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An operational concept flying GLS approaches using satellite-based augmentation systems

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Abstract

A new converter technology allows suitably equipped aircraft to use data provided by the satellite-based augmentation system in receivers originally designed for the ground-based augmentation landing system. For these aircraft, that system enables a lower decision altitude and, hence, improved access to airports. To make this technology usable, air crews require an operational concept and the flight crew has to be presented with the appropriate information in the form of approach charts. Two different possibilities for an operational concept were developed and the corresponding approach charts created. One option is a modified area navigation approach chart, to which the specific information is added. The other chart is an entirely separate procedure for the approach. These two options were tested with airline pilots in an Airbus A320 full-flight training simulator. During the simulator flights, aircraft performance data was recorded and the participants filled in questionnaires regarding workload and quality of the operational concept. The results show different behavior during the intercept of the final course, but all approaches remained within the required limits. The questionnaires revealed that the workload is higher during the area navigation variant and that all participants prefer the separate ground-based augmentation landing system variant.

Keywords Operational concept · GLS · GLASS · SBAS converter · GNSS · Instrument approach procedure

1 Introduction

Nowadays, most instrument approach procedures to land at airports flown in commercial aviation are based on the Instrument Landing System (ILS). At aerodromes where ILS approaches are not available, Global Navigation Satellite Systems (GNSS)-derived position data are used to fly Required Navigation Performance (RNP) approaches based on area navigation. To improve accuracy and integrity, GNSS such as the Global Positioning System (GPS) can be augmented by a Satellite-Based Augmentation System (SBAS) or a Ground-Based Augmentation System (GBAS) [1]. These systems provide added integrity plus enhanced accuracy and continuity compared to a stand-alone GPS system (see, for example [2, 3] and the references therein).

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An SBAS consists of multiple ground stations spread over a whole continent, one or more master control stations that calculate the correction and integrity information plus at least one satellite in a geostationary orbit. The information is transmitted to the user on the civilian GPS frequency via a transponder on the geostationary satellite. In aircraft, the reception of the signal enables Localizer Performance with Vertical guidance (LPV) final approach segments and their corresponding decision heights. At these heights, the pilot must have visual cues with the runway established or otherwise initiate the missed approach procedure [2]. For this type of approach guidance, final approach segment (FAS) data are stored in the aircraft's navigation database. If LPV is available, its corresponding decision altitude is usually the lowest among all minima available for these approaches. Unfortunately, the LPV final approach segment can only be flown by very few commercial transportation aircraft (only the A350 and A220 at the time of writing), because the required equipment is not commonly certified for any other medium or heavy commercial transport aircraft.

A GBAS consists of three–four GPS receivers, a master station, and an VHF transmitter located at the aerodrome. As with SBAS, the master station computes correction and

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integrity information and provides it to a user, this time with a VHF data broadcast from the ground. This data broadcast contains up to 49 FAS data blocks. When an aircraft uses this technology for landing, it must fly GBAS Landing System (GLS) approaches. Even though many commercial transportation aircraft are equipped with GLS receivers to fly these approaches, they are not widely available due to the extensive costs of a GBAS installation at aerodromes. [4].

Dautermann et al. [5] developed a system to combine the benefits of the two different augmentation systems, while eliminating most of the drawbacks. The GLS Approach using SBAS (GLASS) system consists of a ground station, a receiver for the SBAS signal, and a VDB transmitter for the GLS signal (see also Fig. 1) The received SBAS information is combined with the locally stored FAS data to generate a GBAS Approach Service Type A (GAST-A) signal [6]. Therefore, GLS equipped aircraft can fly the LPV final approach segment of RNP approaches. This system could be implemented at aerodromes having limited installation surface area or investment constraints that prevent the installation of a standard GLS providing the GAST-C service comparable to an ILS.

The service provided by GLASS conforms to the GBAS Approach Service Type A (GAST-A), an approach service originally envisioned by the Australian Ground based Regional Augmentation System GRAS [7, 8].

The technology was tested in flight trials and performed well to GAST-A standards [9, 10]. The next step to the deployment of the GLASS technology is the development of an operational concept (CON OPS) for the usage of this technology during airline operations. For this, we present different approach charts and cockpit procedures to airline crews, have each crew fly the different procedures and evaluate their performance and responses.

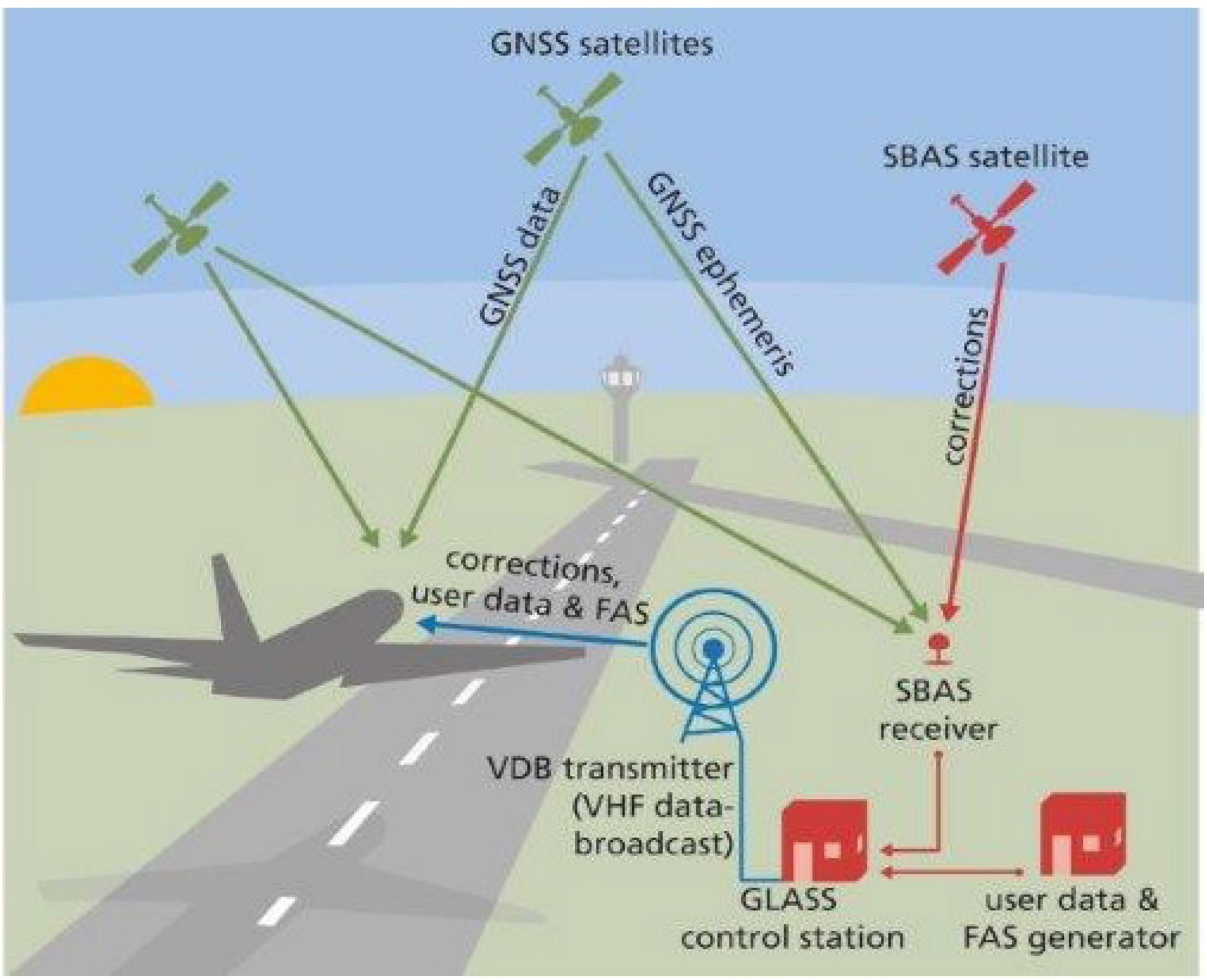


Fig. 1 GLASS architecture enabling GLS equipped aircraft flights to LPV minimum

2 Charting

Every published Instrument Approach Procedure (IAP) to an airport has an associated chart. These charts differ between the approach types and are used by flight crews to obtain the required information about the approach and to set up the avionics in the plane accordingly [11].

Here, we were looking for the best chart to present the required information about GLASS to the crew. The charts we developed are based on the RNP-E approach to runway 15 in Salzburg (LOWS). That chart is published in the Austrian Aeronautical Information Publication (AIP) and can be found at https://eaip.austrocontrol.at/. The approach displayed on this chart is an "LPV only" approach, therefore only aircraft able to use SBAS for IAPs can fly it. The most common commercial air transport aircraft, the Boeing 737 and the Airbus A320 do not have this required equipment. We developed two charts that allow GLS equipped aircraft the usage of that approach.

2.1 GLS variant

The first option is a GLS chart (Fig. 2) with additional information added to inform the pilots it is based on SBAS. The approach needs to be coded as a GLS type and stored the aircraft database in order to enable it to be flown. We applied several changes to the chart compared to the baseline RNP-E chart from the AIP [12]. The chart was renamed to show GLS-E in the upper right-hand corner instead of RNP-E. Another box further to the left in the top row shows the information required to fly the GLS. This includes the 5-digit channel number (22265) which is required to enable the reception of the GLS signal via the avionics and 4-digit identifier S15A. If the correct channel number is tuned and the avionics receive the signal, this identifier is displayed on the Primary Flight Display (PFD) on the flight deck. This allows the flight crew to verify the correct setting of the GLS receiver. In addition to the information at the top of the chart, a box in the center of the chart shows a remark. This remark contains the same channel number and identifier as shown at the top of the chart. Furthermore, it informs the pilots about the fact, that LPV service is provided via this GLS signal.

2.2 RNP variant

The second option is an RNP approach chart for GLASS operation. The difference between the published RNP-E chart and ours is the remarks box next to the final on the drawing. It states that the LPV final is also provided via a GLS channel. The corresponding channel number and identifier are given in the remarks box. (Fig. 3).

3 Operation and task distribution

To be able to accommodate the GLASS concept, we adapted the standard operating procedures for an Airbus A320 aircraft to include the actions that are unique to the GLASS technology. We chose the A320, because it is one of the most common commercial transportation category aircraft and a A320 Full-Flight-Simulator with GLS capabilities allowing data extraction was available at Lufthansa Aviation Training.

Here, we present the crew task distribution for the two variants of GLASS usage. The tables in this chapter show the tasks the flight crew must perform when using GLASS in an A320. The tables start with the preparation of the approach and end at the minimum descent altitude, at which the pilots must decide whether to continue for landing or initiate the missed approach procedure.

Commercial transport airplanes such as the A320 are routinely flown by two pilots. Both can fly the aircraft and have the same controls options on their respective side. The tasks during flight are usually distributed to the pilot flying (PF) and the pilot monitoring (PM). The PF directly controls the flight path of the aircraft either manually, using the control interface, or by using the autopilot. The PM on the other hand performs the tasks that do not influence the path directly such as communication with air traffic control and reading of checklists. As both pilots are trained to perform both tasks, they usually change roles after each flight.

3.1 GLS

During an approach with a GLS approach chart, the crew can use the standard GLS procedures that they learned during their training where the GLS is flown ILS look-a-like. The difference for the flight crews is very small compared to ILS, as the avionics of the aircraft displays GLS deviations the same way as ILS deviations and the system selects the correct settings when the approach is loaded in the Flight Management System (FMS).

The tasks the crew must perform for the approach are shown in chronological order in Table 1. Those tasks that are specific for the GLS approach are shown in bold. Table 1 is divided in three parts, to highlight the three different situations during approach in which the listed tasks are performed.

Especially, the verification of the correct channel number and identifier are important. The channel number is tuned automatically by the aircraft to allow the reception of the GLS signal. The identifier is part of that signal and displayed on the primary flight displays when received. By comparing

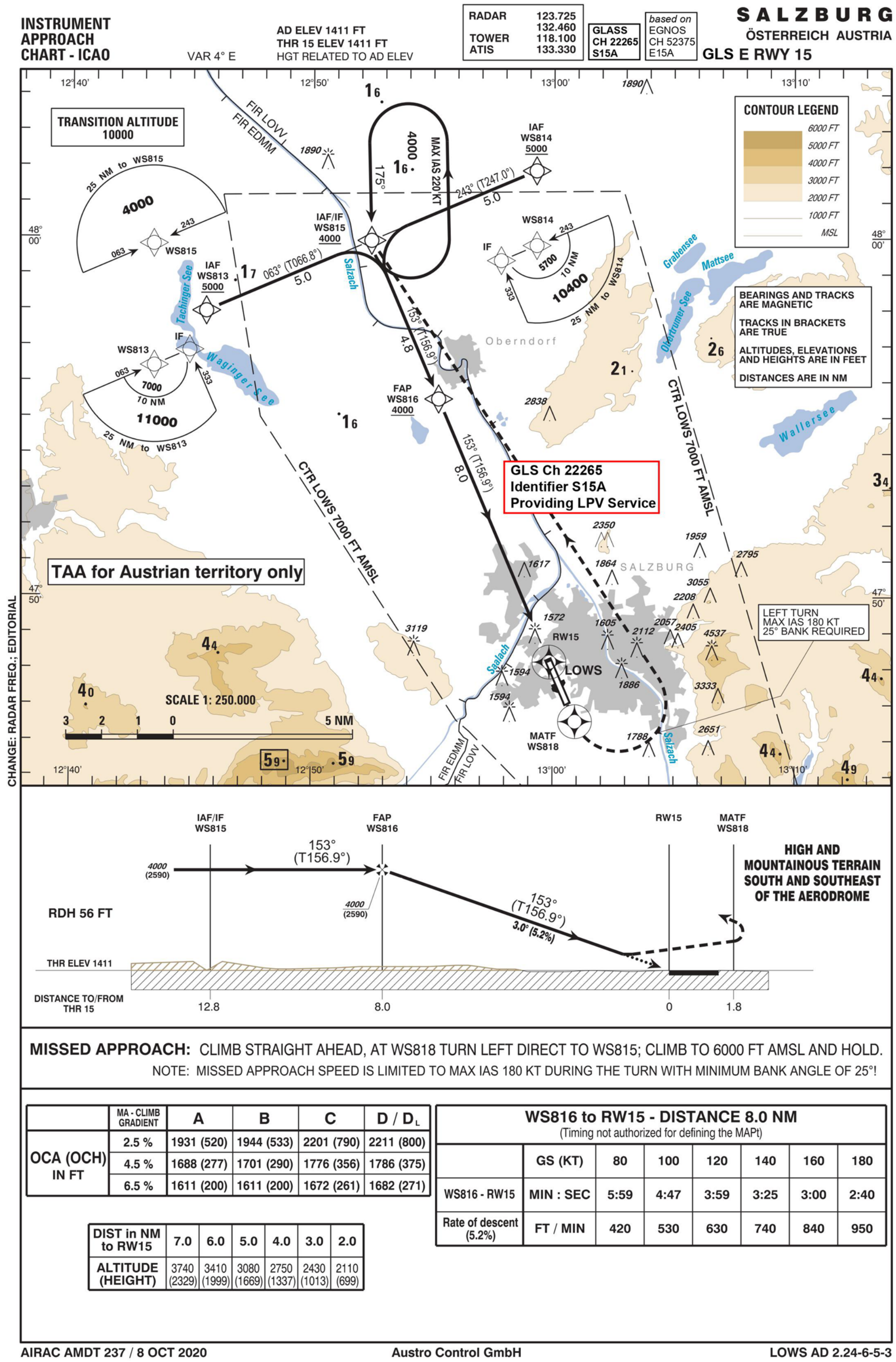


Fig. 2 New GLS chart for GLASS operation to Salzburg adapted from AIP LOWS RNP-E 15 chart

the received identifier with the identifier shown on the chart the crew verifies that the desired signal is received.

3.2 RNP variant

When flying the RNP variant of the approach, the pilots load the RNP approach from the FMS. Usually, the avionics of A320 aircraft selects and tunes the required navigation aids automatically. Since an RNP approach does not require any ground-based infrastructure, naturally the FMS does not automatically tune any specific navigation aid. Therefore, the system cannot tune the required GLS channel number and inbound course automatically to use the GLASS-GLS signal. Manual pilot input of the GLS channel into the FMS

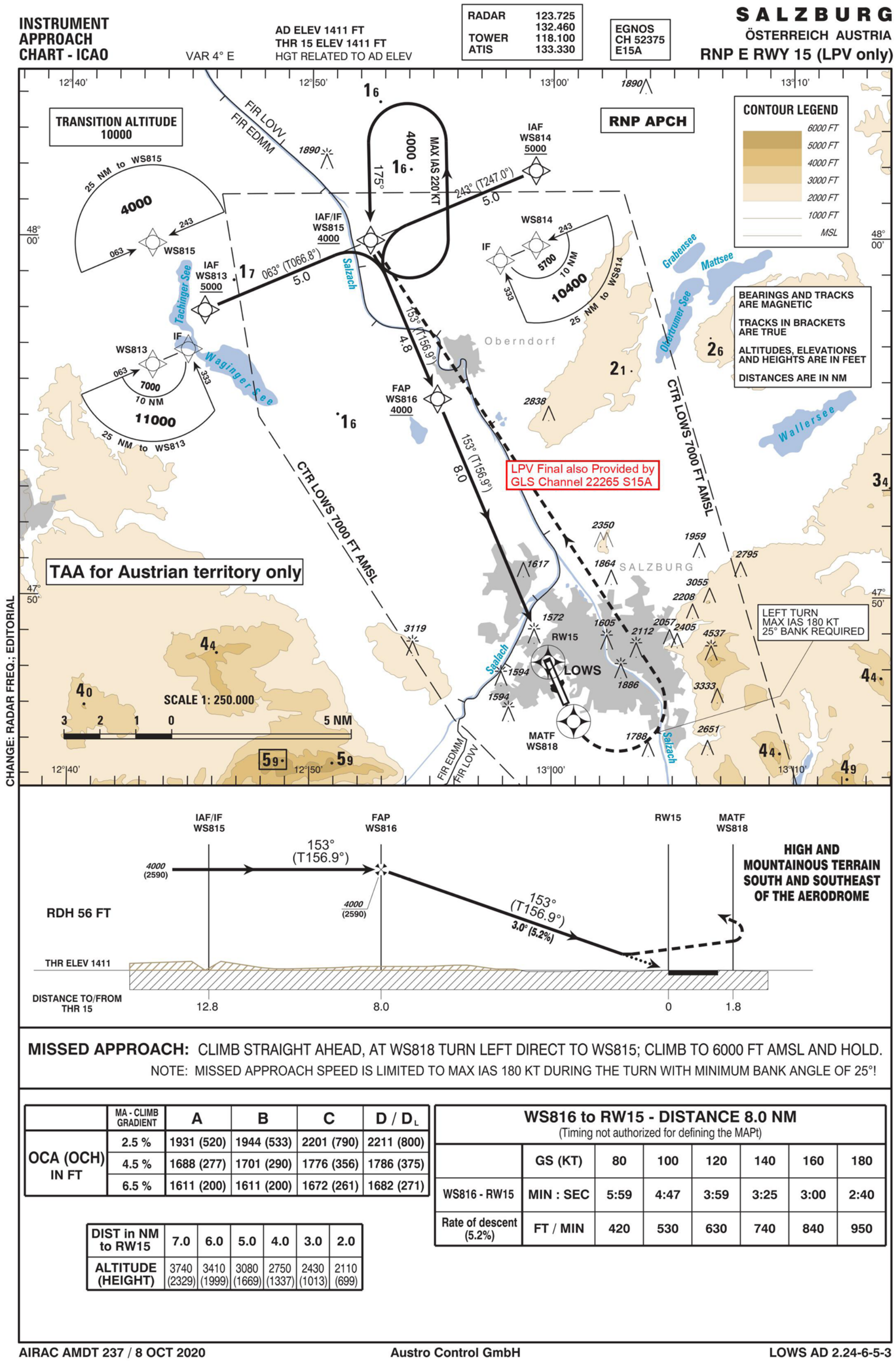


Fig. 3 Adapted RNP-Chart for LOWS RNP-E 15 including GLASS technology information

is displayed on the PFD but ignored by the flight guidance computer.

This leads to the largest difference in operation. The backup tuning function must be used to enable the reception and usage of the GLS signal in the flight guidance computer of A320 aircraft. The pilots must manually switch on backup tuning of the GLS on the COM/NAV panel on the center pedestal and select the correct channel number and inbound course on that panel during an approach using GLASS and a RNP approach loaded from the FMS. All differences in operation by the crew are shown in table Table 2.

Table 1 Task list for pilot flying and pilot monitoring during an approach using GLASS technology and GLS operation. Those tasks that are specific for the GLS approach are shown in bold

Tasks for Pilot Flying	Tasks for Pilot Monitoring
Descent Preparation	
	Obtain Weather and Landing Information
Prepare Nav Charts	Prepare Nav Charts
Confirm Landing Performance	Check Landing Performance
Insert GLS approach in FMS	**Verify Correct Approach Set**
Set GLS Minimum	**Set GLS Minimum**
Check Landing Elevation	
Set Autobrake as Required	
Perform Approach Briefing	
Set Terrain on Navigation Display as Required	Set Terrain on Navigation Display as Required
Adjust Weather Radar as Required	
	Set Anti Ice System as Required
	Obtain Descent Clearance
Set Cleared Altitude in Flight Control Unit	
Descent	
Monitor Descent	
Set and Crosscheck Barometric Reference when Cleared for an Altitude	Set and Crosscheck Barometric Reference when Cleared for an Altitude
	Check ECAM Status
	Switch on Landing Lights and Seat Belt Signs when Passing 10.000 ft
Press Landing System Button on EFIS Control Panel	Press Landing System Button on EFIS Control Panel
	Verify Correct Channel Number and Identifier
Complete Approach Checklist	Complete Approach Checklist
Aircraft configuration for approach	
On Initial Approach Adjust Flight Plan Sequencing	
Approximately 15 NM before Touchdown Activate Approach Phase	
Check Managed Speed	
Monitor and Adjust Flight Path as Required	Monitor Navigation Accuracy
Adjust Weather Radar as Required	
	Readback Approach Clearance when Received
Press Approach Button on FCU	
Check LOC and GS Armed	
Call out LOC when Intercepting GLS LOC*	
Check Correct Lateral Intercept of Approach	**Check Correct Lateral Intercept of Approach**
Callout GS when Intercepting GLS GS*	
Check Correct Vertical Intercept of Approach	**Check Correct Vertical Intercept of Approach**
Set Go Around Altitude	
At Green Dot Speed Order Flaps 1	Select Flaps 1 when Ordered
Check S Speed	
Order Flaps 2 Minimum 2000ft AGL	Select Flaps 2 when Ordered
Check F Speed	
Order Landing Gear down when Flaps are 2	Select Landing Gear Lever Down when ordered
	Confirm Auto Brake
	Arm Ground Spoilers
	Set Exterior Lights
Order Flaps 3 when Landing Gear is deployed	Select Flaps 3 when ordered
	Check ECAM Wheel Page
Order Flaps FULL when Flaps are 3	Select Flaps FULL when ordered
Check Speed Target	Check Auto Thrust on Speed Mode or Off

Table 1 (continued)

Tasks for Pilot Flying	Tasks for Pilot Monitoring
	Turn Wing Anti Ice System off if not Required
Stow Sliding Table	Stow Sliding Table
	Check Landing Memo no Blue on ECAM Display
Receive Cabin Report	Receive Cabin Report
	Advise Cabin Crew
Complete Landing Checklist	Complete Landing Checklist
Call Out any Flight Mode Annunciator Change	Monitor Flight Parameters
Continue or Go Around at GLS Minimum	Monitor One Hundred Above and Minimum call

[12] derived from A320 Quick Reference Handbook [13]

Table 2 Task list for pilot flying and pilot monitoring during an approach using GLASS technology and RNP operation. Those tasks that are specific for the GLS approach are shown in bold. GS* and LOC* are specific modes of the Airbus autoflight system [13]

Tasks for Pilot Flying	Tasks for Pilot Monitoring
Descent Preparation	
	Obtain Weather and Landing Information
Prepare Nav Charts	Prepare Nav Charts
Confirm Landing Performance	Check Landing Performance
Insert RNP approach in FMS	**Verify Correct Approach Set**
Tune GLS Channel Number	**Tune GLS Channel Number**
Select Inbound Course	**Select Inbound Course**
Set LPV Minimum	**Set LPV Minimum**
Check Landing Elevation	
Continued as Shown in Table 1	
DESCENT	
As shown in Table 1	
Press Landing System Button	Press Landing System Button
	Verify correct Channel Number and identifier
Complete Approach Checklist	Complete Approach Checklist
Aircraft Configuration For Approach	
As shown in Table 1	
Press Approach Button on FCU	
Check LOC and GS Armed	
Call out LOC when Intercepting GLS LOC*	
Check Correct Lateral Intercept of Approach	**Check Correct Lateral Intercept of Approach**
Callout GS when Intercepting GLS GS*	
Check Correct Vertical Intercept of Approach	**Check Correct Vertical Intercept of Approach**
Set Go Around Altitude	
As shown in Table 1	
Call Out any Flight Mode Annunciator Change	Monitor Flight Parameters
Continue or Go Around at LPV Minimum	Monitor One Hundred Above and Minimum call

[12], derived from A320 Quick Reference Handbook [13]

4 Simulator study

To evaluate the different variants described above, we performed a simulator study in an Airbus 320 CAE7000XR type full-flight certified level D simulator. Aim of the study was to find the variant of representation and operation that produces the highest amount of safety. Safety plays the most important role in aviation but cannot be easily measured. To assess safety in the simulator, we recorded the flown tracks for later analysis and measured the task load of the flight crews [12].

For every published approach an obstacle assessment must be performed by the procedure designer before publication. Thus, the published track assures the obstacle and terrain clearance for approaching aircraft. For every segment of the approach, a Cross-Track Tolerance (XTT) is considered during approach design. This XTT is 1.9 km during the initial and intermediate approach and reduces to 556 m on final approach during an RNP-LPV approach [14]. Naturally, the terrain clearance cannot be guaranteed when deviating further than this from the published track. Therefore, the pilot and aircraft must maintain the deviation from the desired track as small as possible.

The cross-track error is influenced by several factors. The largest effects come from pilot and autopilot input whilst these inputs are influenced by different factors themselves. The autopilot inputs are mostly influenced by the input signals such as the deviation from the desired track that is calculated inside the aircraft's Multi-Mode Receiver (MMR). Whether the autopilot follows that signal also depends on the active mode and loaded path in the FMS. As these differ between the RNP and GLS variant, the cross-track deviation may differ. Another reason for differing deviations is the pilots' inputs to control the modes of the autopilot. Lastly, because the operating procedures for the flight crew differ between the two variants, different cross-track errors behavior might result.

In addition to the deviation from the ideal track, the crew workload is a factor that influences safety. Optimal performance of flight crews can be achieved with tasks that do not overwhelm, but also do not underchallenge [15]. Since the workload during a standard approach is enough to assure the crew is not underchallenged [16], the focus lies on not overwhelming the crews during the approaches with the operations considered in this manuscript. Consequently, a low task load is desired.

The study was performed with two professional flight crews. We restricted ourselves to booking one simulator slot lasting four hours, resulting in two hours per crew of two pilots. Due to the hygienic and social distancing regulations during the pandemic situation in fall 2020, when the study took place, this was also the maximum allowable traffic load of the simulator facility. Hence, no statistical significance test could be run on the data collected. Other simulator studies to similar topics but utilizing statistical analysis used a minimum of 13–26 pilots as test subjects [17–19].

Three of the test subjects possessed an Airline Transport Pilot Licence (ATPL) and one held a Multi-Crew Pilot Licence (MPL). Flight experience ranged from 1500 flight hours to the most experienced pilot with 16,000 h.

Figure 4 shows the course of the simulator study. Before entering the simulator, the crews were briefed on the GLASS technology and the tuning of the backup navigation panel during the RNP approaches. During the flights we stayed as close to real world training scenarios as possible. The flight of each crew started with a standard instrument departure followed by several approaches. Each pilot flew both variants as PF and PM resulting in a total of 4 approaches per crew.

Pilots were free to use the autopilot, as they would during flight in a real aircraft for their airline. All pilots kept the autopilot on until some point on the final. A former DFS air traffic controller handled the tasks of the air traffic control officers.

During the approaches we recorded the track and altitude for later analysis. Additionally, the participants were asked to fill in questionnaires to access their workload and preferences.

4.1 Questionnaires

In the study, we used two types of questionnaires to evaluate the approach variants, NASA Task Load Index

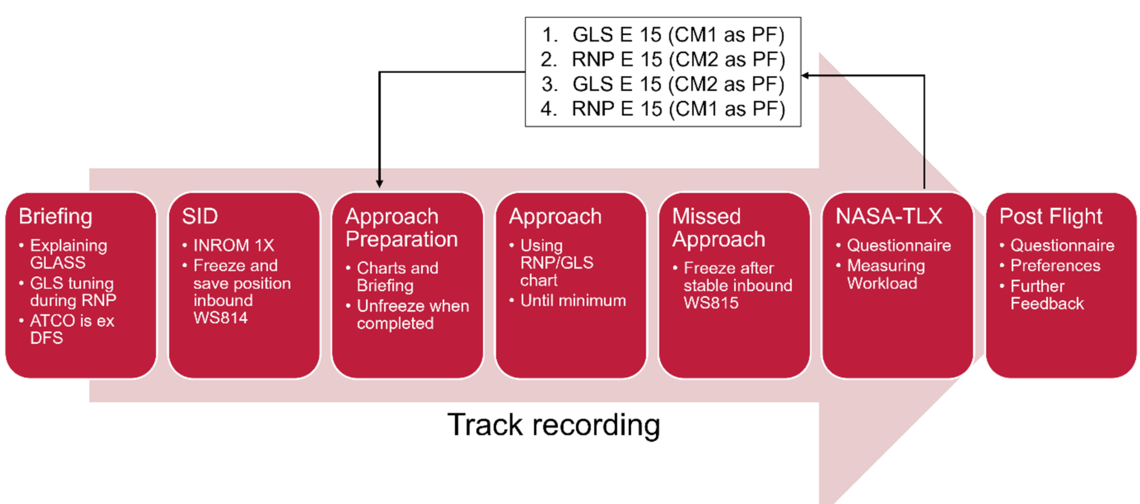


Fig. 4 Sequence of events during the simulator study

(NASA-TLX) and a customized satisfaction survey. NASA-TLX is a multi-dimensional scale designed to obtain workload estimates. It consists of six subscales on which the participants rate their experience during the task. This procedure was developed by [20]. The six subscales are also described there. The results of the six subscales can be weighted using the procedure originally published with the NASA-TLX to account for the individual perception of workload. Here, we were only interested in overall task load and we chose hence to not perform any weighting on the results [21]. Each pilot completed one NASA-TLX questionnaire after each individual approach was completed to assess workload for the different variants.

The second questionnaire was filled by the participants after the simulator session was completed. Here, we asked the participants for their personal comfort during the different approach variants and their opinion on which version is more prone to error and which option, in their opinion, has the clearer presentation. Additionally, we inquired which version the participants would prefer for an operational implementation. The personal comfort was rated on a 0–100 scale and with each of the other questions the participants could choose between the options GLS and RNP. As a third option, 'No Difference' was added in case the participants could not detect differences. Additionally, the post-flight questionnaire had fields for open feedback by the participants.

5 Performance data results

Figure 5 shows the trajectories flown during the simulator study. The GLS approaches that commence at a higher and lower altitude than the others are a result of miscommunication. The first crew was not aware that they were responsible for the descent planning. When this was detected and the crew was informed about their own responsibility, they immediately initiated a descent. Even though they were on a higher profile compared to the other approaches, they rightfully felt confident to reach the required altitudes. The second crew was told about their own responsibility to plan the descent and as a result were very cautious. That lead to one approach that was lower than the others. Apart from that, no other large-scale differences could be found in the trajectories.

Figure 5 indicates the lateral deviation from the line connecting the waypoints WS815, WS816 and the runway threshold. The X-axis shows the distance from the runway threshold in kilometers. It starts at 2 km, because the crews initiated a missed approach procedure when reaching the decision altitude approximately 2.2 km from the runway. The deviation during the missed approach procedure was not part of our study. At 14.3 km, a black vertical line shows the location of WS816 with respect to the runway. Deviations in flight direction to the right are shown as negative deviations. Positive values on the y-axis indicate a deviation to the left of the ideal track.

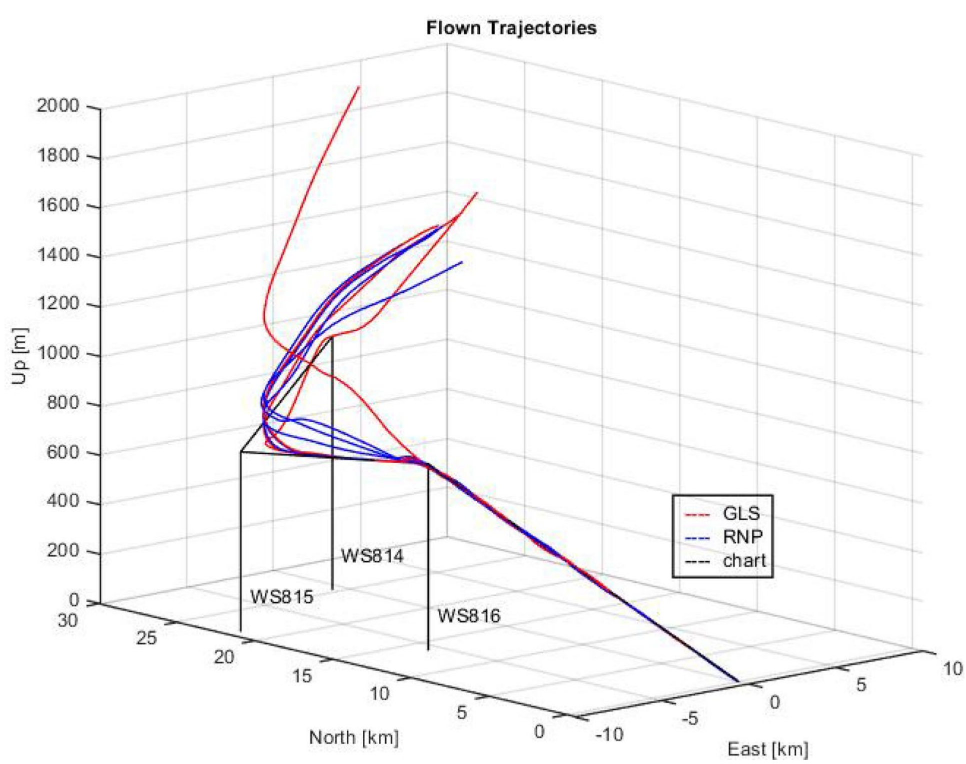


Fig. 5 Trajectories flown during the simulator study. Blue trajectories were flown using the RNP variant. Red shows the approaches flown with the GLS chart

The large deviation on the far side of WS816 is a result of the fly-by waypoint WS815. At such waypoints, the aircraft shall turn before reaching the point to intercept the track towards the following waypoint. The aircraft's FMS calculates the turn and commands the autopilot or flight director to fly it.

In Fig. 6, the deviations during the RNP variant are shown in blue, while those during approaches with the GLS variant are shown in red. Using the RNP variant, the deviation after the turn reduces quickly to approximately 7 m. After that, it takes about 5 km to reduce the deviation to almost zero. No overshoot was recorded during the RNP variants.

The resulting turns during the GLS variant do not show such a uniform picture. During two of those approaches the deviation was diminishing slower than during the RNP variants, but continuously down to zero and stayed there. In the other two instances, the deviation does not decrease continuously but stagnates, respectively, increases slightly, before decreasing again and intercepting the ideal track. During two approaches using GLS operation, an overshoot was recorded.

We could not determine the reason for the different behavior using GLS operation beyond doubt, but it is assumed, that the FMS calculation of the turn is responsible. Additionally, we recorded the speed during the approach and use it for explanation of this behavior. We can explain the slight increase in deviation in such a way, that the deceleration was happening at that time resulting in a bank angle that is too large for the speed, as the turn was calculated with the speed prior the initiation of the turn. The FMS than detects the deviation and corrects for it. It could not be verified that this behavior is responsible for that increase, because the exact algorithms used by the FMS are not publicly available.

Another possible explanation is that during a GLS approach the FMS expects to follow the localizer deviation after the intercept course and, therefore, does not anticipate the turn once the aircraft is on the intercept course. During an RNP approach, the FMS calculates and directs the turn to final just as any other turn. When on localizer intercept course, the corresponding intercept mode (LOC*) takes over without the plane anticipating a turn.

After the intercept of the desired track, one approach using the RNP variant deviates 10 m to the right of the course. This deviation is likely caused by manual flying of the respective pilot. Apart from that we found no differences between the variants after the intercept. Since the autoflight system is in the same mode (LOC GS) at this stage and the crews' tasks also do not differ, no significant difference was expected during this phase. During an GLS approach, the maximum lateral deviation an aircraft may have at the minimum of 356 ft height, while still having the full vertical tolerances, is 58 m [14]. This is the point with the lowest XTE tolerance. The recorded values of up to 10 m in 10 km distance are well below that limit.

Analysis of the other legs, the vertical deviation, and speed revealed no connection between the variant of chart with its type of operation and possible deviations. Therefore, no option is clearly superior to the other, but during

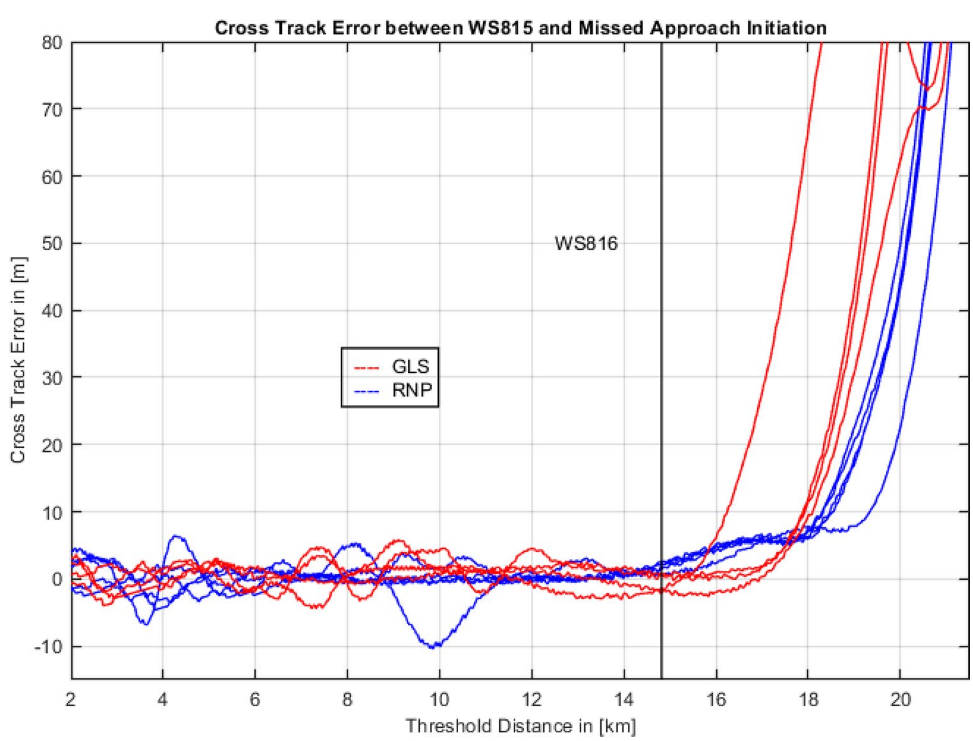


Fig. 6 Cross-track error during the simulator flights between waypoints WS815 and the initiation of the missed approach procedure

the intercept the RNP variant led to less overshoot and to a continuous intercept.

6 Post flight questionnaire

After the last approach and the last NASA-TLX questionnaire, we asked the participants to fill in the post-flight questionnaire. In this questionnaire all participants revealed that they felt more comfortable during the GLS variant of the approach as shown in Fig. 7. The values differ a lot between the individual pilots. One pilot rated his comfort during the GLS variant with about 90 on a scale of 0–100 and during the RNP variant less than a third of that. One pilot on the other hand felt almost the same comfort during both variants with a difference in rating of about 5.

With respect to the question which variant is more prone to error, half of the pilots taking part in the study chose either option. Therefore, no advantage for either option can be determined from the answers to this question. With three out of four and four out of four the results to the questions for the clearer presentation and the personal preference of the participants were very much in favor of the GLS variant.

Additionally, the post-flight questionnaire had a field for open feedback by the participants. This feedback was focused on the way the tuning of the GLS was performed during the RNP version of the approach. The participants criticized this way of tuning and do not recommend it, as it induces the feeling of being in a non-normal situation. The results from this questionnaire indicate that the GLS variant is the better option for the implementation of GLASS, but it is possible that the results are strongly influenced by the "non-normal" feeling of the crews during the backup tuning. The way of tuning could influence the personal comfort during the approaches and, therefore, the preference of the participants greatly.

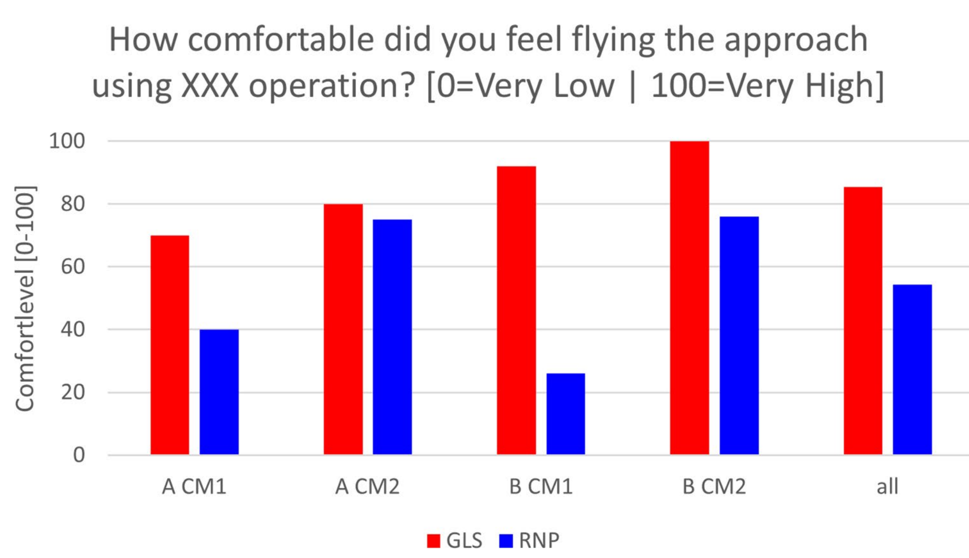
7 NASA-TLX questionnaire

To assess the workload which the crews experienced, we compared the reported TLX values of every participant for the different variants to each other. Overall, the reported values again vary a lot between the individual pilots. While one participant reported an experienced workload of up to 67 out of 100 another pilot reported a maximum value of 22. That difference and the small number of participants in the study lead to the decision to not use average results but compare the two variants for every pilot individually. Figure 8 shows the results of the raw NASA-TLX that is calculated by averaging the subscale reports of the individual participants.

It can be seen that the RNP generates higher workloads for all PFs and two PMs, whereof one is almost the same for both variants. On the other hand, only one participant experienced a higher workload during the GLS as PM. Even though the differences in the values vary, in most cases the RNP variant resulted in higher crew workload. Due to a software glitch, two datasets for the first crew were lost, therefore we could not use that data for comparison.

Since the results of the post-flight questionnaire indicate a strong influence of the "non-normal" feeling, we checked the subscales "Mental Demand" and "Frustration Level" of the NASA-TLX. These subscales were chosen, because we expected that the stress resulting from the tuning method is prominent. Especially, the values for PF show the increased workload during the RNP variant for all pilots. The values for the PM show larger values for two participants during the RNP variant and no difference for one.

Fig. 7 Personal comfort results from the Post Flight questionnaire



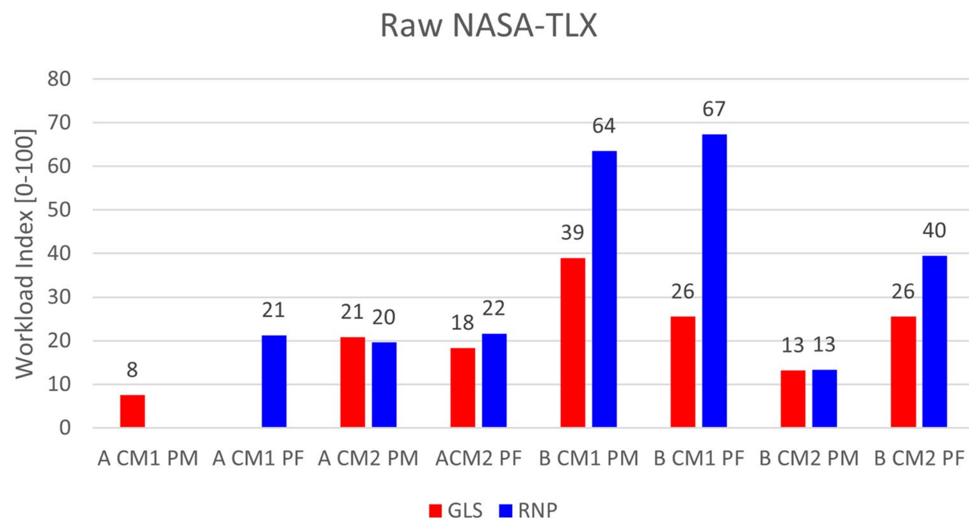


Fig. 8 RAW NASA-TLX results for each crew member in both roles

8 Conclusions

The criticism of the participants in the post-flight questionnaire indicate that the GLS variant is the better option for a chart representation of approaches using GLASS. This is further substantiated by the other results of the questionnaires. The NASA-TLX questionnaire with its lower workload during the GLS variant, as well as the post-flight questionnaire with the subjective opinions of the participants indicate the superiority of the GLS variant. This agreement in both questionnaires could be a result of the unusual tuning and the feelings pilots associate with this unusual technique. It is, therefore, possible that the workload would be felt differently in another airplane type, in which no backup tuning function must be used.

The objective track analysis on the other hand did not show any advantage of the GLS. During the intercept of the GLS variant two tracks showed a non-continuous decrease of the XTE. Additionally, the aircraft speed of convergence with the final approach track was faster during the GLS variants, leading to two of the approaches overshooting the ideal track line. On the other hand, the reduction of the cross-track error during the RNP variant of the approach was in all cases continuous and no overshoot was recorded. However, none of these deviations were safety critical.

Overall, this study shows that a separate GLS chart for approaches using the GLASS technology results in less workload for the flight crew of an Airbus A320. This is also the option pilots prefer for the new technology and the option they feel more comfortable using. We also found that apart from the effects of the tuning method, the results of the variant using a modified RNP chart are not significantly worse.

As no new approach would have to be generated and published by the national Air Navigation Service Provider (ANSP), the RNP variant is expected to be quicker and easier in implementation from a ANSP perspective. For the publication as GLS approach, a completely new obstacle assessment would need to be performed for the FAS as required by PANS-OPS.

The flight crew could also be trained to load a GLS type approach from the database when performing GLASS RNP approach. For the Salzburg example, air traffic control would clear the aircraft for the RNP-E approach. The flight crew knows from training, that in this case they need to load the GLS-E if they want to make use of the LPV minimum. If this technique is used, the safety impact of the mismatch between ATC instructions and pilot procedure must be assessed. It would lead to a lower cockpit workload, since no backup tuning is required, but necessitates a tailored database for the FMS.

Our recommendation is that only specially trained pilots should use the RNP chart for approaches using GLASS technology in A320 aircraft, so they are aware of the different tuning and higher taskload.

It is possible that the difference between the variants is significantly lower or even non-existent when another type of aircraft is used to fly the approaches. The way of tuning the required navigation aid differs between the manufacturers and even between different models. Additionally, the FMS calculation of turns that resulted in the higher deviation during the GLS variant may differ in another aircraft type.

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