GBAS CURVED APPROACH PROCEDURES: ADVANTAGES, CHALLENGES AND APPLICABILITY

Meiko Steen*, Thomas Feuerle*, Mirko Stanisak*, Takayuki Yoshihara, Peter Hecker***
*** Institute of Flight Guidance, Technische Universitaet Braunschweig, Germany**
**** Electronic and Navigation Research Institute (ENRI), Japan**
m.steen@tu-bs.de
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Abstract

Satellite based Navigation Systems (Global Navigation Satellite Systems, GNSS) will become a major element in the navigation infrastructure of the future. Already today, they allow the flight guidance task for Area Navigation (RNAV) and Required Navigation Performance (RNP) for en-route, terminal area and approach procedures. To meet the requirements of accuracy, integrity, continuity and availability for precision approach operations, the Ground Based Augmentation System (GBAS) has been developed. Category-I straight in approach procedures based on GBAS are certified for operational usage. The definition and development of Category-II and III equivalent approach and landing operations with the usage of GBAS are currently in progress. The deployment plans for future air traffic systems in the US (Next Generation Air Transportation System, NextGen, [1]) and in Europe (Single European Sky Air Traffic Management Research, SESAR, [2]) foresee the operational availability of GBAS CAT-III equivalent approaches in the timeframe of 2018. Beside the required performance, GBAS also provides broadcasted data for the construction of a Terminal Area Path (TAP) [3] consisting of straight legs, radius to fix legs and others, which allow for flexible curved approach procedures.

1 Introduction

In order to support GNSS precision approach operations at airports, Ground Based Augmentation Systems have been developed over the recent years. A GBAS ground station consists of up to four GNSS reference antennas and receivers. The accuracy of GNSS without augmentation systems is not accurate enough to provide precision approach operations mainly due to ionospheric and tropospheric errors in the pseudoranges between the satellites and the GNSS antenna. Typical accuracy of stand alone GNSS without augmentation systems is in the range of 20 meters, while precision approach operations typically need an accuracy of up to 2 meters for CAT-II/III operations. A GBAS ground station thus uses the known position of its reference antennas and the measured pseudoranges and range rates to determine the errors in the measured pseudoranges and to calculate range and range rate corrections. These corrections are applicable in an area defined by a nominal range of 23 NM [4] around the GBAS ground station. They are broadcasted using the Very High Frequency Data Broadcast (VDB) and received by approaching aircraft which are equipped with GBAS airborne equipment. On-board the aircraft the received corrections are then applied to the GNSS pseudorange measurements, such that the airborne position solution is more accurate than stand alone GNSS without augmentation. The VDB data link can theoretically contain up to 256 different Message Types (MT), of which four are currently in usage for commercial applications. The differential corrections for the GBAS Positioning Service, TAP Service and CAT-I equivalent approaches (GBAS Approach Service Type (GAST) C) are broadcasted in Message Type 1, while for CAT-III equivalent approaches (GAST D) the differential corrections are broadcasted in Message Type 11.

Beside corrections for the position solution, integrity information are also calculated by the GBAS ground station and broadcasted via VDB in Message Types 1 and 2. In addition, flight path information is also being generated by the ground station and broadcasted in Message Type 4. These flight path definitions typically contain all the information necessary to construct a virtual Final Approach Segment (FAS) on-board the aircraft. Based on this flight path, the corrected GBAS position is used to calculate the lateral and vertical deviations that can be displayed on a course deviation indicator in an ILS-Look-a-Like mode or serve as input to the automatic flight system. The GBAS ground station is also able to generate Terminal Area Path messages that provide flight path data to conduct curved and/or segmented approaches consisting of e.g. straight legs and radius-to-fix legs. Although the TAP service is currently neither certified nor part of the Minimum Operational Performance Standards (MOPS) [5], the technical possibility is given within ground and airborne GBAS equipment [3]. In contrast to Required Navigation Performance (RNP) approaches, these TAPs are also contained in the vertical domain, since they use vertical GNSS (GBAS) position instead of barometric altitude.

In this paper, curved approach procedures are described that use the technical possibilities of GBAS. The work was jointly conducted by the Institute of Flight Guidance of the Technische Universitaet Braunschweig (Braunschweig, Germany) and the Electronic and Navigation Research Institute (Chofu, Japan). In this work, a special curved approach procedure was developed for runway 22 of Haneda airport in Tokyo. This approach is basically referred to a LDA (Localizer Type Directional Aid) approach (see standard approach in Figure 1) and additionally arranged with a scope of reduction of noise pollution. The developed procedure is depicted in Figure 2 and consists of a leg sequence followed by a Final Approach Segment. The procedure was transferred to Braunschweig research airport (see Figure 3). The coordinates of the legs were stored in the experimental navigation system of the test aircraft, while the final approach segment was taken from the data broadcast of the GBAS ground station.

This paper will first introduce the developed procedures and the used navigational equipment. At the time of the flight trials, the GBAS ground station at Braunschweig Research airport was neither equipped for GAST D, which allows for conducting equivalent CAT II/III approaches, nor with the ability of providing TAP information. This is why an offline simulation of the relevant GAST D correction data and TAP information was conducted and described in chapter 3.2.

At the end of this paper, advantages and the applicability of GBAS curved approaches are discussed based on the example of meteorological impact and wake vortex issues.

2 Developed Procedures

The standard ILS approach to runway 22 of Tokyo's Haneda airport is depicted in Figure 1. Aircraft arrive from north easterly direction and intercept the glidepath above one of the suburbs of Tokyo. The available instrumentation consisting of ILS, VOR/DME and NDB does not enable the avoidance of these suburbs if instrumental flight rules are applied.

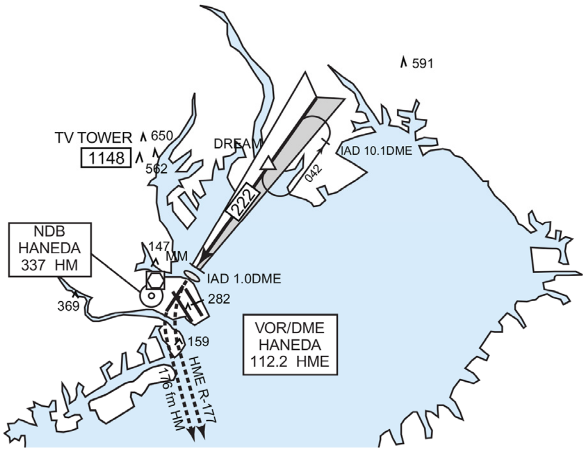

Fig. 1. Standard Approach for Haneda Airport, Runway 22

Although the Terminal Area Procedures using GBAS are not certified nowadays, GBAS

Tab. 1. Terminal Area Path definition

Waypoint name	Type	Latitude / [°]	Longitude / [°]	Height / [m]
WPTS	Initial Fix	52.14304172	10.49261108	308.50
WPT0	Track to Fix	52.15866371	10.76195518	281.68
WPT1	Radius to Fix	52.21717566	10.79817893	279.32
	Turn Center	Offset: -0.02380482	Offset: -0.04143885	279.32
WPT2	Track to Fix	52.24149395	10.76118982	278.24
WPT3	Track to Fix	52.30598326	10.66308324	270.70
WPT4	Radius to Fix	52.32147338	10.59685010	265.96
	Turn Center	Offset: -0.04922169	Offset: +0.00732070	265.96

technically allows for these procedures [3], which in the described example avoid the aircraft flying over the suburbs of Tokyo.

These TAPs could be followed by a precision approach, also using GBAS. Figure 2 shows the procedure, which was developed by ENRI and the Institute of Flight Guidance for research purposes. The procedure contains five legs starting with the Initial-Fix (WPTS) followed by a Track-to-Fix leg (WPT0). WPT1 is a Radius-to-Fix leg and is followed by two subsequent Track-to-Fix legs, where WPT2 is at constant altitude and WPT3 additionally contains a vertical descent path. The TAP is finalized by a Radius-to-Fix leg, which directly leads to a Final Approach Segment (FAS) of a GBAS approach procedure.

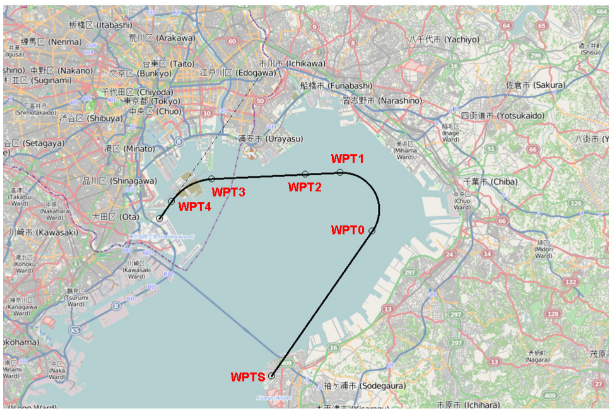

Fig. 2. Developed Procedure for Haneda Airport

To judge the feasibility of the developed procedure – e.g. whether the Radius-to-Fix legs are flyable by commercial aircraft – the TAP was programmed into the flight management system of an Airbus A320 simulator of the Institute of Flight Guidance and flown manually and also automatically by the auto flight system.

To further enable an assessment of the developed procedure with special focus on the algorithms, the TAP was transferred to Braunschweig Research Airport in Germany. The procedure is shown in Figure 3 (black line) together with the Precision Approach Region (PAR, blue lines). The definition of the waypoints and leg types is shown in Table 1.

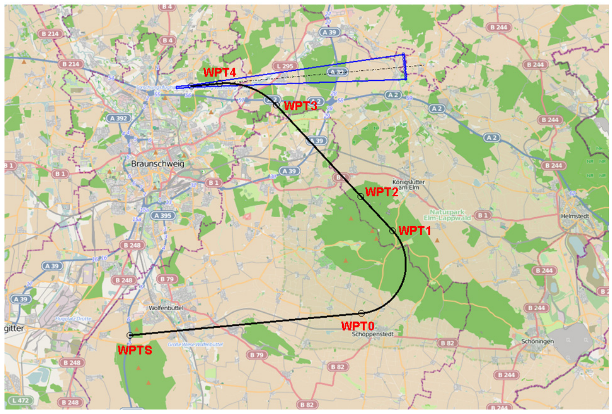

Fig. 3. Haneda approach procedure transferred to Braunschweig Research Airport

3 Navigation System

During the flight trials, airborne equipment according to [5] was used. For flying the defined procedures, airborne GAST C equipment was used for calculating the current aircraft position. GBAS correction data and data for the Final Approach Segment were received via an airborne VDB receiver based on the broadcasted Message Types from a Thales ATM GBAS ground station. The waypoints and leg types for the Terminal Area Path were provided by a database on board the aircraft, containing the waypoints shown in Table 1. The procedure was then flown with flight guidance provided by an experimental flight director display. Since the GBAS ground station was not equipped for GAST D, raw GNSS data was recorded additionally using three reference receivers located near to the airport. During the offline assessment of the flight trial, this reference GNSS data was used in a GAST D station simulation. The simulated binary VDB messages for GAST D were then used in a replay mode together with the GNSS data recorded during the flight test in order to assess the behaviour of an on-board GAST D navigation system during the flown procedure. Chapter 3.1 will introduce the most relevant navigation algorithms used in this paper. One focus of the assessment will be on the transition between the different GBAS approach service types (GBAS Positioning/TAP Service for Terminal Area Procedures, GAST C for Category-I and GAST D for Category-III precision approaches). An overview of the simulated GAST D raw data is given in chapter 3.2.

3.1 GBAS airborne solution

For better understanding, the basic equations of the airborne GBAS position solution will be briefly described. In the GBAS ground station, the measured pseudoranges are subjected to a defined smoothing process for several reasons, like e.g. to alleviate the error influence of the individual antennas and reference receivers. The pseudorange and range rate corrections are determined based on those smoothed pseudoranges. Thus, both airborne and the raw GNSS measurements within the ground facility are smoothed first by using the respective code measurements:

$$P_n^i = \alpha \rho_n^i + (1-\alpha)\cdot\left[P_{n-1}^i + \frac{\lambda}{2\pi}\left(\Phi_n^i - \Phi_{n-1}^i\right)\right] \qquad (1)$$

with:

P_n^i smoothed pseudorange to satellite i at time n

ρ_n^i raw pseudorange to satellite i at time n

α sample time divided by smoothing time constant

P_{n-1}^i smoothed pseudorange to satellite i at time n-1

Φ_n^i carrier phase measurement to satellite i at time n

Φ_{n-1}^i carrier phase measurement to satellite i at time n-1

λ wavelength

For the GAST C (Category-I equivalent) solution the smoothing time constant is 100 seconds, while the GAST D solution needs two separate smoothing filters with time constants of 30 seconds and 100 seconds. The pseudorange and range rate corrections from Message Type 1 are then applied to the pseudoranges smoothed with a time constant of 100 seconds. For GAST D, this also needs to be done for the corrections within Message Type 11 that needs to be applied to the 30 seconds smoothed data:

$$\begin{aligned} P_{GBAS,n}^i = P_n^i + PRC^i + RRC^i \cdot \left(t - t_{zcount}\right) \\ + TC + c\Delta t_{SV}^i \end{aligned} \qquad (2)$$

with:

$P_{GBAS,n}^i$ GBAS corrected pseudorange to satellite i at time n

PRC^i broadcasted pseudorange correction for satellite i

RRC^i broadcasted range rate correction for satellite i

t current time

t_{zcount} time of applicability of broadcasted pseudorange and range rate corrections

TC calculated (differential) tropospheric delay corrections

c speed of light

Δt_{SV}^i satellite clock error correction for satellite i

Subsequently, a position solution needs to be calculated based on the corrected pseudoranges. According to [5], one acceptable means for the position solution is the use of a weighted least square algorithm, where the position error $\Delta\underline{\hat{x}}$ is iteratively minimized by using:

$$\Delta\underline{\hat{x}} = \underline{\underline{S}} \cdot \Delta\underline{y} \quad (3)$$

with:

$$\underline{\underline{S}} = \left(\underline{\underline{G}}^T \cdot \underline{\underline{W}} \cdot \underline{\underline{G}}\right)^{-1} \cdot \underline{\underline{G}}^T \cdot \underline{\underline{W}}$$

The observation matrix $\underline{\underline{G}}$ in equation (3) uses the elevation and azimuth to the available satellites with available GBAS corrections:

$$\underline{\underline{G}} = \begin{bmatrix} -\cos El^i \cos Az^i & -\cos El^i \sin Az^i & -\sin EL^i & 1 \\ \vdots & \vdots & \vdots & \vdots \\ -\cos El^n \cos Az^n & \cos El^n \sin Az^n & -\sin EL^n & 1 \end{bmatrix} \quad (4)$$

with:

EL^i Elevation to satellite i

Az^i Azimut to satellite i

The weighting matrix $\underline{\underline{W}}$ in equation (3) uses the standard deviation for the received pseudoranges:

$$\underline{\underline{W}} = \begin{bmatrix} 1/\sigma_1^2 & 0 & \cdots & 0 \\ 0 & 1/\sigma_2^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1/\sigma_n^2 \end{bmatrix} \quad (5)$$

with:

$$\sigma_i^2 = \sigma_{pr\_gnd}^2[i] + \sigma_{tropo}^2[i] + \sigma_{pr\_air}^2[i] + \sigma_{iono}^2[i]$$

and:

$\sigma_{pr\_gnd}[i]$ standard deviation term associated with ground station for satellite i

$\sigma_{tropo}[i]$ standard deviation for residual tropospheric uncertainty for satellite i

$\sigma_{pr\_air}[i]$ standard deviation term associated with airborne equipment for satellite i

$\sigma_{iono}[i]$ standard deviation for residual ionospheric uncertainty for satellite i

The different terms of the standard deviation in equation (5) are calculated as required in [5]. Some of the standard deviation terms like the ground and ionospheric uncertainties are calculated differently depending on the used Service Type (Positioning/TAP Service, GAST C or GAST D, see [5]).

If for example an aircraft is using the GBAS Positioning service for TAP procedures followed by a Category-III equivalent precision approach, the airborne navigation system first needs to calculate a GBAS position solution using equations (1) to (5) using a smoothing time constant of 100 seconds and the differential corrections from Message Type 1 (further referred to as 100 seconds solution). If the aircraft is entering the Precision Approach Region (PAR), the used positioning solution needs to be based on the smoothing time constant of 30 seconds and the differential corrections from Message Type 11 (further referred to as 30 seconds solution). Additionally, the 100 seconds solution has to be provided for airborne monitoring (Dual Solution Ionospheric Gradient Monitoring Algorithm, DSIGMA [5]), while at the same time additional monitors have to be applied to the 100 seconds solution, that do not have to be applied for sole GAST C solution. Also, a standard GNSS solution has to be conducted for backup reasons to enable the conduction of standard RNP or RNAV operations.

For GAST D operations in the Precision Approach Region, several monitoring algorithms have to be conducted [5]. Among them are fault detection algorithms, which ideally use fault exclusion in the presence of detected errors. Same applies, if new satellites get visible and are to be included in the navigation solution. To detect ionospheric gradient errors [6], a Dual Solution Ionosperic Gradient Monitoring Algorithm has to be applied in addition [5]. This monitor compares the GBAS corrected position solutions based on

100 seconds and 30 seconds smoothed pseudoranges in the lateral and vertical domain. If the solutions divert more than 2 meters in any direction, GAST D operations have to be stopped. In this case, GAST C position solution is still usable, but ideally the airborne equipment should provide a redundant sub-set of satellites that is not affected in order to continue GAST D operations, i.e. the Category-III precision approach. A redundant sub-set of satellites implies that ideally n-1 sub-solutions are needed for n used GAST D corrected pseudoranges. In addition, the position solution for GAST C is needed with the full set of available, GBAS corrected satellites, but also has to provide n-1 sub-solutions to allow the DSIGMA monitor for GAST D operations to use the same sub-set of satellites both in the 100 seconds and the 30 seconds solution. Also – for backup operations – a stand alone GNSS solution including also fault detection (one solution on all n pseudoranges) and exclusion (on n-1 sub-set solutions, each excluding another pseudorange) should be provided by the equipment. This means, that for the investigated procedure following solutions have to be calculated:

- GNSS stand alone (n solutions)
- GAST C solution (n solutions)
- GAST D solution (n solutions)

3.2 GAST D Emulation

At Braunschweig research airport, the German Aerospace Centre (DLR) operates an experimental research GBAS ground facility. At the time of the flight trials, this station sent GAST C messages with Final Approach Segment data blocks only. Thus, even though the VDB data has been recorded during the flights, the test of GAST D and/or TAP processing can not be done using this VDB data.

The Institute of Flight Guidance has developed a simple ground facility simulation, which can generate VDB data according to [3] based on recorded GNSS data. This simulation is not only capable of generating GAST D like signals (i.e. including Message Type 11 and additional Message Type 2 messages), but can also encode predefined approach definitions like the approaches designed in chapter 2. The processing scheme is based on the algorithms in [7].

Within this ground facility simulation, all GNSS data available needs to be synchronized first. The synchronized GNSS data is then smoothed with time constants of 30 seconds and 100 seconds in order to generate both sets of differential corrections.

The calculation of differential corrections is exactly the same for both input data sets. First, for each satellite i and reference receiver j the raw differential corrections are calculated based on the known slant range R, the satellite's clock correction and the smoothed pseudorange:

$$PRC_{CSC}^{i,j} = R^{i,j} - P_{CSC}^{i,j} - c \cdot \Delta t_{SV}^{i} \qquad (6)$$

with:

$PRC_{CSC}^{i,j}$ raw differential corrections for satellite i and reference receiver j

$P_{CSC}^{i,j}$ smoothed pseudorange for satellite i and reference receiver j

$R^{i,j}$ slant range between satellite i and reference receiver j

Afterwards, the receiver clock error is estimated for each reference receiver and used to correct the pseudorange correction to obtain PRC_{SCA}:

$$PRC_{SCA}^{i,j} = PRC_{CSC}^{i,j} - c \cdot \Delta t_{j} \qquad (7)$$

with:

$PRC_{SCA}^{i,j}$ differential corrections for satellite i and reference receiver j with receiver clock error removed

Δt_{j} receiver clock error for reference receiver j

Finally, for each satellite the pseudorange correction that shall be transmitted is calculated by taking the mean over all reference receivers that are tracking the satellite:

$$PRC_{TX}^{i} = \frac{1}{M(i)} \cdot \sum_{j=1, j \in S_i}^{M(i)} PRC_{SCA}^{i,j} \qquad (8)$$

with:

PRC_{TX}^{i} transmitted pseudorange correction for satellite i

$M(i)$ number of reference receiver tracking satellite i

These pseudorange corrections are then encoded into the Message Types 1 and 11. Based on the pseudorange corrections, the range-rate corrections and the B values are calculated as well. These values are just for the Message Type 1 and are based on the 100 second smoothed input data. The resulting VDB data is saved along with a GPS time track, which allows to synchronize this simulated data with other measurements.

During the flight trials, the measurements of three GNSS receivers have been recorded with an update rate of 2 Hz. In order to allow subsequent research on future GBAS concepts (like multi-constellation GBAS), these receivers were not only capable to receive the GPS L1 signal, but also received other GNSS signals (like GLONASS and SBAS). Based on this real GNSS raw data and the approaches described in chapter 2, the ground facility simulation generated a VDB data stream for later postprocessing. This VDB data not only contains the TAP data, but also the additional messages that are required for GAST D. By combining both the airborne GNSS measurements and the simulated binary VDB data during post-process, all necessary information are available for an assessment in replay mode.

4 Findings and initial results

Based on the recorded flight trial data and the simulated GAST D messages, the described curved approach procedure and subsequent GAST D approach have been assessed in replay mode of the navigation system of the Institute of Flight Guidance. Since also other procedures have been flown during the flight trial, the data allows for testing the algorithms for a relatively long period, longer as the described procedure itself. The four solutions – GPS, GBAS TAP service, GAST C and GAST D – were conducted in parallel within the navigation system. The reference trajectory was calculated with a commercial of the shelf software using phase differential GPS with reference stations of the German SAPOS® Service. Figure 4 shows the horizontal accuracies for the 30 seconds solution (used for GAST D) and the 100 seconds solution (used for all other GBAS services) for the whole flight trial. During the flight trial, GBAS services were not available at two times (backup GPS solution plotted in dark blue): at the beginning of the flight, the service was suspended, since the navigation algorithms wait for six minutes to have the smoothing filters reached a steady state and at the end of the Haneda approach procedure, the GBAS service was suspended, since the airborne GNSS receiver was not adequately configured during the flight trials: the ephemeris data were delivered to the navigation system only every five minutes and this led to a time out of 200 seconds after the GBAS ground station transmitted the corrections based on new available ephemeris data.

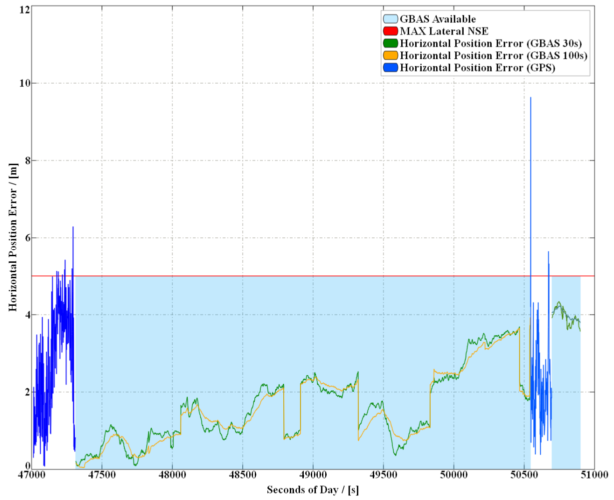

Fig. 4. Horizontal accuracy of all solutions for the whole flight

The green and yellow plots in Figure 4 and Figure 5 show the GBAS solutions with 30 seconds and 100 seconds smoothing time constant. As expected, the 100 seconds solution is less noisy and has a slight delay in contrast to the 30 seconds solution. The horizontal and vertical error of both solutions are within the bounds of allowed error up to GAST C precision approaches (16 meters lateral and 4 meters vertical).

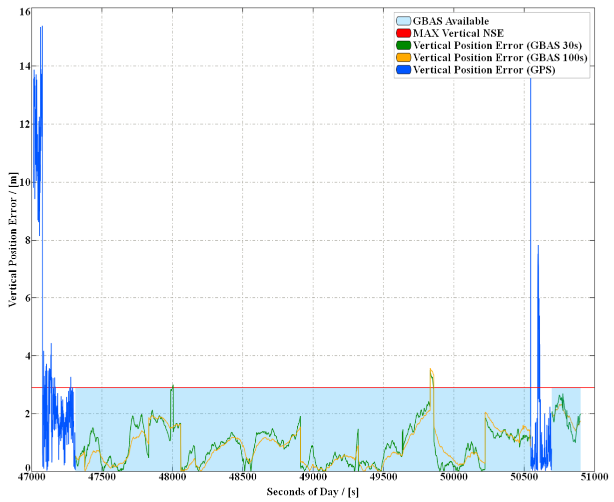

Fig. 5. Vertical accuracy of all solutions for the whole flight

The accuracy for GAST D approaches cannot be assessed completely, since in contrast to GAST C, the Total System Error (including the Flight Technical Error) has to be below certain margins. These margins depend on the individual aircraft, which have to meet the touchdown performance requirements [5]. During the flight trials, only a simple directional aid was used for the pilot, thus the Flight Technical Error was relatively large by known reasons. Nevertheless, the GAST D solution accuracy (Navigation System Error) is below the nominal values given in [4]. The jumps in the Navigation System Error, which can be seen in Figure 6 and Figure 7, are due to a change in the used constellation of the position solution, i.e. satellites were newly added or removed from the position solution.

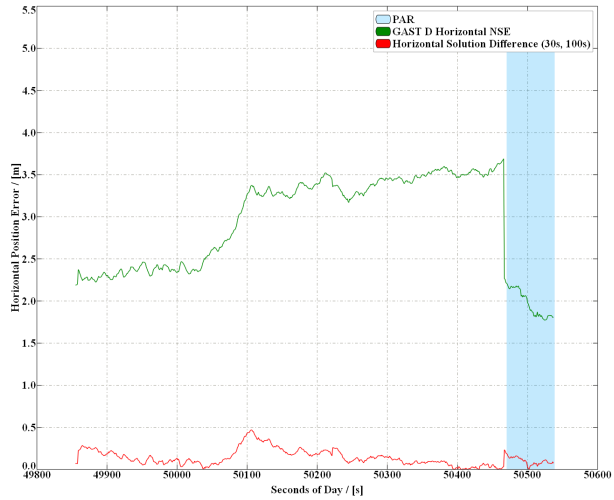

Fig. 6. Horizontal accuracy and position solution difference for the TAP and FAS

As already described, the navigation system has to conduct several monitoring algorithms if operating in GAST D mode. As part of the Dual Solution Ionospheric Gradient Monitor Algorithm, the horizontal and vertical differences between the 30 seconds solution and the 100 seconds solution are shown in Figure 6 and Figure 7. Since the GAST D navigation solution is currently not completely implemented, the horizontal and vertical differences are shown, while in operation, the lateral and vertical projections (with reference to the glidepath) are compared to the thresholds. Nevertheless, both the horizontal and the vertical difference stay far below the (lateral and vertical) threshold of two meters.

Fig. 7. Vertical accuracy and position solution difference for the TAP and FAS

Concerning the parallel conduction of the different navigation algorithms, no objections were found in this assessment. During the complete flight trial, a backup GPS solution was available and as long as GBAS service was available, both the 100 seconds solution and the 30 seconds solution were available. While switching the navigation system position output from the 100 seconds solution to the 30 seconds solution, no major jumps in the horizontal or vertical position were found. If GBAS service is not available or not usable, the solution output switches to sole GPS. As seen in Figure 4 and Figure 5, this can go along with larger jumps in the horizontal and vertical position information. If a flight procedure is being conducted manually by the pilot, these jumps are not seen as an issue, but it has to be further investigated, how automatic flight systems deal with those jumps, e.g. if both the GAST C and GAST D solution are suddenly not usable and the system has to switch to sole GPS.

5 Meteorological Impact

For future on-board systems, arrival at the final approach fix within 5 seconds of the assigned time is required [8]. Since terminal area procedures include descent phases and complicated aircraft manoeuvres, the aircraft trajectory should be affected by meteorological wind variations in the vertical domain and local weather within a horizontal scale of several 10 km. However, weather prediction information in such scale is not so reliable. Therefore, it is important to obtain meteorological information using on-board measurement equipment for now-cast.

We performed flight experiments three times with the same procedure depicted in Figure 3 under different meteorological conditions as shown in Table 2. Wind direction was almost from West to East on all of the three days. We compared time period for each approach from the waypoint WPTS (see Figure 3) to the runway threshold with a modification of flight path length to align to the ideal path because actual flight trajectories were distorted with manual controlled operations by the pilots.

Tab. 2. Meteorological wind conditions

#	Date	Direction	Velocity / [m/s]
1	Apr. 5, 2011	WNW	5 - 20
2	Apr. 7, 2011	W	7 - 25
3	Apr. 11, 2011	WNW	3 - 12

Although an ideal transition time from waypoint WPTS to the runway threshold was calculated as about 697.7 seconds with a constant true airspeed of 70 m/s, time durations of flight transition from WPTS to WPT0 were shorter and one from WPT1 to WPT3 were greater than the ideal reference in all cases because of west wind. A range of their differences was up to about 60 seconds, although flight controls were performed by different pilots. Further analysis is required for evaluation of wind velocity variation and its accumulation effects along the flight path. However, its effect could not be neglected for arrival time estimation.

6 Operational Impact

The operational implementation of novel approach procedures are always subject to comprehensive systematic safety reviews. It is obvious that a safety level equal to already certified procedures must be assured. Nowadays, the spacing between approaching aircraft is achieved by strict adherence of certain criteria, e.g. the wake vortex separation minima matrix. With novel procedures like the discussed GBAS curved approaches or even time-variable GBAS approaches, new hazards must be addressed during the safety reviews and assessments for the certification process.

As an additional safety net, different options of wake vortex advisory systems on-board of aircraft are needed. This is already acknowledged and mentioned in the programs of SESAR [2] and NextGen [1]. The Institute of Flight Guidance at TU Braunschweig is developing a concept to identify the strength and position of the vortices of the own aircraft. The idea is to monitor the wake vortices and their decay behind the aircraft in order to be able to steer on-board control surfaces (e.g. high-lift devices or even ailerons) in a way that the aircraft will not be disturbed in its safe and comfortable flight behaviour but the strength of the vortices will be minimized or, in other words, the speed of their decay will be maximized. In contradiction to other concepts where the position of the own-ship vortices (mostly obtained with model prediction and the well-known input parameters like airspeed, power of lift, actual weight etc.) will be distributed to surrounding traffic with data link capabilities, in the novel concept only a single parameter will be transmitted. This parameter will indicate whether the vortex decay has passed a pre-determined threshold (and is therefore of minor relevance) or not. If its decay is "good", a closer separation (be it steered by ground based air traffic control or under self-separation rules) can be used without negative safety impacts. There are other concepts under discussion and development, of course, where forward looking sensors will try to detect wake vortices of preceding aircraft. These forward looking sensors have the disadvantage of not exactly knowing where the search volumes for the vortices are. Additionally, the sensors have to be much more powerful to receive a certain observing distance in front of the aircraft to give alerts in time. With the TUBS concept, smaller (and most probably cheaper) sensors can be used.

A proof-of-concept hardware-setup is currently under development and will be installed into the research aircraft of the University in late 2012. Using this test setup the concept of own vortex monitoring will be tested and demonstrated. It is expected that this will help to implement novel approach procedures like the GBAS curved approaches into a real world operation environment.

Besides the impact of spacing limitation for approaching aircraft, different other operational limitations have to be considered. For example there is a need for air traffic controllers to monitor the incoming traffic even if the aircraft are on different approach paths inbound a single runway. It must be assured that the aircraft will have their spacing (be it in time or distance units) over a predefined gate. These topics have been addressed already in different research projects [9] and are not subject of this work.

7 Further work

The Institute of Flight Guidance and ENRI are continuing their work on GBAS curved approach procedures. Currently, an improved flight director using the online navigation system and the characteristics of the research aircraft is implemented. It is planned to repeat the flight trials using this flight director. Based on this, also an assessment of the Total System Error is planned. In 2013, the Institute of Flight Guidance is planning additional flight trials with a backward locking LIDAR sensor for monitoring the formation of the own wake vortex. These are planned to be combined with GBAS curved approach procedures.

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