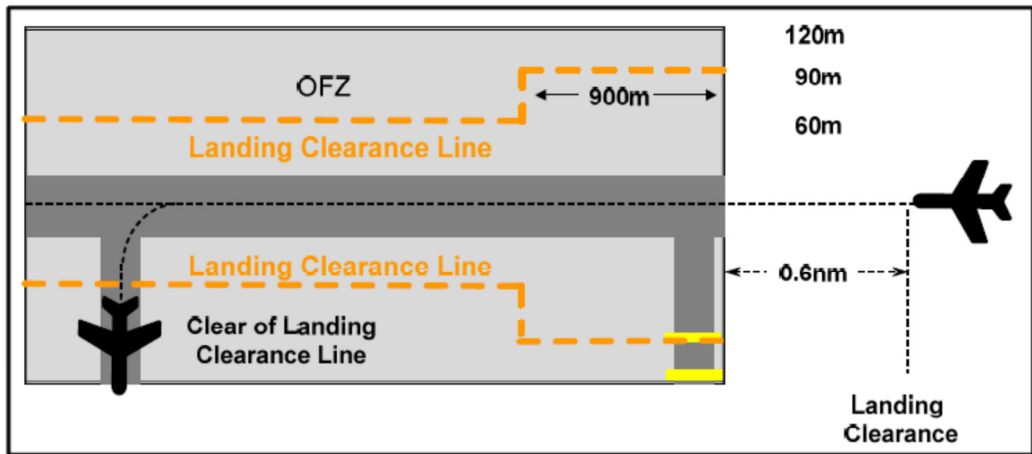


Figure 5 Evacuation of runway with aircraft operating on GBAS on approach

3.2.2 Increased Glide Slopes (IGS)

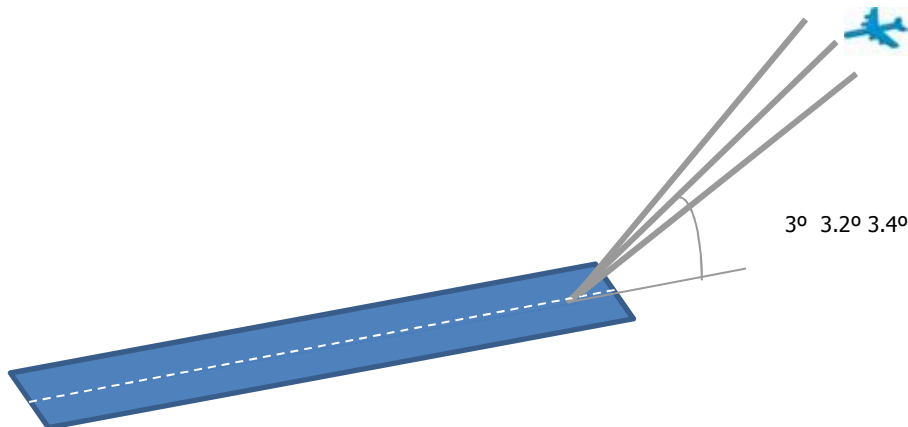


Figure 6 Increased Glide Path Angles.

GBAS technology provides the possibility to vary the glide slope angle, per approach or set of approaches, instead of the non-adjustable angle currently provided by the ILS. Figure 6 shows an example of three different glide slope angles (3°, 3.2° and 3.4°). Potential benefits of increased glide slope angles are changes in noise contours underneath the flight path and also a potential capacity increase due to less stringent wake turbulence separation if different angles for different approaching aircraft are applied. For example, light aircraft could follow an increased glide slope angle behind heavy aircraft on lower glide slope angle. This could potentially reduce the required separation due less risk of wake vortex encounter, i.e. light aircraft flies above dispersing wake vortex from heavy aircraft.

3.2.3 Multiple Runway Aiming Points (MRAP)

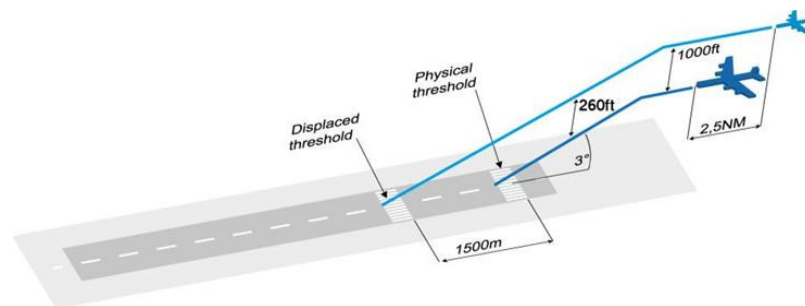


Figure 7 Multiple Runway Aiming Points

GBAS can also provide different threshold aiming points (Figure 7) and could thereby provide potential benefits in terms of increased capacity (reduced separation), noise mitigation etc. similar to IGS discussed above. Using diverging runway aiming points between different aircraft categories (e.g. light, heavy) it may be possible to sequence aircraft more efficiently as lighter aircraft can have their final approach path above dispersing wake vortex from heavier aircraft.

3.3 GBAS Approval Process

The GBAS concept has been standardized by ICAO³ and EUROCAE⁴ for CAT I operations. EUROCONTROL has developed a Concept of Operations and a Preliminary System Safety Assessment for GBAS CAT I operations.

³ International Civil Aviation Organisation

⁴ European Organisation for Civil Aviation Equipment. EUROCAE documents are widely referenced as a means of compliance to European Technical Standard Orders (ETSOs) and other regulatory documents.

ICAO has also drafted a Baseline Development SARPs (Standards and Recommended Practices) for GBAS CAT III. The draft SARPs for GAST D/CAT III has been subjected to an extensive validation process in the context of ICAO and SESAR. The draft documentation was endorsed by the ICAO Navigation Systems Panel in November and December 2016. It is currently in the process of being issued as basis for a State Letter. The process of developing a State Letter is expected to be completed early fall 2017. Assuming that the current draft documentation is approved in this process, it is expected to become effective late 2018.

Several relevant documents addressing GBAS CAT III have been produced within SESAR 1. The operational aspects related to GBAS were addressed in the projects SESAR 6.8.5 and SESAR 6.8.8. Another document of interest is the CAT III/GAST D Concept of operation. In addition, some specific documents related to different types of advanced operations are available from SESAR 6.8.5. One document of particular interest is the Operational Services & Environment Description (OSED) for RNP Transition to GLS, see Section 4.3.4. Swedavia, LFV, Indra Navia AS and Novair have all been involved in the SESAR 1 work and therefore have access to these SESAR deliverables. On the basis of these and other developments, ICAO will amend additional regulations to cover GAST D operations, for instance, ICAO PANS OPS (ICAO DOC 8168) will be included to update these procedures in 2020.

Although an operational approval process is not within the scope of this pre-project, a brief overview of a typical approval process and associated regulations are outlined below.

Typically, in order to enter new ATM/CNS equipment into operation, the Interoperation regulation, EC 552/2004 applies. The manufacturer issues a Declaration of Suitability for Use (DSU), which in effect, is a compliance statement towards the requirements of EC 552/2004. Typically, the manufacturer agrees with the service provider and the NSA⁵ which lower level standards and requirements need to be complied with, in order to declare compliance with EC 552/2004 for a specific type of equipment. For GBAS, the lower level standards that form part of the Acceptable Means of Compliance are identified in Eurocae ED-114, and other European regulations such as the R&TTE directive. . The service provider and the NSA may, and for new types of safety critical equipment typically also typically will, perform audits of the manufacturer's compliance material against the detailed standards and requirements. If the particular equipment has been approved in another European country, the service provider and NSA may choose to rely, more or less, on approvals from this country.

⁵ National Supervisory Authority – e.g. Transportstyrelsen

Based on the DSU from the equipment manufacturer, as well as internal activities in order to bring the system into operation and ensure that the operation will be safe, the service provider will issue a Declaration of Verification in accordance with EC 552/2004 and associated guidance issued by EUROCONTROL. Figure 8 gives a high level overview of the activities involved. The approval process in 1.C includes an operational safety assessment, proving that the ANSP has the adequate training and procedures in place to safely manage the operation. One important regulation in this process is EC 1035/2011 – Common Requirements for the Provision of Air Navigation Services.

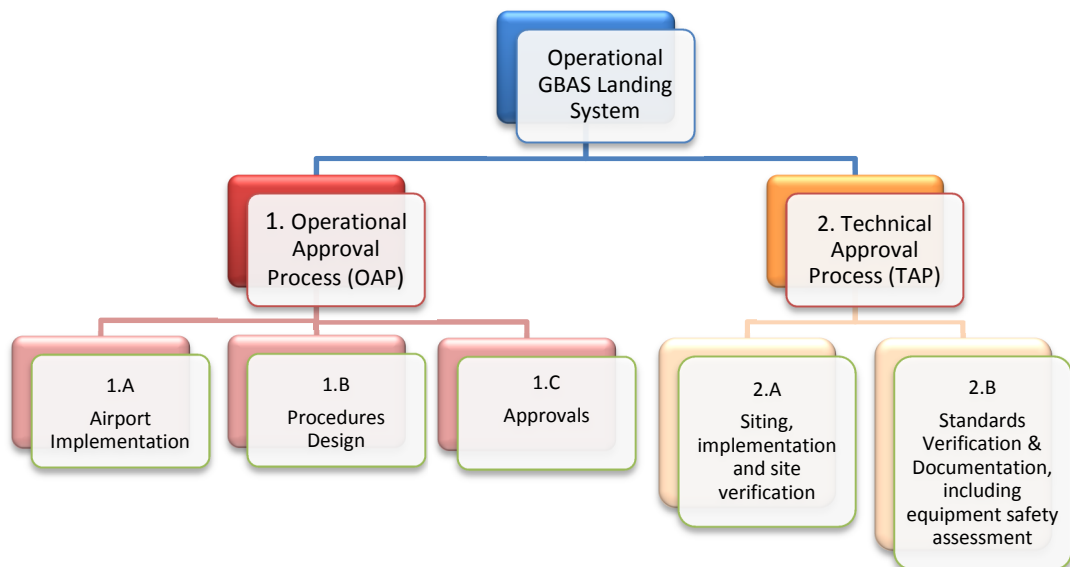


Figure 8 High-level Approval Process.

4 GBAS OUTLOOK

This sections aims to give an overview of the possibilities that GBAS can provide, and how these can be transformed to operational benefits. It also looks briefly into how GBAS can be combined with other GNSS based navigation concepts.

4.1 GBAS Procedures in Operation Today

GBAS approaches are already used today around the world, but to a limited extent. This is mainly due to the lack of GBAS stations at airports but also due to the low aircraft equipage rate (see Section 5.1.1 below).

GBAS procedures that are in use are often overlays to existing ILS procedures, i.e. straight-in approaches with a final approach segment of 8-10 NM. In Europe, such approaches can be found in Malaga, Frankfurt, Bremen and Zürich. This is also valid for the U.S. where GBAS approaches are published for Newark, Houston and Seattle.

An increasing number of GBAS approaches have also been deployed in Russia, Australia and China.

Although ICAO recommendations regarding GBAS are becoming more coherent and conclusive in parallel with both GBAS deployment and with its technical evolution, the interpretation and actual regulation still vary between countries and/or continents (for example EU vs. the U.S.). Therefore, at this point, when investigating the possibilities of deploying GBAS at a local airport or the possibility to introduce GBAS at a national level within a major infrastructure change, it is imperative that all stakeholders (airport, community, ANSP, airlines, NSA etc.) are involved to collaboratively follow the global development in order to make justified decisions.

4.2 GBAS Enhanced Procedures Review

GBAS technology has a potential to be used in several future applications by changing current precision approach capabilities, for example:

- A precision approach based on GBAS can be used separately from any ILS installation and may follow a normal straight-in approach or be used together with a curved RNP path transitioning to a short GBAS final approach segment (RNP Transition to GLS). Short final approach segments (i.e. shorter than compared to nominal length) are generally more fuel efficient for the airline operator.
- GBAS can enable flexibility in using variable approach path angles, e.g. IGS, as described above.
- GBAS provides the ability to design multiple runway aiming points (MRAP) permanently displaced from the standard touchdown zone.

4.3 GBAS Enhanced Procedures in SESAR 1

In Europe, the main research exploiting the operational potential of GBAS enhanced procedures has been conducted within the SESAR framework, and particularly within the project SESAR 6.8.8 (previously SESAR 6.8.5). The concepts investigated within these projects have been aligned with the technical characteristics and specifics described in Section 3.2, including some additional concepts (e.g. Double Slope).

- Increased Glide Slope (IGS)
- Double Slope (DS)
- Multiple Runway Aiming Points (MRAP)

Furthermore, as there is significant potential in the concept, the project SESAR 6.8.8 has also investigated RNP to GLS.

Although not yet certified, all research has focused on enhancing GBAS in low visibility conditions, i.e. CAT II/III conditions.

4.3.1 Increased Glide Slope (IGS)

In today's operational environment, most airports provide ILS PA services at a standard Approach Path Angle of 3° , known as Glide Slope (G/S). By increasing the G/S during the last 20 NM before the threshold for arriving traffic, the noise contours underneath the approach path could be reduced. Moreover, by using an increased G/S for some aircraft, wake vortex encounters could be reduced and subsequently wake turbulence separation distances could be reduced, i.e. final approach path angle will be different between aircraft and therefore wake vortex can be dispersed by taking different aircraft categories into consideration.

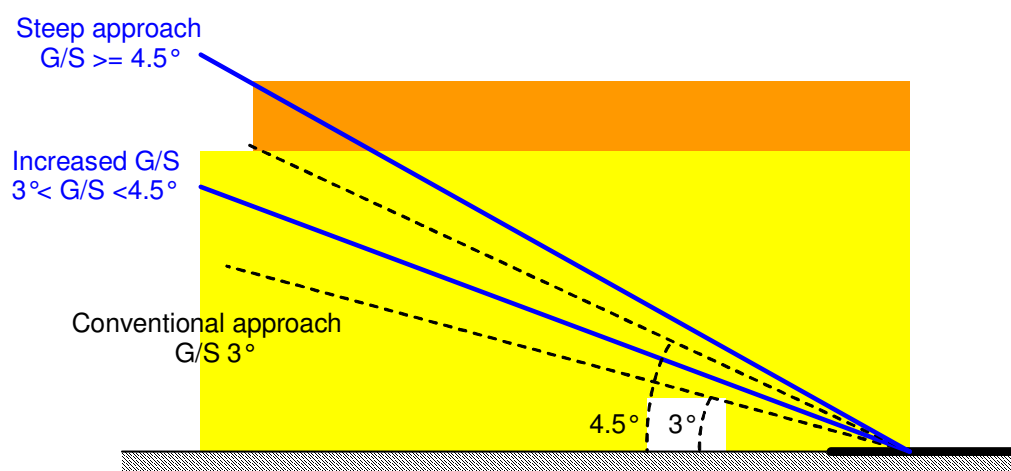


Figure 9 Increased Glide Slope.

4.3.2 Double Slope (DS)

The Double Slope Approach concept contains two different slopes/approach path angles for the intermediate and final approach segment providing the same potential benefits as for IGS (above), i.e. noise mitigation and reduced wake turbulence separation. The first segment of the approach contains a steeper slope than the second one with a seamless and successive transition from above between the two. The higher angle slope is expected to be set between 3.0° and 4.49° , depending on local restrictions and requirements, followed by a nominal approach path angle of a 3.0° slope.

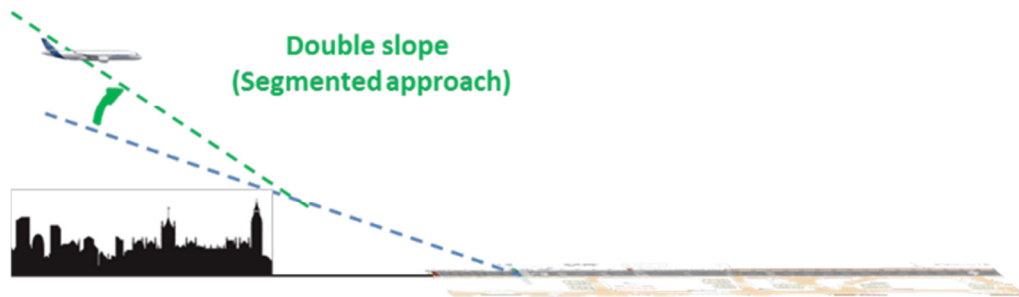


Figure 10 Double Slope Approach.

4.3.3 Multiple Runway Aiming Points (MRAP)

MRAP is a concept utilizing the GBAS technology by providing various touchdown points along the runway, i.e. a kind of displaced threshold(s). The potential benefits are similar to previous concepts, such as reduced noise exposure below the final approach path and reducing separation due to less risk of wake vortex encounters.

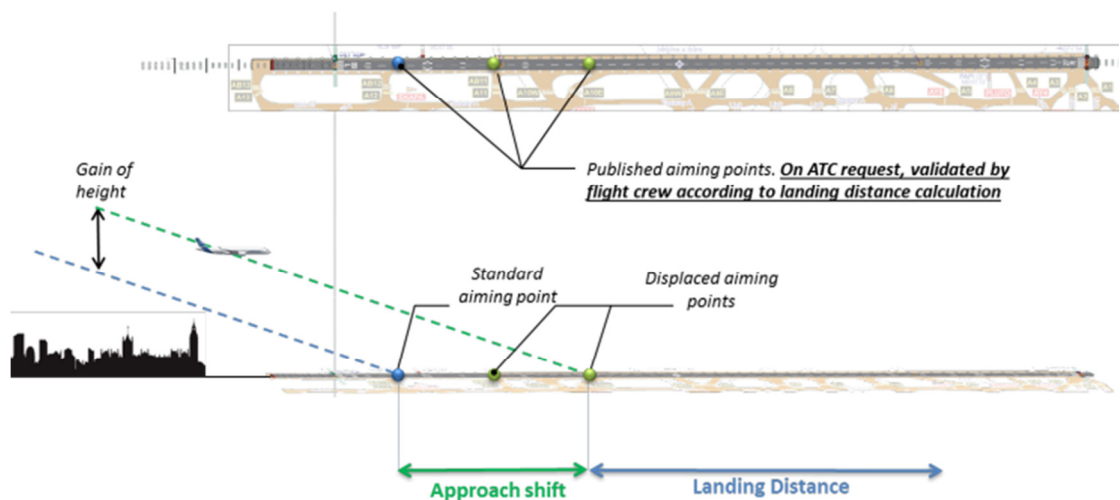


Figure 11 Multiple Runway Aiming Points.

4.3.4 RNP Transition to GLS

GBAS enables the use of a curved RNP initial or intermediate approach segment with a continuous descent profile transitioning to a short GLS straight-in final approach segment, as illustrated in Figure 12. Research shows that the final approach segment could be as short as 3 NM for manual landing or 5 NM for an automatic landing (used in reduced visibility conditions). The potential benefits are numerous; for example, dispersion of noise with high precision, fuel and emission efficient trajectories, increased accessibility to the airport etc.

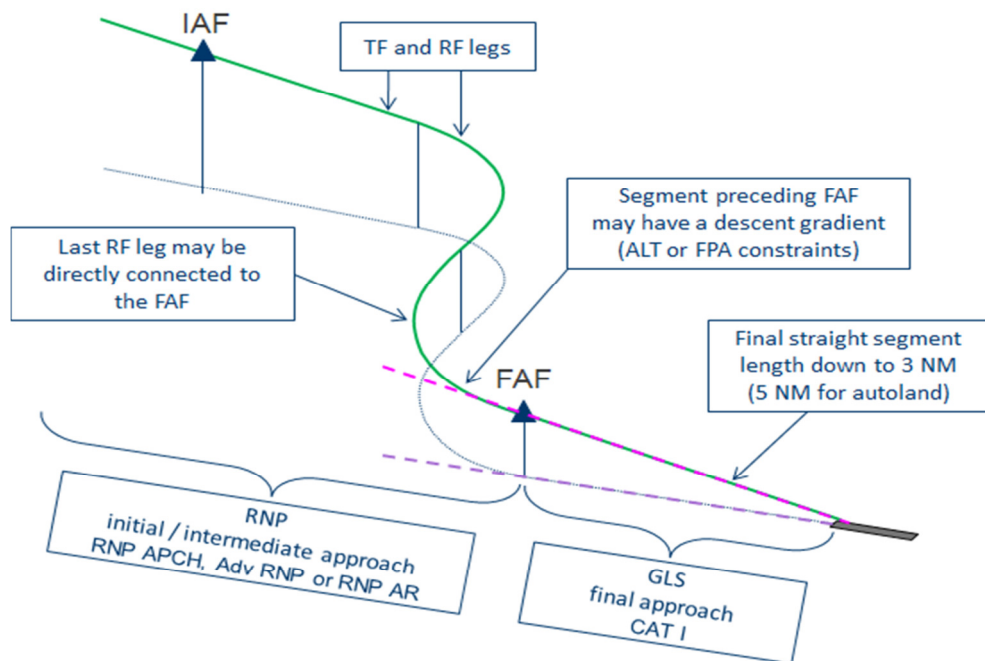


Figure 12 RNP Transition to GLS.

4.3.5 SESAR 1 Results

Extract from SESAR Project 6.8.8 Final Report

All SESAR 1 concepts mentioned in Sections 4.3.1-4.3.4 above have shown the expected benefits in terms of noise reduction. However, for the Double Slope (DS) concept the benefits were not evident and therefore the concept still has to be refined.

None of the concepts showed any significant impact on capacity, in terms of runway throughput, while potential benefits were observed for MRAP in terms of runway occupancy time or taxi-in time.

RNP Transition to GLS could, according to results from SESAR 1, be an enabler for significant benefits in terms of fuel consumption, depending on the specific procedure design.

For the Increased Glide Slope (IGS), Double Slope (DS) and Multiple Runway Aiming Point (MRAP) concepts, further validation activities are recommended by the SESAR 1 projects in order to refine the concepts to achieve acceptance from air traffic controllers and flight crew. Additionally, the role of supporting tools and the impact on airport and TMA performance should be further investigated.

Variable touchdown points/zones for MRAP imposes additional challenges in terms of visual cues for the flight crew, i.e. runway markings and lighting. These can be either physical (on the actual runway) or virtual (built-in software). Further investigation is needed to agree on a proposal for standardization.

For curved RNP Transition to GLS, it is recommended to minimize the impact on current operations when mixing curved RNP Transition to GLS with standard straight-in approaches, in particular for medium and high density environments.

Appropriate and adequate training periods and training contents are recommended for all concepts in order to familiarize air traffic controllers and flight crew with the new concepts and their integration with existing operations.

4.4 Demonstrations and Further Research

There are some ongoing research and development programs and demonstration initiatives addressing enhanced and future GBAS procedures. These encompass various levels of the potential of GBAS. Some of these initiatives are

4.4.1 San Francisco RNP to GLS Demonstration

In 2016, Delta Air Lines and United Airlines conducted a series of precision approaches into San Francisco International Airport (SFO) with the objective to improve the airport efficiency by introducing new approach procedures. The demonstration focused on the benefits of linking RNP to GLS and enabled stakeholders to study the benefits of the approaches, evaluating the performance of the procedures, and understand the impacts on infrastructure aiming at accelerating the implementation of RNP to GLS.

Specifically, the procedures were designed to decrease flown track distance and thereby minimize fuel usage and exhaust emissions as well as mitigate community noise. In addition, some of the procedures had the potential to reduce the ceiling and visibility requirements for simultaneous parallel runway approaches and reduce air traffic control workload while maintaining a high rate of arrivals in poor weather conditions.

In the short term perspective, it was recommended to implement RNP procedures for two of the runway ends at SFO (runway 10L and 19R). For the long term, it was recommended to install a GBAS ground station to enable RNP to GLS procedures, improving simultaneous approaches to two parallel runway ends

(runways 28L and 28R) and also to add Precision Approach (GLS) capability to runways 10L and 19R.

4.4.2 Project AAL (Augmented Approaches to Land)

In 2015-2016, the European SESAR AAL project performed over 360 demonstration flights to validate new approach and landing technologies with a number of different aircraft types and at a number of airport environments.

The AAL project aimed to develop and demonstrate the feasibility of several advanced augmented approach procedures at all types of airports, based on the following five technologies:

- Curved Required Navigation Performance (RNP) paths
- Ground-Based Augmentation Systems (GBAS)
- Satellite-Based Augmentation Systems (SBAS)
- Synthetic Vision Guidance System (SVGS)
- Enhanced Flight Vision System (EFVS)

Specifically related to GBAS, the project designed RNP Transition to GLS procedures at Frankfurt, Bremen and Zurich airports (where GBAS stations are installed). The procedures were flown by Lufthansa and Swiss aircraft equipped with GLS equipment on revenue flights by trained flight crews when weather conditions so permitted.

The demonstration results regarding RNP Transition to GLS showed positive and/or potential benefits for almost all KPAs measured (Safety, Environment/Fuel Efficiency, Human Performance and Accessibility).

4.4.3 Curved Approach Segments based on GBAS

More forward-looking research is undertaken by the Electronic Navigation Research Institute (ENRI) in Japan. ENRI is currently performing studies to conduct curved approaches utilizing GBAS not only for the final approach segment but also further away from the runway end by using curved approach segment(s) with a function/enabler called TAP (Terminal Area Path). With TAP, GBAS acts as the single source of navigation, without incorporating RNP Transition to xLS or RNP AR (being today's navigational enabler of curved segments).

Associated benefits are increased navigation performance in the curved segment, and a more predictable transition onto the final approach, since the transition from barometric to geometric height occurs at an earlier stage.

4.5 Visionary Concepts

From a research perspective, the potential of GBAS is very promising. As the final approach segment is created virtually by the airborne equipment (based on the information transmitted from the GBAS ground station), there are many possibilities to create very innovative approach procedures in addition to the enhanced procedures mentioned in Section 4.2. Examples of potential future

concepts are listed below. Note that besides technical evolution, these concepts require development of the current regulatory framework, e.g. PANS-OPS:

- Extend the GBAS operational limit well beyond today's 23 NM from the GBAS ground station. Inbound aircraft would then be able to transfer from other navigation means to GBAS and follow a pre-described GBAS trajectory even before entering the TMA, potentially already during the initial part of the descent from cruising altitude.
- As previously described, today's solution for curved approaches is to combine GBAS with RNP including curved segments (RNP transition to GLS). From a technical point of view, it might be possible to design GBAS procedures with the entire (curved) procedure based on GBAS transmissions solely, as described in 4.3. The combination of innovative, efficient and curved procedures, together with GBAS CAT II/III operations has the potential of significantly enhancing both the approach procedures and the airport accessibility.
- A sophisticated sequencing tool (e.g. an advanced AMAN) in combination with (curved) approaches based solely on an extended range GBAS could be used to provide each arriving aircraft with a unique trajectory. The trajectory could be dynamically adjusted to fit the arrival sequence and should preferably be given to the aircraft before its Top of Descent (ToD). The trajectory would be a closed-loop trajectory down to touchdown and will therefore be fully predictable to all users. To further enhance the operation, the concept could be developed to also include the taxi-in segment.
- Most GBAS applications only relate to the arrival and approach phases. However, GBAS could potentially also be applied to departure(s), not only determining lateral trajectories (e.g. curved departures), but also vertical trajectories. Departing traffic could, for example, be separated vertically from arriving traffic based on GBAS trajectories. The potential for an overall enhanced air traffic management would be large if dynamically adjusted trajectories based on both the departing and arriving flows could be applied.

Of course, there are a number of challenges related to these future, visionary applications of GBAS. In the end, some of them might not be possible to deploy, but the main message is that there is a large potential and the only limitation in the future is the collaborative willingness to further research and explore the different applications and concepts.

5 OPERATIONAL ASPECTS

A change from using ILS to GLS during final approach segments, or in the future moving from RNP approaches to navigating the entire curved approach segment using GBAS will have an operational effect on both airlines and air traffic control.

5.1 Flight Operational and Airline Aspects

From an airline operator perspective, GBAS is considered to be the most promising replacement for ILS aiming to enhance approach procedures in the future, at least when it comes to PA CAT II/III operations. There are other means to enhance approach procedures (SBAS, ABAS, PBN etc.) but GBAS is considered the most promising. However, to fully explore the benefits of combining advanced approach procedures with PA CAT II/III operations, GBAS is seen as the prime enabler.

To maintain conformity from a flight operation perspective, GBAS operations and procedures are, in general, developed and designed in a way that do not introduce any additional considerations for the user than associated with the current, conventional procedures. In addition, GBAS airborne equipment and associated Human-Machine Interface (HMI) applications of today are very similar to their ILS equivalents. This enables a seamless transition to the new type of approach for the flight crew. Therefore, any operator considering upgrading their aircraft fleet to be GBAS compliant, should anticipate a minimum of additional instruction and training compared to conventional navigation means.

Even though it is not yet certified, and therefore not in operation, PA CAT II/III operations are expected to follow the same strategy in terms of conformity compared to current, conventional procedures and design, including airborne equipment.

There are some specific elements related exclusively to GBAS operations (procedures, airborne equipment etc.). However, these are considered to be within the normal variance of existing navigation specifications. This also includes possible failures of either the ground part of the GBAS equipment, loss of Signal in Space (SIS), failure of the airborne equipment or a combination of these. Any single failure or combination of failures will be part of the initial and recurrent training and do not require any additional measures other than stipulated in the aircraft manual or training syllabi.

That said, as GBAS operation(s) is a relatively new feature for many operators as well as their associated national NSAs, there may be additional requirements imposed depending on local interpretations of the regulatory framework.

5.1.1 Aircraft Equipage

The number of GBAS capable aircraft is increasing. All Boeing aircraft models in production, except the Boeing 777, are certified for GBAS and once the new Boeing 777X is approved, all new Boeing aircraft will be approved for GBAS. In 2016 40% of all new deliveries of Boeing aircraft have the GBAS equipment

activated. For instance, Norwegian Air Shuttle is currently the airline in the world with the biggest GBAS equipped fleet with an equipage rate of more than 98%.

For Airbus aircraft, GBAS equipage rates are not easily obtainable. However, it can be expected that more or less all newer Airbus models are GBAS capable in the same way as the Boeing fleet. It is interesting to note that Scandinavian Airlines Systems (SAS) confirms that in the procurement of their new Airbus 320neo aircraft they decided not to activate the GBAS functionality upon delivery. However, the GBAS capability can be activated later since the aircraft is prepared for GBAS operation.

Although the GBAS equipage rate amongst airline operators is increasing, the main issue of today is the lack of incentives for AUs to invest in new technology without a clear and positive business case. GBAS has a great potential, but as long as ILS, in the existing operational frameworks implemented at airports brings similar value and allows the same accessibility to the runways, the incentive to invest in GBAS is not evident. From an airline perspective, GBAS ground equipment must first of all be implemented globally, at least for the main airport hubs, to further encourage and increase the equipage rate and in that way reach a critical mass. This is solely dependent on the drive of airports together with the concerned stakeholders to include GBAS in their future investment plans. Moreover, if GBAS procedures primarily will be designed as overlays of existing ILS procedures, there will not be any additional benefits for the airline operators in the short term perspective, such as increased fuel efficiency, enhanced noise abatement procedures, improved airport accessibility etc. There may be indirect, positive effects of overlays of existing ILS-procedures, such as increased capacity in low visibility conditions (e.g. reduced separation) or reduced fees due to less maintenance cost for the airport. However, for the full exploration of GBAS, the developed and designed procedures must also consider the potential of combining GBAS with enhanced approach procedures, for example RNP Transition to GLS, allowing flight efficient trajectories and increased accessibility to the airport. Only then will the AUs have a clear and positive business case and equipage rate can therefore be expected to further increase, establishing positive synergies for all stakeholders.

5.2 General Air Traffic Control Aspects

The main objective of air traffic control is to maintain a safe, orderly and expeditious flow of air traffic in the global air traffic control system. This includes both civil and military aviation.

Except from an emergency or distress situation, all air traffic operating inbound or outbound to or from a controlled airport is well known to the air traffic controller (ATCO) and is planned ahead. A flight plan, which includes information on whether the individual aircraft is GBAS capable or not, is filed in advance by the airline operator. In addition, as soon as the flight becomes airborne, a number of information messages are transversally sent between the different air traffic control centers (ATCCs). To regulate the flow of aircraft approaching the airport

with better precision, various support tools are available, such as an arrival manager (AMAN) and the Network Manager (NM) in Europe.

5.2.1 Considerations regarding enhanced approaches

Today, airports are normally configured based on straight-in approaches, unless special circumstances prevail. However, the rate of enhanced approaches to fit a more demanding and challenging airport environment is increasing and air traffic management is therefore facing some areas of concern. These areas must be addressed in parallel with the increased complexity.

To be able to plan the sequence of approaching aircraft efficiently, the ATCO must have easy access to information regarding the capability of each arriving aircraft to perform these various enhanced approaches (see section 6.3.1 below).

In order to develop an efficient ATM system, a high equipage rate is of utmost importance.

Finally, ATC foresees the need for advanced support systems when different approach types are mixed, particular when the traffic intensity is high. These tools will be necessary for example in order to distinguish what level of equipage is present, to aid with sequencing and to better present necessary information to all actors.

6 INSTALLING A GBAS STATION AT STOCKHOLM ARLANDA AIRPORT

The GBAS station must be sited on airside which is the surveilled/controlled part of the airport. A number of siting criteria exist, however the siting is very flexible compared to an ILS, allowing any airport to install a GBAS ground station even if it has not been catered for in the original airport planning and layout.

As with the ILS, a connection to ATC needs to be in place. As a minimum, ATC must have information as to the operational status of the GBAS station, and potentially must be able to control the station or individual approaches on/off. Potentially also a technical/maintenance facility needs to be in place.

6.1 Criteria for Siting at Arlanda

A number of potential sites within the airport boundaries were studied. A site next to the threshold of runway 01R was identified to be the most interesting candidate for the GBAS station (see Section 1.1).

The two main criteria for the siting are:

- The GPS antennas should not be located too far away from any operational runway thresholds, as then errors would decorrelate (mainly due to ionospheric and ephemeris errors). As a rule of thumb, the GPS antennas should be located within 5 km from any operational threshold.
- There needs to be line of sight from the VHF transmitter antenna to all operational areas. In particular, for CAT III operations, there needs to be coverage down to 3.7 m above the runway.

The first of these criteria is fulfilled for the recommended site. For the second criterion, it is clear that the coverage of runway 26 to 3.7 meters may not be adequate. This may be mitigated at a later stage, by adding a second transmitter station within line-of-sight of the required coverage areas for runway 26. Such a transmitter station needs a dedicated, point-to-point fiber pair for communication with the GBAS ground station. The communication between the main rack containing the GPS processing and the transmitter function is very time critical, so fibers connecting to transmitters outside the GBAS shelter must not have components in the loop that may delay the communication.

The high level summary and conclusions from the site survey can be found in the following section.

6.2 Stockholm Arlanda Airport Site Survey

The purpose of the site survey has been to get an overview of:

- Potential sites for the GBAS station
- Mode of operation of each runway
 - Landing/Take-off
 - Precision Approach Category (CAT)

- Restrictions according to ICAO Annex 14 (obstacle limitation surfaces etc.)
- Public roads
- Properly scaled maps

Detailed maps with proper scale were not available at the site survey, and need to be provided at a later stage. On the basis of the information collected for the site survey, it is attempted to find a suitable area which:

- Is located within 5 km from all CAT III thresholds and within 5 km from all CAT I thresholds.
- Has line-of-sight to all operational areas.
- Has an open space of 300-400 m length for antenna array, parallel to CAT III runways. Refer to Instruction manual for details regarding protected areas for antennas.

A number of candidate sites were identified and visited, and Figure 13 shows the sites that were discussed.

Airport
Stockholm Arlanda Airport
Swedavia ATM

Prepared by
The GBAS Project Group
Anette Näs

Reference

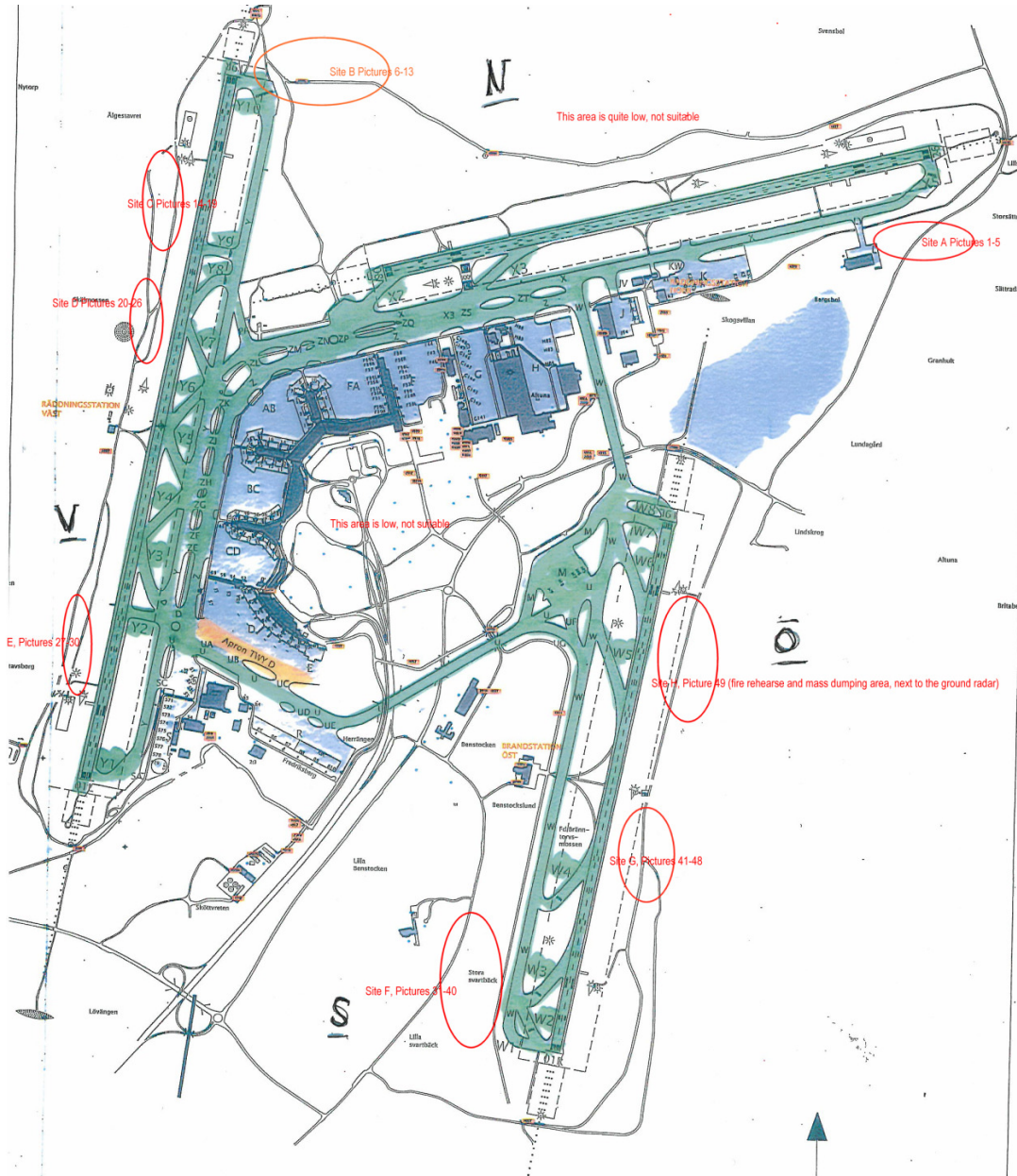


Figure 13 Candidate Sites.

The operational modes of the six runway ends are as follows:

All six runway ends are used for landings and the categories listed in Table 3 apply. Site G was identified to be the most interesting candidate. The distance from each runway threshold to Site G is listed in Table 3.

Table 3 Categories for Different Runway Ends and Distance from G.

Runway End	Current Operation	Distance from Site G
01L	CAT III	2,5 km
01R	CAT III	0,9 km
19L	CAT III	1,7 km
19R	CAT I	4,2 km
26	CAT I	3,7 km
08	NPA	3,1 km

Note that runway 08 is used less than 1% of the time, only during specific wind conditions, due to noise restrictions. Runway 26 is heavily used, about 46% of the time.

Note that there supposedly may be GPS repeaters in hangars at the airport. If these repeaters perform according to international regulations, this should not be a problem, but the output power with open hangar doors should be verified.

Due to the layout of the airport - with quite flat terrain and line-of-sight blocking by woods and buildings – it was not possible to find a spot which had line of sight to all operational areas where VDB (VHF Data Broadcast) coverage is required according to ICAO regulations. Covering all runways down to CAT III requirements (3.7m above the runway surface) is therefore not expected to be possible using a single transmitter station.

At the initial stage, it is recommended to prioritize VDB (VHF Data Broadcast) coverage at runways 01R/19L. Therefore, Site G (refer to Figure 13) is recommended. From this site, CAT I coverage at runway 08 should be achievable. CAT I coverage at runway 26 may be achievable, but it needs to be investigated how far down there is line-of-sight from the recommended ground station site (taking a 10 m high antenna into account). Similar considerations should be made for runway 01L/19R.

As mentioned in the introduction to this section, it is possible to amend the station with an additional VDB transmitter station at a later stage, in order to ensure coverage for all runways, should this turn out to be required.

6.3 GBAS Pilot Project

A step-wise implementation of a GBAS ground station is proposed. This implies that a fully functional GBAS station may be implemented at a relatively low cost, as basis for further research and validation flights. This station can provide the basis for operational trials and all associated processes that need to be carried out. This gives an opportunity for later modifications of the installation should it be found necessary during the data evaluation period. Such a modification could, for example, include moving GPS antennas. A proposed pilot project only addresses

the first step which will be necessary to perform flight trials, assess VHF coverage etc. At a later stage, the station can be expanded to a permanent installation with full operational capability.

6.4 A GBAS Pilot Project as Basis for Further Research and Flight Trials

Implementation of a pilot GBAS installation at Stockholm Arlanda Airport would imply the following steps:

- A draft Concept of Operation to identify and describe which operational concepts will be further studied. Generic GBAS training for relevant operators/stakeholders.
- Involvement (and training?) of ATC to prepare for flight trials.
- A Practical site assessment including data logging for performance assessment.
- Delivery and installation of a prototype GBAS GAST D station.

It is proposed that the immediate next steps to a pilot GBAS installation that may form the basis for further operational and implementation studies should be:

- Apply for a frequency license in order to be allowed to use the VDB signal for trial purposes.
- Derive a civil works specification to conclude on the nature of the installation.
- On the basis of the civil works specification, initiate processes to acquire the required permissions, such as planning permissions, approvals related to obstacle considerations and any other necessary permits.
- Initiate discussions with the Swedish NSA (Transportstyrelsen) in order to agree on what operations would be allowed, and under which conditions, during validation flights.

7 IMPLEMENTING GBAS APPROACH PROCEDURES TO STOCKHOLM ARLANDA AIRPORT

7.1 ATC Aspects Concerning Introduction of GBAS Approaches

Stockholm Arlanda Airport handles approximately 230 000 aircraft movements (arrivals and departures) per year, and an average of around 800 movements per day during weekdays. Management of such a volume of traffic is dependent on a predictable and safe working method for pilots and ATC.

Introduction of enhanced GBAS approaches in this environment is a complicated task because xxx. Nevertheless, it is deemed relevant for the stakeholders at Arlanda to participate in the development of different GBAS approaches in the same manner as elsewhere internationally. As described in section 4.3 there are a number of different GBAS approaches that are envisioned for future development. For example; a straight-in GBAS approach with a slightly increased glide-slope compared to today's nominal ILS might be manageable to be studied in flight validations. From an ATC perspective the most challenging task is to mix the curved approaches with the straight-in ILS and still maintain a high efficiency.

At Arlanda there have been flight trials with curved RNP AR approaches to both rwy01R and rwy26 which took place during low traffic/off-peak. Those curved RNP AR approaches are since some years fully approved and published in the Swedish AIP.

7.2 Development of new (or refined) ATC tools to enable enhanced GBAS approaches at a larger scale

The Flight Data Processing (FDP) system at Arlanda (TopSky) is based on the assumption that arriving traffic can accept a straight-in (ILS) approach. However, TopSky does not today display aircraft capability or additional approvals such as GBAS, RNP AR, increased glideslope etc. for the ATCO in an intuitive way. As stated in section 5.2.1 above, introducing non-standard approaches requires addressing the challenges of information exchange between all impacted ATC units and sectors. This means that information whether a specific flight is able to conduct a GBAS approach needs to be correctly distributed, perceived and incorporated in the regular air traffic flow.

To illustrate this, Figure 14 shows a snapshot of a radar label for a particular flight (SAS061) during approach to Arlanda. There is no information on the label indicating aircraft capability and/or approval. The radar label only displays aircraft type (B737-600), altitude, speed and heading.

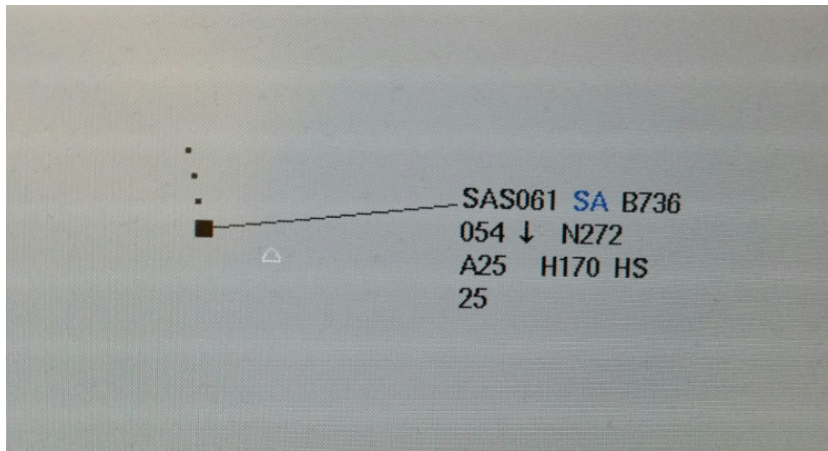


Figure 14 ATCO radar label from the TopSky system.

7.2.1 Approach to Stockholm Arlanda Airport

All airspace is divided into a number of different airspace sectors. The size of a sector depends mainly on the number of airports and the possible complexity of traffic within the sector. Normally, a flight arriving and departing at Arlanda is controlled by at least five ATCOs within Swedish airspace. The ATCO who is controlling a particular flight hands it over to the next ATCO when the flight is about to leave the current sector. Subsequently, the handover needs to be secured for vital information, such as aircraft capability, if the intention is to perform a GBAS approach.

Airport
Stockholm Arlanda Airport
Swedavia ATM

Prepared by
The GBAS Project Group
Anette Näs

Reference

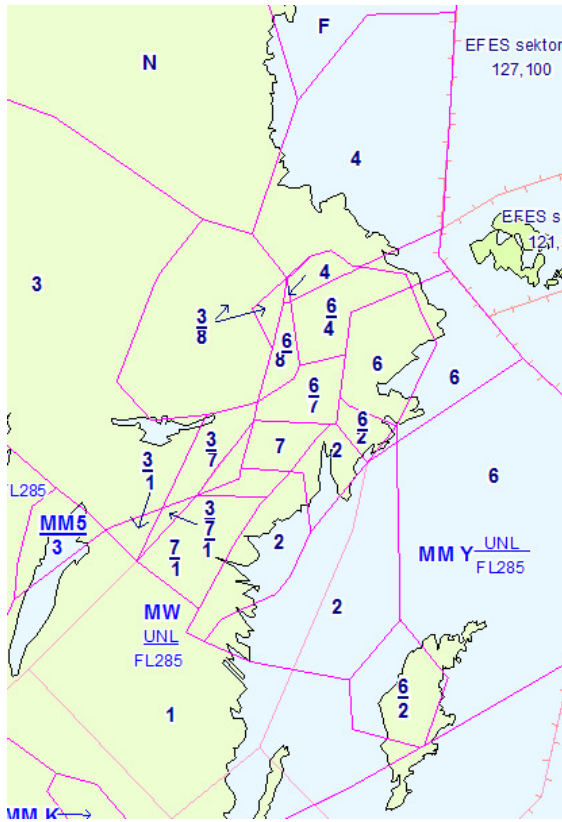


Figure 15 ACC-sectors in the vicinity of Arlanda.

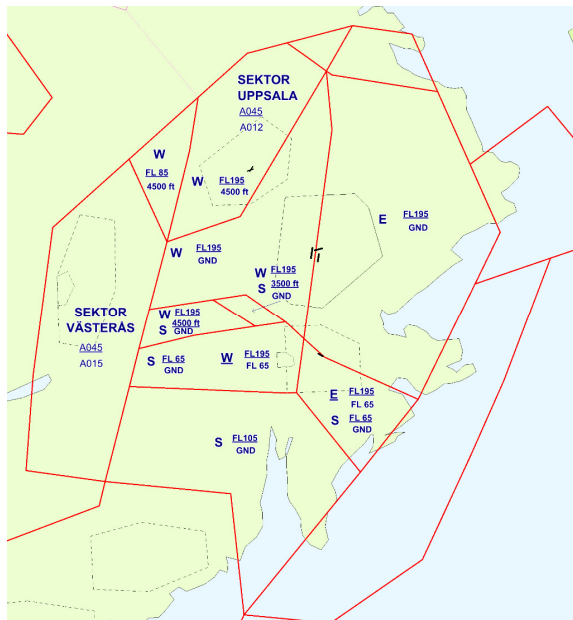


Figure 16 Approach sectors in Stockholm TMA.

Managing a non-standard approach, such as a curved RNP AR at Arlanda today, induces transversal, verbal communication and coordination. Beyond flight trials and initial low-frequency GBAS arrivals, developing supporting tools for ATC will be required to be able to facilitate a combination of standard and non-standard approaches.

7.2.2 Final Approach at Stockholm Arlanda Airport

As previously mentioned, from an ATC perspective it is considered to be more demanding to mix enhanced approaches the more they differ from the standard straight-in approach. Today there is no ATC tool in operation that can support the ATCO when mixing traffic that fly approaches with a very different route in a safe and efficient way.

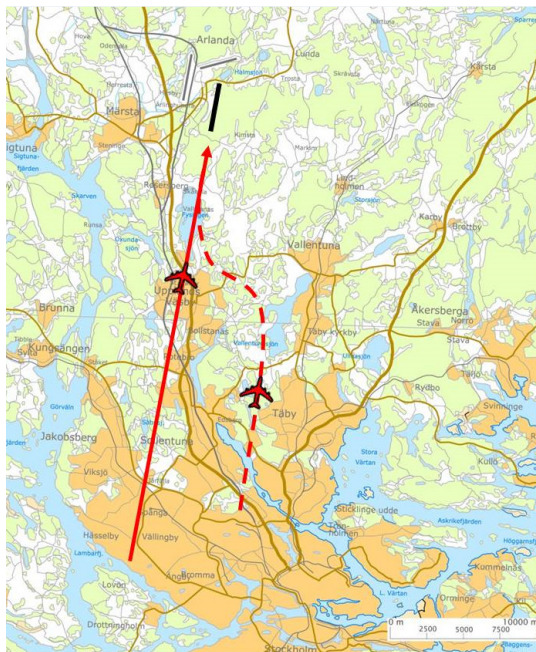


Figure 17 Conventional vs. curved approach to runway 01R

7.2.3 ATCO Training

All ATCOs at Stockholm ATCC i.e. ACC, TMC as well as the Tower Control will need training to ensure a safe handling of air traffic with a mix of different approaches, such as GBAS in combination with ILS. Additional training is envisioned for ATCOs working within Stockholm TMA.

One way to facilitate training and familiarize the ATCOs would be through training sessions in an ATC simulator. Training syllabuses and associated instructions would require additional effort and personnel, which must be included in the overall planning.

Another way for the ATCOs to gain experience from different GBAS approaches could be to conduct initial validation flights during off-peak hours. Nevertheless, some additional briefings and study material would be needed prior to the trials.

However, previous experience from validation flights at Arlanda with different non straight-in approaches, for example RNP AR, has proven beneficial and with a safety record well within limits.

7.2.4 Summary of ATC Aspects

In the foreseeable future, there will be a mix of traffic with different capabilities or of approved approach categories arriving at Arlanda (as well as other airports). Some of them will have very basic capabilities and some will be able to conduct high-end approach procedures. Therefore, deploying GBAS at Arlanda must not only be seen as a standalone solution, but as one of the building blocks when developing Arlanda for the future.

For ATC, this implies the need to create a safe and efficient, overall system providing the necessary tools to manage mixed traffic in a safe, orderly and efficient way.

7.3 **Potential Operational Benefits of GBAS at Stockholm Arlanda Airport**

The potential benefits listed in Section 4.3 could apply for Arlanda, at least to some degree and in the future. A gradual implementation of GBAS will be explored were e.g. reduced separation can be one potential benefit for aircraft on a GBAS approach.

It is worth noting that at this stage, in order to gain the operational benefits, it is necessary for the service provider to consider the experiences made in SESAR and other projects, and adapt to the local operational context and work procedures.

8 PROPOSED NEXT STEPS

In the long term perspective, deploying GBAS at Arlanda is considered vital to remain on the frontline of developing technologies. ATM research and development regarding GBAS is accelerating, on at local and regional level but also globally, within SESAR and NextGen⁶. The collective understanding within the aviation community is that the ATM domain will need to change in order to be able to meet future societal requirements for service and environmental sustainability. GBAS is one enabler to accommodate these requirements. However, GBAS will not be a standalone solution but must be combined with other promising solutions, concepts and technologies such as RNP AR.

For Arlanda, there are numerous synergies and experience to be gained from a collaborative GBAS deployment. This is especially evident when it comes to Avinor (Norwegian ANSP) and Oslo Gardermoen, an airport with similar challenges as Arlanda, but which also has some fundamentally different solutions for its operations. However, Arlanda and Oslo Gardermoen have the same airlines as main customers, and both airports have relatively high GBAS equipage rates in their traffic. Scandinavian collaborations have proven successful in the past and should therefore be promoted in future research and development.

The initial driver for this pre-study has been to investigate the potential of GBAS to contribute solution(s) for avoiding Upplands Väsby for approaches to runway 01R when feasible. However, during the preparation of the pre-study, additional synergies and benefits have been identified. These benefits will potentially enhance the overall operations at Arlanda, and are therefore deemed equally important to consider in future research and studies.

GBAS is still in an early development phase. By installing a GBAS station at Arlanda for research and validation purposes, innovation and research could be pushed further. The aim should be to develop and implement an ATM infrastructure for the future with enhanced and visionary procedures combining all the potential of GBAS of today and tomorrow. In this aspect, Sweden and Scandinavia could steer the development in a pioneering direction, endeavoring to become the foremost explorer within the GBAS domain.

Based on the above, the joint effort in carrying out this pre-study, has concluded the following initial steps as a proposal for further study and research:

1. Investigate interfaces with the IRIS Program⁷ to conclude on solutions, concepts and technologies that should be prioritized for Arlanda. Propose either a separate GBAS project or a project under the IRIS umbrella.

⁶ NextGen - The Next Generation Air Transportation System. US Department of Transportation funded project to modernize air transport.

⁷ IRIS is an abbreviation for the Swedish name "Icke-raka inflygningar till Stockholm Arlanda Airport" which translates to Non Straight-In Approaches to Stockholm Arlanda Airport.

2. Establish working groups covering all aspects of deploying GBAS at Arlanda including all relevant stakeholders, such as airport, ANSP, airlines, NSA etc.
3. Investigate further and conclude on high-level KPA/KPIs involved in a GBAS deployment at Arlanda, such as Cost Efficiency, Operational Efficiency, Capacity, Environment and Safety.
4. Develop a project plan to install a GBAS station at Arlanda, encompassing the following elements:
 - a. Draft Arlanda Concept of Operations (ConOps) to identify GBAS operational concepts required for Arlanda.
 - b. Draft GBAS approach procedure designs identified in Arlanda ConOps (above).
 - c. Perform simulator trials to verify the draft procedure design.
 - d. Simultaneously, derive information from drafting Arlanda ConOps, procedure design and trials to develop requirements of ATC supporting tools, e.g. to combine various approaches safe and efficiently.

In parallel, initiate a GBAS Pilot Project as stated in section 6.4