GNSS SOLUTIONS FOR INCREASED GA AND ROTORCRAFT AIRPORT ACCESSIBILITY DEMONSTRATION

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Abstract
Within the framework of the SESAR programme concepts were developed to integrate general aviation aircraft and rotorcraft into the airspace and airports without influencing the main traffic flow. On the one hand this paper discusses the idea of a low-level route network to allow IFR operations separately from the regular routing. On the other hand the concept of simultaneous non-interfering approaches is presented to guide these aircraft to or from a point in space located at a final approach and take-off area from which it can continue visually to land. Both concepts have been evaluated in real-time simulations by DLR in preparation for a flight trial. The exercise will be explained in detail and the results show that operational concepts should work. It is concluded to continue the process of implementing these concepts and advised to enable safer flight by further promoting advanced point-in-space procedures.

1. INTRODUCTION

The main objective of the GRADE project is to enable General Aviation (GA) and Rotorcraft (RC) to benefit from the concepts developed in the framework of the SESAR programme, through the integration of GA and RC into the airspace and the airports where the SESAR concepts and technologies are implemented. Here, we describe the layout and results of one of the exercises, a real-time simulation campaign, of one solution. This solution looks at the concept of low-level route networks (LLR), simultaneous non-interfering (SNI) approaches and departures enabled by standard or advanced Point-in-Space procedures (PinS). The PinS procedure is designed to and from final approach and take-off areas (FATO).

The rotorcraft can follow a LLR network from one hospital to another or to a local airport under IFR. At the airport, the rotorcraft flies a PinS procedure which was designed to be an SNI approach with fixed wing aircraft approaching at the same time on conventional RNP or ILS approaches. Final approach separation for the rotorcraft on the PinS is assured by proceeding visually from the missed approach point to a dedicated helipad on the apron. If visual reference is not established at the PinS, the rotorcraft will execute a SNI missed approach procedure. The PinS is designed such, that all separation limits are respected according to SESAR 4.10 Deliverable 23.

The approach procedure (see also Figure 1) commences at point LELUH near the Wolfenbuettel General Hospital. The procedure as depicted can be coded and flown as standard or advanced PinS, but is optimized using Radius to Fix (RF) before the Final Approach Point (FAP) and in the missed approach. The final approach begins at the FAP and is a Localizer performance with vertical guidance (LPV) segment with a fictitious threshold point located such that the glide path intercept point is exactly at the desired helipad. Vertical Guidance is an ILS Lookalike guidance provided by SBAS using a 4.4° glide path angle. Minimum descent altitude is 628ft MSL (350ft GND), thereafter proceed visually if the helipad is in sight.

The missed approach commences upon abortion of the approach procedure, i.e. if no visual references are established by the time the aircraft reaches the Missed Approach Point (MAPt). The pilot must initiate a climb to 2200ft MSL and follow the track as depicted. Upon crossing the MAPt an immediate left turn to “WP4” is required. For advanced PinS, this leg is coded as a RF to “WP4” with a radius of 1 NM and RNP0.3. In lieu of the RF, a fly-by waypoint FB5 can be used, but for track keeping accuracy and separation assurance, we strongly recommend using RF. After “WP4” a 1.5NM straight leg follows to “WP6”. After “WP6”, if an advanced PinS is desired, the leg from “WP6” to “WP7” can be coded as RF with a radius of 2.75NM. If an advanced PinS is not desired, “FP8” can be used in lieu of the RF. After “WP7”, the aircraft returns to LELUH with a track to fix of length 5.1NM. We designed the missed approach track along the track of the city tangent motorway to reduce noise exposure of downtown Braunschweig.

During the real-time simulation event several environmental conditions were demonstrated. It also serves as preparation for an upcoming real flight demonstration, where visual meteorological condition (VMC) is required. In the alternate solution scenario, the execution of a missed

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approach was conducted in visual conditions by the rotorcraft. It was shown that SNI missed approaches are possible and safe. For the matter of time saving and complexity reduction the design of the missed approach is altered slightly to allow continuous approach and missed approach segments.

In the following the technology and procedures are described, the real-time simulation is explained and the results are presented.

1.1. Advanced PINs

Radius to fix (RF) legs are fixed radius curve elements and provide a repeatable track over ground. Advanced PinS instrument approach procedures, as opposed to the classical PinS, further utilize RF ARINC424 leg types when transitions between straight segments of different ground tracks are desired. With advanced PinS these RF legs can be placed in the intermediate approach up to the FAP, after the initial departure fix (IDF), and after the MAPt. We designed our approach with a glide path angle of 4.4° out of 2200ft MSL with a 50 degrees track offset to runway 26 (263 + 50 = 313) towards the Helipad West at Braunschweig-Wolfsburg International Airport (ICAO EDVE, IATA BWE). Advanced PinS design also utilizes Track to Fix (TF) legs and an LPV final approach. Moreover, the missed approach guidance is also via a left turn provided by a RF leg. In case of early missed approach, the pilot can climb but must follow the track guidance as provided by the procedure. In case of visual references at the MAPt, the pilot can opt to continue visually to the FATO. Details can be found in [7] and [8].

The missed approach was placed such that the distance d > XTT=0.3nm when 45° track divergence is achieved (SESAR 4.10 D23, p26) using a RF leg with radius of 1NM

The Minimum Visual Segment Length is 0.85NM (PANS-OPS IV-2-7, 2.9.2.6.3). The turning missed approach is the same as for standard LPV (PANS-OPS III-3-5).FTP is located at the Turning Point (PANS-OPS III-3-5-8, 5.5.3.3). Turning point is 0.3NM + 6s times 90kts = 0.45NM before latest turning point (PANS-OPS III-3-5-8, 5.5.3.3.1). The earliest turning point is ATT before the MAPt, the latest turning point at SOC + pilot reaction time + bank angle delay (PANS-OPS Table III-2-2-1). SOC is coincident with the earliest TP (PANS-OPS III-3-5-8, 5.5.3.3.1). Pilot reaction time in missed approach is 3s and bank angle delay is 3s (PANS-OPS Table I-2-3-1) totaling to 6 seconds at 90kt = 0.15 NM. Hence the latest turning point is earliest TP + 0.15NM. ATT at the MAPt is 0.24NM for RNP0.3/advanced RNP (III-1-2-6, Table III-1-2-10). Hence earliest turn is 0.24NM before the MAPt. SOC is defined by the height and range at which the plane GP' reaches an altitude OCA/H – HL (HL=Height Loss, PANS OPS Table II-1-1-2, Cat H 115ft using pressure altimeter).

The entire procedure is shown in Figure 1 and Figure 2.

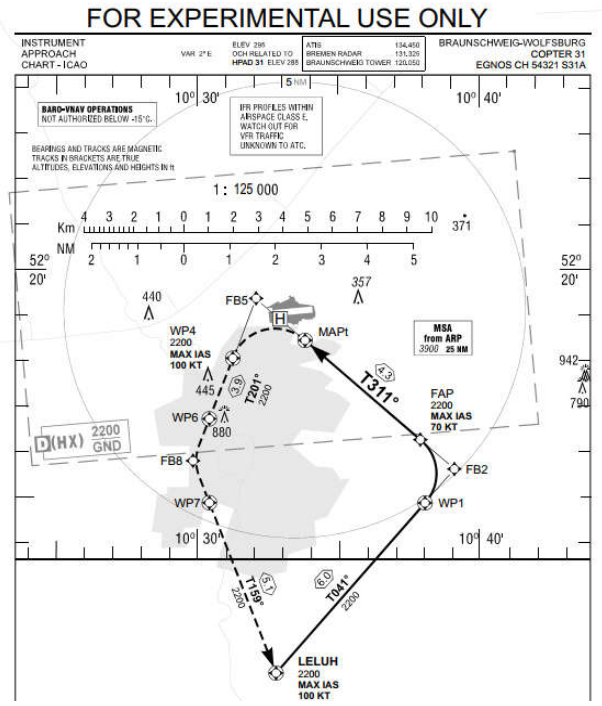

Figure 1: Possible Simultaneous Non-Interfering approach

1.2. SBAS LPV Final Approach

General and business aviation often augment their GNSS navigation solution using satellite based augmentation systems (SBAS) as they normally fly to smaller airfields with little infrastructure. SBAS systems provide regionally valid differential corrections [9] and integrity [15] information for GNSS by means of a satellite downlink. A detailed review of SBAS use for aviation can, for example, be found in [1].

Lateral and vertical final approach guidance using GNSS augmentation systems such as SBAS (called Wide Area Augmentation System (WAAS) in the US [10], European Geostationary Navigation Overlay Service (EGNOS) in Europe [4]) is possible by means of a final approach segment (FAS) data block. The set of parameters contains, amongst others, the coordinates of the runway threshold, glide path angle, threshold crossing height, course width at the threshold and

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a flight path alignment point which is usually the opposite runway threshold [12].The FAS data is stored as part of the approach procedure in the FMS' navigation database. The computation of angular deviations from FAS data block data is described, for example, in [3], [2] or [11]. Based on the FAS data block and the present position, the FMS can compute angular deviations from a centerline and a desired glide path. Those deviations are then displayed to the pilot in the same way as data from the instrument landing system. This final approach segment guidance based on the FAS data block and the SBAS augmented navigation solution is called SBAS Localizer Performance with Vertical guidance (LPV) and enables decisions heights as low as 200ft.

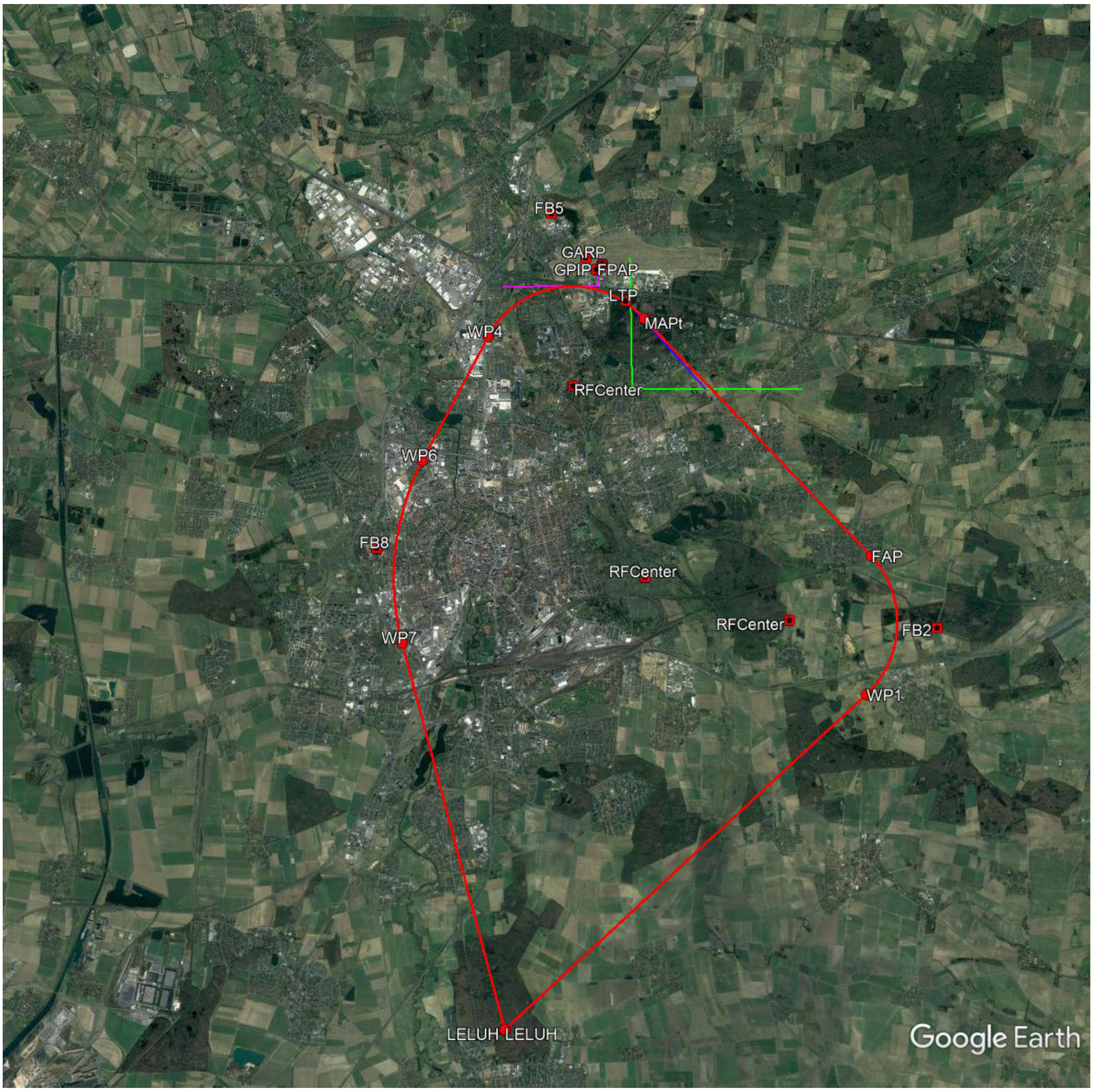

Figure 2 PINS procedure design for the advanced SNI PinS at Braunschweig Wolfsburg airport. The purple line depicts the 0.3NM ATT at the 45degree divergence point. The green line denotes 1.37NM (2538m) from the runway center that was used in the Malpensa case in SESAR WP4.10 between runway and Helipad.

1.3. Simultaneous Non Interfering PINS

Currently, neither PANS OPS nor DOC9643 [6]provide guidance on the implementation of simultaneous operations involving fixed wing aircraft and rotorcraft. If such operations are conducted, they should not interfere with each other, i.e. in analogy to independent parallel approaches and independent parallel departures,

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the procedures are called simultaneous non-interfering (SNI). The rotorcraft part of the procedure can be a Point in Space (PinS) procedure, but in order to guarantee horizontal separation, missed approach track guidance must be provided.

SESAR WP4.10 (2016) [12] investigated the possibility of SNI using LPV PinS convergent Approach. This approach type was selected as the most promising solution out of six different possibilities that were analyzed for safety in the GARDEN (GNSS-based ATM for Rotorcraft to Decrease Noise) project.

SESAR 4.10 D23 [13] provides some implementation guidelines based on a simultaneous non interfering approach, designed for Milano Malpensa and Cascina Costa Heliport. Key points in the implementation of the PinS procedure alongside a classical ILS approach were ".. Distance between FATO edge and runway edge is compliant for VMC operations. The distance between the PinS and the runway edge is greater than the minimum distance for parallel instrument approaches. "

Several key distances were defined in D23 (See also Figure 3 below) and some requirements were imposed on these distances: A1 shall always be larger than d_{min_vfr}. A2 should be larger than d_{min_ifr}. A3 should be larger than 3 nautical miles. d should never be less than the cross track tolerance of the RNP approach.

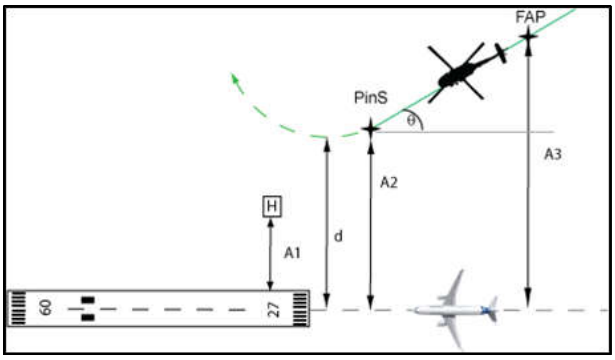

Figure 3 Location of design distances from [5]Low Level Route Networks

- A1 is the distance between Helipad and Runway edges;
- A2 is the lateral distance between the DA/H point and the runway centerline or its extension. It is a key distance used in order to discern which options are compliant with current separation standards applicable for the "Independent parallel approaches";
- A3 is the distance between the FAF of the rotorcraft approach and the extension of the fixed-wing runway centerline. This parameter is used in order to assess the actual need of radar vectoring and radar monitoring. In case of parallel approach, it takes the same value of A2;
- θ is the convergence angle between the final segment of the rotorcraft procedure and the extension of the fixed-wing runway centerline.
- d, the distance between the two approach paths, where d_{min_IFR} is a reference parameter which takes the value of the minimum distance between parallel runways for independent parallel approaches and d_{min_vfr} is a reference parameter defined in ICAO Annex 14 vol. II, the distance between the FATO (Final Approach Take Off area) edge and the runway or taxiway edges where simultaneous VMC operations are planned:

The FAP at the altitude of 2200ft MSL of our procedure design is at 3.2NM horizontal distance, hence criterion A3 is fulfilled.

Our MAPt is at 1200m from the centerline, decision height is 340ft AAL. This is larger than d_{min_ifr} for parallel runways which is 1035 meters with suitable radar surveillance equipment [DOC9624]. Criteria A2 is hence fulfilled.

d_{min_vfr} for an aircraft with a MTOW of 2825kg like the EC135 is 60 meters for masses up to 3175kg (Table 3-1 of ICAO Annex 14, Volume 2). The distance of the edge of helipad west to the runway edge of EDVE airport is 210 meters. Therefore, the A1 criteria is already fulfilled.

A LLR network in conjunction with SNI PinS procedures allows to circumvent the problem of merging rotorcraft and fixed wing traffic. Or, in general, slow traffic from fast traffic.

The low level route is designed at an altitude below Minimum Radar Vectoring Altitude. At the same time, ATC surveillance is assured and the flight path is monitored by a controller. The use case of urgent medical transport is just one of many, but for the demonstration of LLR and SNI it serves as the driving use case.

Figure 4 shows the LLR network for the GRADE project integrated into a departure chart for

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runway 26 at EDVE. With this network it would be possible to transport patients from whatever hospital required to the airport under IMC. In detail there are 6 hospitals, a federal police force heliport and the airport EDVE connected to this network. The design altitude for all segments is 2200ft, roughly 2000ft above ground level. Generally speaking, it is easy to implement the waypoints of a local level route network when obstacles are known. The RNP containment defines the required obstacle free zone. The major difficulty when implementing a LLR network is to ensure adequate separation in instrument meteorological conditions when more than one helicopter is travelling in the network. As a LLR is usually implemented below the MRVA, separation of traffic in IMC needs to be assured procedurally. Since this has vastly different requirements from radar separation, an extra ATCO would be required. This officer would need to provide clearances for specific route segments to each rotorcraft. These route segments cannot overlap, unless the rotorcraft is able to comply with RTA constraints. Upon reaching a radar-controlled aerodrome and performing an instrument approach, especially a SNI, the procedural ATCO would need to coordinate with the radar controller. The reverse applies, of course, to departures from a radar-controlled aerodrome into the LLR. Demonstrating a LLR with one rotorcraft only, and no air traffic control concept is trivial.

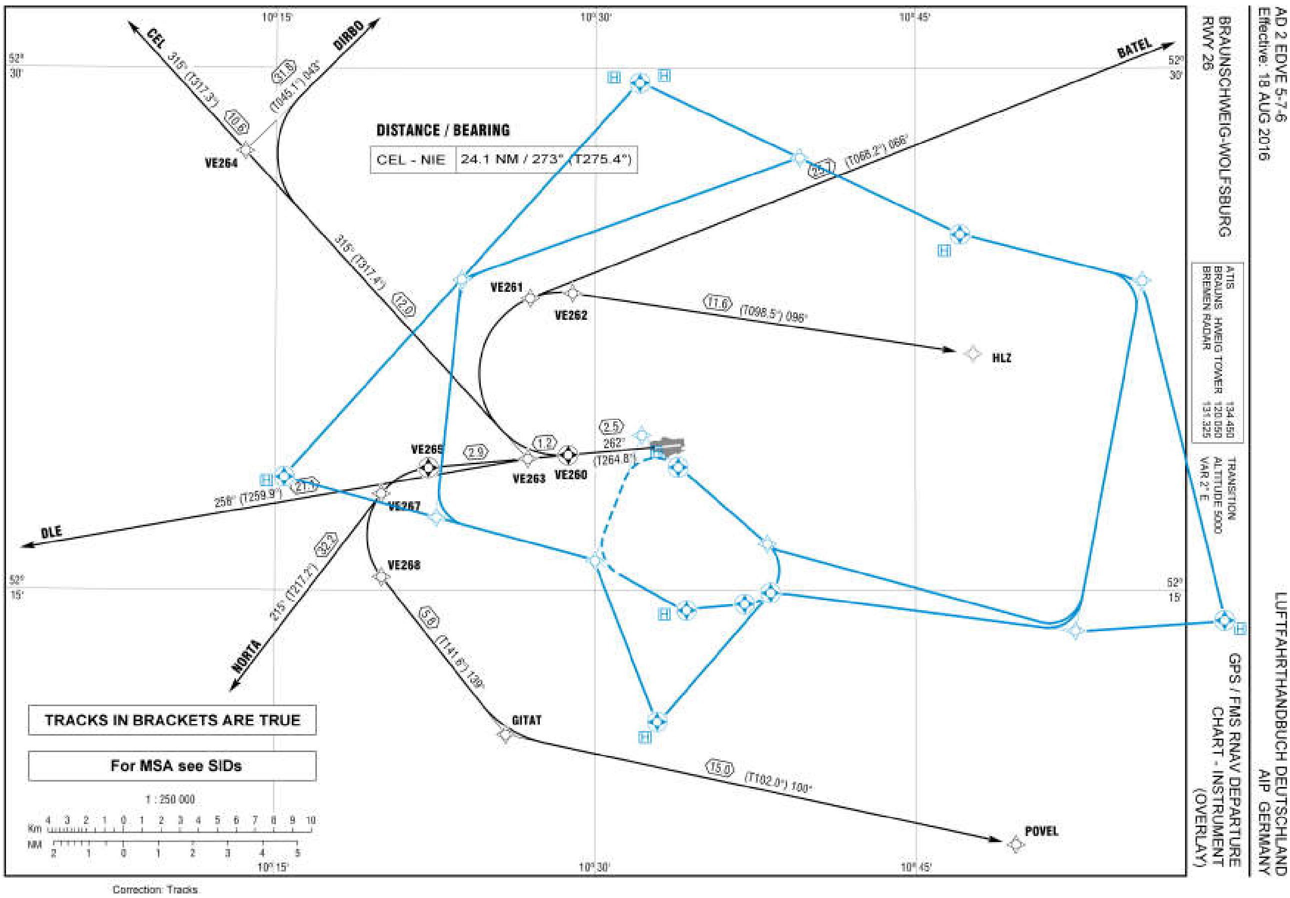

Figure 4: Possible Low-Level Route Network

2. REALTIME SIMULATION

2.1. Participants

For the exercise one demonstration day was planned for the 29th of November 2018 with two sessions and one additional session on the 4th of December. The three pilots had to perform four runs for a total of 12 evaluation runs. The participants were all male test pilots with a mean age of 48 years and 5500 hours mean flight time.

The participants were briefed thoroughly about the procedure and display before conducting the trials. The pilots were involved during the design phase of the procedure, but they were using the HubSim test bed for the first time and never flew the procedure before.

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2.2. Apparatus

The DLR Institute of Flight Guidance has developed and operates several cockpit simulators for the purposes of demonstrating and evaluating new helicopter pilot assistance systems with both hardware and human in the loop. In 2018, a new simulation platform has been developed and implemented including active control components, a dome projected outside vision system with a flexible and simple Head-Down-Display (Figure 5).

Just like a conventional helicopter, the simulator is flown using three control elements: cyclic stick, collective and pedals. These are active control components which apply force feedback technology. Integrated motors generate precise force feedback to give the pilot a realistic impression of the controls. The simulation was powered by X-Plane 11 as well as an outside vision dome projection of 210 by 95 degree. This evaluation was conducted to prepare the real flight test scheduled end of summer 2019, but also allowed first analyses of the expected aircraft and human performance using objective measurements and subjective ratings in a controlled environment. The candidates were asked to fill-in standardized questionnaires (NASA-TLX [5] and SART [14]) as well as a detailed de-briefing questionnaire. The simulated flight data was recorded. For the simulation within the framework of the GRADE project, a tablet computer has been used as Head-Down-Display (HDD) running both navigation (see Figure 6) and primary flight display (see Figure 7) in order to give the pilot adequate information of the planned flight path. There was no cockpit shell present during the simulation.

During this demonstration the simulator additionally included the controller display “Traffic Sim” of DLR. This simulator can provide a representative and dense traffic scenario during the simulated non-interfering helicopter approach. During the runtime single aircraft can be moved along the trajectory in time to adjust the arrival or departure sequence or e.g. create or avoid conflicts between aircraft at a crossing point.

Figure 5: DLR HubSim simulator

2.3. Experimental Design

The design of the evaluation was to fly the departure from the hospital with a Cat A departure and climb out in the direction of the LLR entry LELUH. The level of 2200ft was reached after LELUH before “WP1”. After the LPV segment at the MAPt pilots conducted the missed approach procedure after acknowledging “proceed visually”.

The evaluation was performed in a standardized way to minimize differences in performance due to environmental conditions. The sessions started with a briefing of approximately 15 minutes where mainly the goal of the demonstration and the procedure was discussed. Thereafter a short refresher of the extended display content was briefed. The variation to the scenario was generated changing daytime, visibility, ceiling, and wind (see Table 1). Due to the small number of participants it was chosen to use a static test pattern.

In-between the runs the pilots were asked to fill-in a NASA TLX and a SART questionnaire. After the last run they were asked to weight the TLX parameter and filled-in a de-briefing questionnaire.

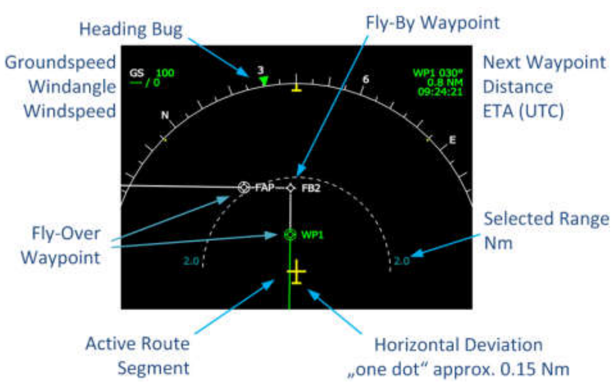

Figure 6: DLR’s ND display format

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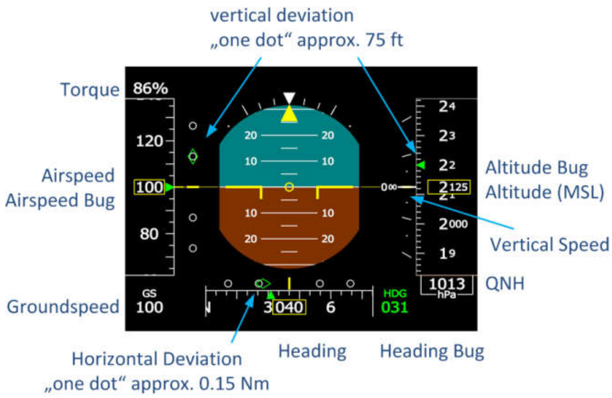

Figure 7: DLR's PFD display format

Table 1: Scenario of the evaluation session

Run	Name	Visibility	Ceiling	Daytime	Wind
1	CAVOK	CAVOK		12:00am	0°/0kt
2	NIGHT	2500 m	2600ft	5:35am	180°/15kt
3	WIND	1500 m	2500ft	12:00am	360°/50kt
4	CLOUD	1500 m	670ft	12:00am	0°/0kt

During the first demonstration session the pattern was conducted completely to provide the best picture for the guests of the demonstration day. Thereafter the run was stopped as soon as both parameters were met (level 2200ft and on radial T201° to FB8).

3. RESULTS

All but one run could be used for analysis. Due to technical issues one flight had to be neglected for the performance evaluation. The subjective rating of this flight could still be used.

All runs remained well in the RNP of 0.3NM for the straight segments (see Table 2). For details lateral and vertical plots of the flight path and angular deviation during the LPV can be found in Figure 8 to Figure 11. One flight during scenario CLOUD did not immediately turn left as the missed approach procedure defines. Pilots did not have a cross deviation indication during the turning phase because the procedure was flown as standard PinS procedure. For this type of procedure the regulation defines a RNP of 1.0NM while turning, which would have been met. But this low RNP and the absence of track guidance would not qualify as SNI. Besides this one late turn pilots immediately turned left after passing MAPt. Doing so pilots were by trend cutting the curve what is safe by all means as long as flying above the OCA. The not regulated vertical limit of 150ft deviation was met by all flights but one during the CLOUD scenario. Except for the CLOUD scenario all runs met the 2-Dot deviation limits, most of them 1-Dot deviation during the LPV approach. All pilots called out "proceed visually" before continuing with the missed approach, but for one CLOUD scenario where the pilot had trouble controlling the rotorcraft in the vertical axis and therefore never reached an altitude below ceiling. He correctly conducted the missed approach procedure at MAPt.

Table 2: Cross-Track Error (1.96σ) along the Approach and Missed Approach Leg

	Approach Leg			Missed Approach Leg		
Scenario	A [NM]	B [NM]	C [NM]	A [NM]	B [NM]	C [NM]
CAVOK	0,056	0,093	0,062	0,083	0,126	0,061
NIGHT	0,083	0,086	0,056	0,032		0,114
WIND	0,086	0,166	0,074	0,204	0,234	0,139
CLOUD	0,059	0,210	0,076	0,128	0,051	0,119

From the pilot's comments and the de-briefing questionnaire it became obvious that the realism of the simulation was rather limited. Especially the command model of X-Plane did not meet the expectations of the participants and the procedure was harder to fly than usually. The out-of-the-window simulation was also adding workload due to the fact that the cockpit shell was missing. Other than expected this led to unintended disorientation. Especially while in the clouds the optical flow was different than in reality, but also outside of clouds the exposed seating caused difficulties controlling the rotorcraft (see Figure 16 for further details).

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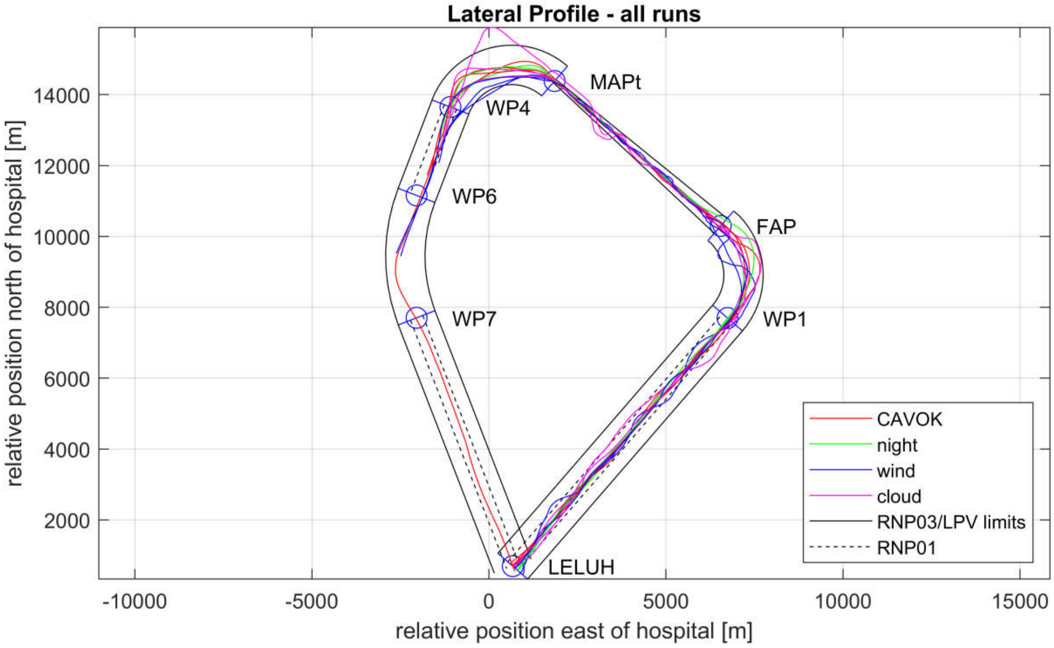

Figure 8: Lateral plot of recorded simulation data for all flights

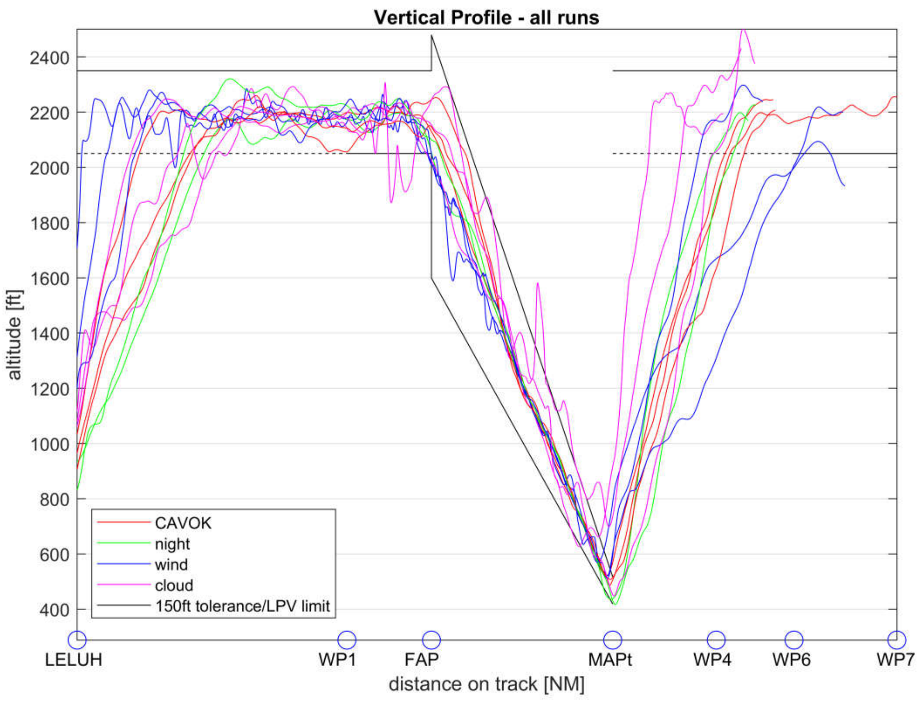

Figure 9: Vertical plot of recorded simulation data for all flights

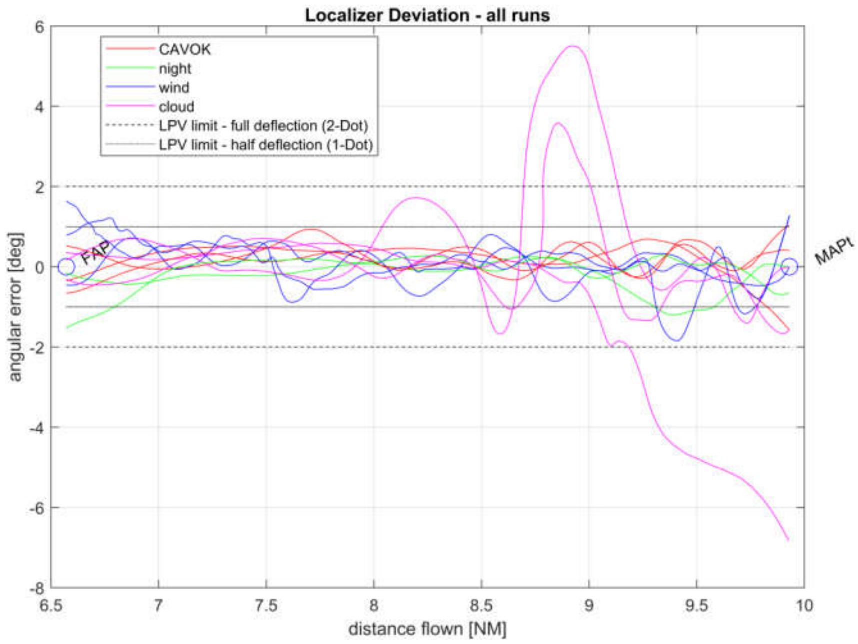

Figure 10: Localizer angular track error during LPV approach

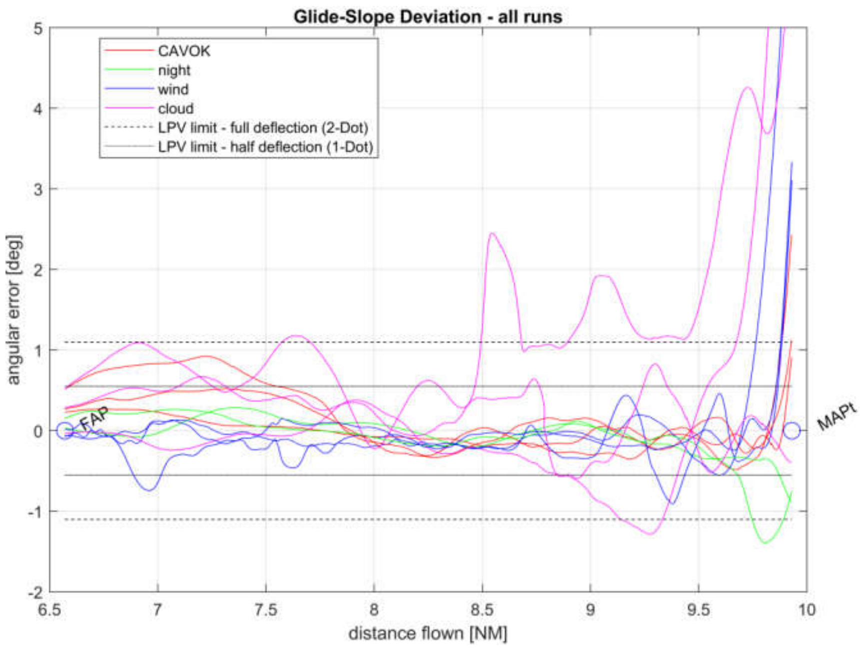

Figure 11: Glide-Slope angular error during LPV approach

Figure 12 to Figure 15 show the subjective ratings for SART and NASA-TLX. Figure 12 shows the task load and the situation awareness rating together. There seems to be a strong coupling of both. One can see that the situation awareness is not affected as much between the four scenarios, but the workload is. The good weather condition (CAVOK) produces as expected the lowest workload (49%) and the highest situation awareness (5.9) followed by the night scenario, then the high wind scenario, and the IMC scenario produces the highest workload (89%) while situation awareness is lowest with 4.6 global score. The details for each flight and pilot can be found in Figure 13 and Figure 14. There is no baseline reference to the data therefore all values need to be looked at as relative changes. Considering the task weighting (Figure 15) pilots chose very similar weights. They picked Mental Demand as the dominant factor followed by Performance and Effort. Temporal Demand and Frustration are the least contributing factor besides Physical Demand which was neglected by all pilots to have influenced the workload at all.

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

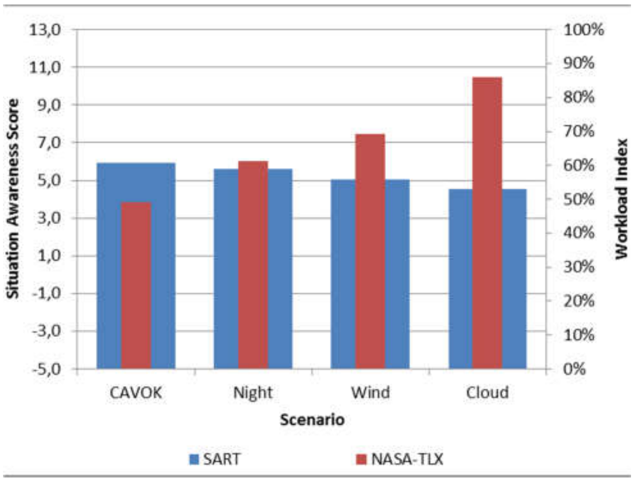

Figure 12: Mean SART Score and Workload Index for the different scenarios

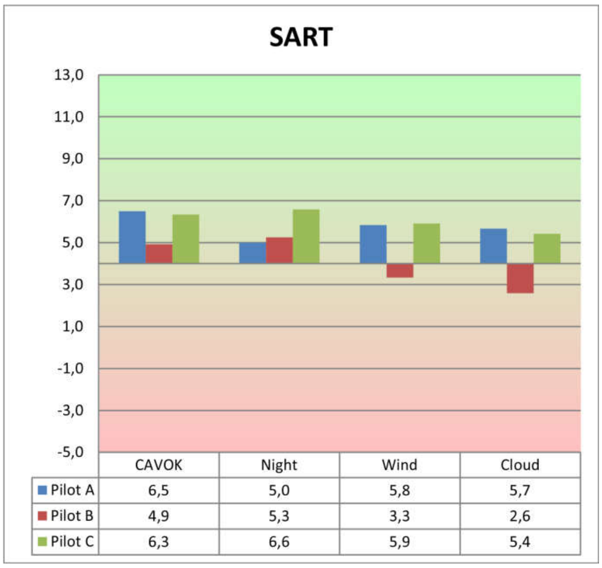

Figure 13: Global SART Score for all scenarios and pilots

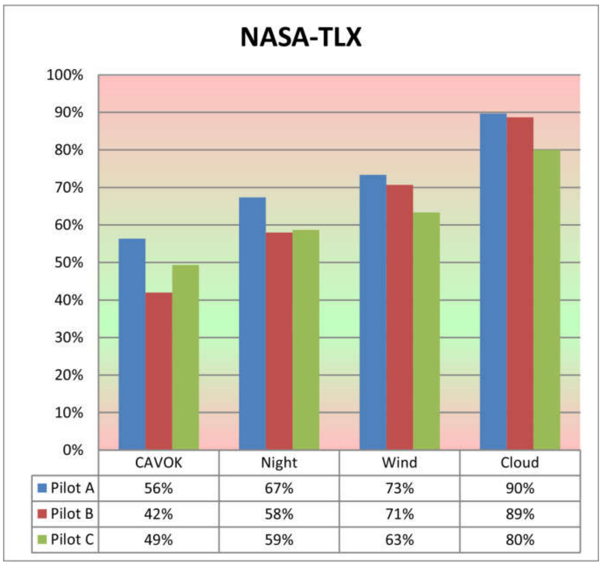

Figure 14:NASA TLX for all scenarios and pilots

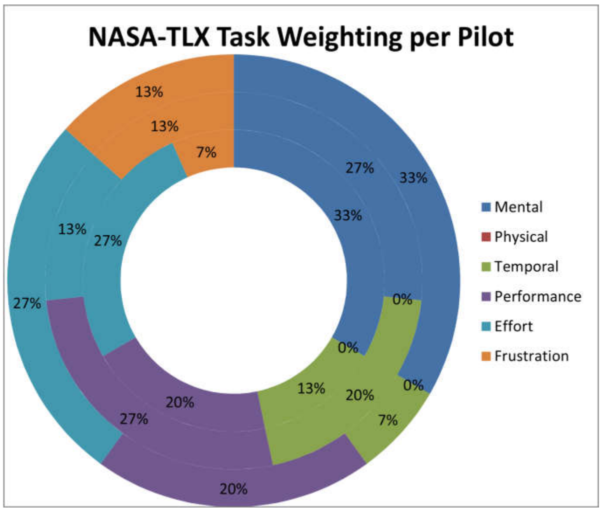

Figure 15: NASA-TLX Task Weighting of the pilots

Figure 16 to Figure 20 show the pilot's ratings of the de-briefing questionnaire. The in general limited simulation environment (Figure 16) has already been discussed. In addition to that there also was a problem with the seat causing back pain after some time (see Figure 20). Other than that only fatigue was rated moderate. This is pretty usual in simulation campaigns and still should not have influenced the performance.

Concerning the procedural questions Figure 17 denotes the ratings. Pilots answered very conservative about the procedure. They answered positively about the ability to control the cross-track error, to "proceed visually" at MAPt, the situation awareness during missed approach, and the SNI concept, but commented rather neutral about their performance, glide slope interception, CDI scaling, safety, workload, training, and traffic awareness. The change of CDI scaling in general is not a problem, but was noticed. The performance and workload must have been influenced by the simulation environment and should be rated more positively in a more realistic situation. This argument is supported by the fact that situation awareness is rated fine by most pilots. Considering the safety, and immediate left turn at MAPt, it can be argued that the concept of SNI as well as advanced PinS procedure, in detail RF legs before FAP and at MAPt, is new and untrained. If there is a familiarization and system trust problem causing this effect, than, more training should mitigate this.

The less than expected traffic awareness can be appointed to the absence of radio communication.

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

Pilots were not able to localize other simulated traffic other than by the concept of operation itself.

On the questions considering the symbol set used (see Figure 18) one thing can be pointed out. Due to the high workload of the controlling task together with the immersive out-of-the-window simulation, because of the missing cockpit shell, pilots tend to have kept the head down on the display not to get disturbed. Along with this argument the same is true for the IFR-VFR transition.

Considering the optical issues with the display no evidence of technical issues can be pointed out (see Figure 19).

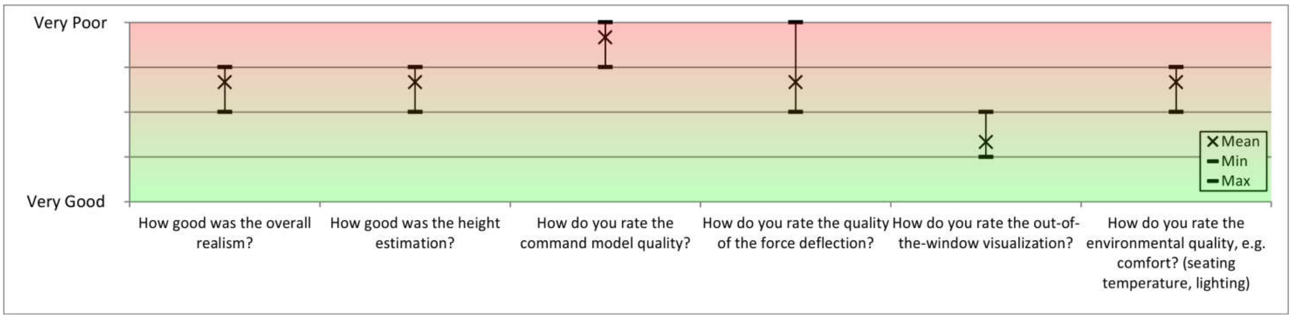

Figure 16: General questions about the realtime simulation

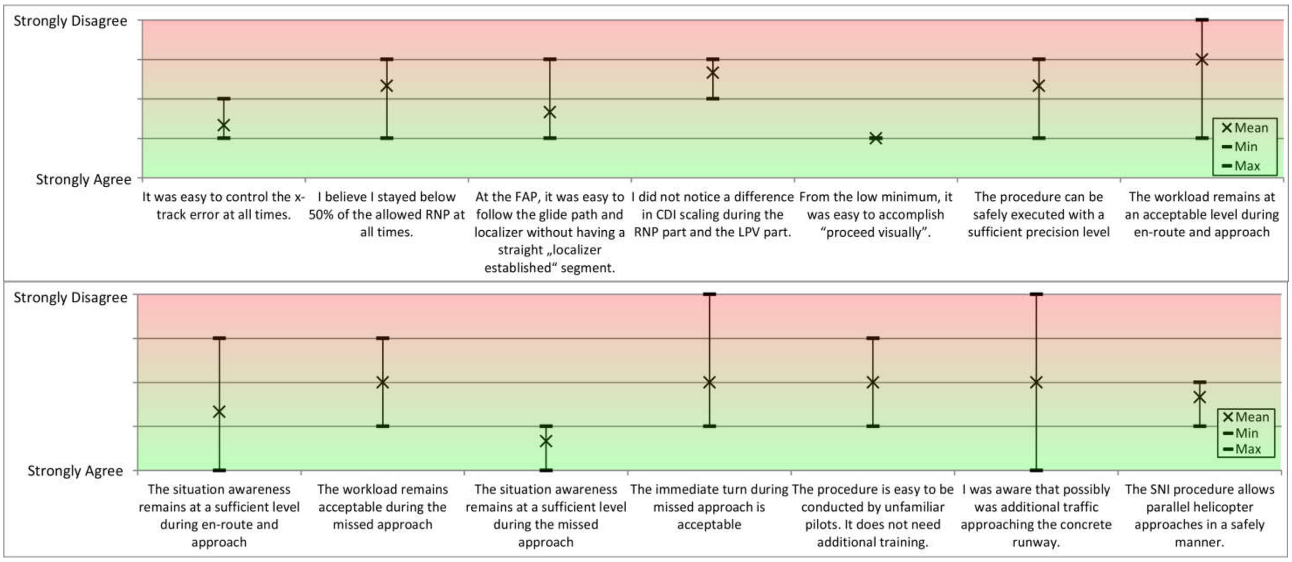

Figure 17: Procedual questions

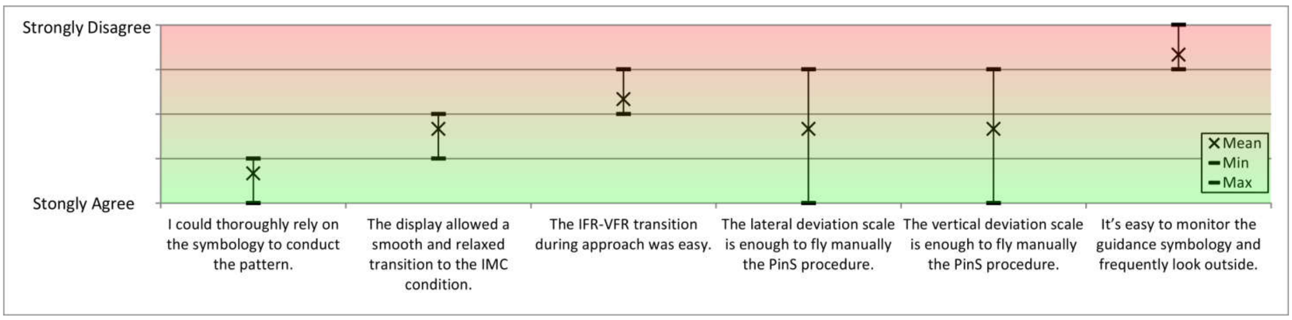

Figure 18: Questions concerning the symbology

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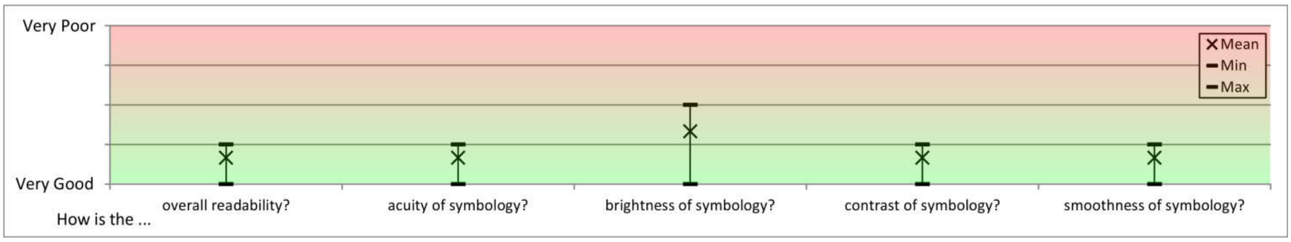

Figure 19: Optical issues with the display

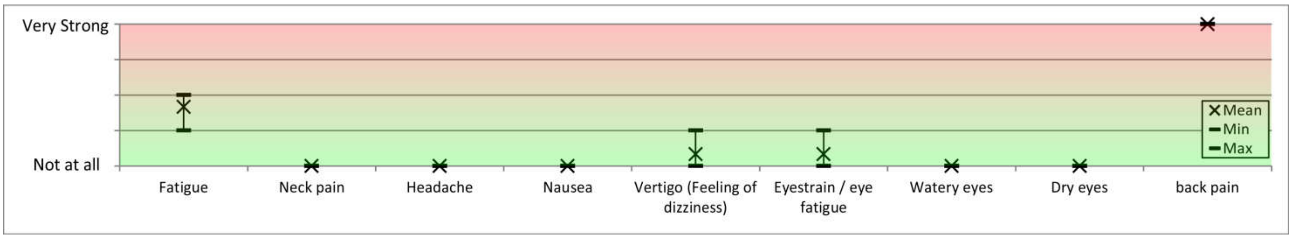

Figure 20: Issues caused by the experiment

4. CONCLUSION

With the results from the real-time simulations it has been shown that the LLR and SNI concept can be successfully realized and performed. The concepts were further explored and demonstrated. Pilots were able to fly the pattern with a fully manually controlled rotorcraft. The limitations of the visualization and the control model did influence the task load negatively, but it even substantiates the confidence that an implementation of LLR and SNI would not only be beneficial on accessibility of airspace for its users, but be equally safe.

Nevertheless, it is strongly recommended that SNI approaches shall be designed as advanced PinS procedures, in detail the use of RF legs, so that pilots will have continuous guidance in the vicinity of an independent runway and its traffic. Additionally, one should keep in mind that most of rotorcraft operations are conducted in VMC and therefore the familiarization and training of pilots can pose a problem. Workload and situation awareness always have to meet acceptable levels. Both can be positively influenced by using higher control laws and stabilization modes. It is trivial to notice that, if available, they should always be used at least in IMC conditions.

The perspective of air traffic controller has not been investigated in detail within this simulation, but it is believed to be very similar to parallel runway operations.

As a next step, the same procedure as described here will be flown in a flight test campaign at EDVE in September 2019. There will be parallel flight testing of SBAS short final approaches with a single piston engine aircraft. Both routes are designed closely together. The flight program is synchronized and will further demonstrate the concept of SNI.

5. ACKNOWLEDGEMENT

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