

## FLIGHT TRIAL DEMONSTRATION OF INCREASED GENERAL AVIATION AND ROTORCRAFT OPERATIONS SUPPORTED BY GNSS SOLUTIONS

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### Abstract

The project GRADE has received funding from the SESAR Joint Undertaking under grant agreement No 783170 under European Union's Horizon 2020 research and innovation program. The operational scope of one of the project's exercises was to demonstrate the feasibility and benefits of executing SESAR 1 solution Sol#113, which covered the demonstration of Standard Point In Space (PinS) helicopter procedures as well as low level IFR routes for helicopters. In addition, it was demonstrated that the PinS procedure can be conducted independently from approaching fixed wing traffic, resulting in a Simultaneous Non-Interfering (SNI) operation. For guiding the pilot along the planned flight route, different display formats of a primary flight display, navigation display, and tunnel-in-the-sky guidance display were customized and finally tested on a head-down display on DLR's HubSim simulator in the scope of a real-time simulation. The results of this campaign were already presented on 45th European Rotorcraft Conference in Warsaw. Following up on the outlook given at that conference, this subsequent paper describes the results of the flight tests that were carried out from 20th August until 18th September 2019.

### 1. INTRODUCTION

The overall objective of the GRADE project was to demonstrate the capability of general aviation (GA) including rotorcraft to benefit from the concepts developed in the SESAR program, thus facilitating their integration into the airspace and at the airports where the SESAR concepts and technologies are implemented. Specifically, the GRADE project aims at demonstrating the following elements of existing SESAR solutions, by using two GA aircraft and one rotorcraft, equipped with non-certified or specific on-board equipment.

The demonstrations were performed through live flight trials, which were preceded by preparatory exercises executed through real-time simulations with humans and hardware in the loop [1]. The whole project was structured in five exercises. Two of them were real-time simulations, executed in the period October - December 2018. The other three exercises were flight trials, carried out in the surrounding area of Capua airport (Exercise #03) and of Braunschweig airport (Exercises #04 and #05), in the time period from July until October 2019. The exercises differed from each other by the used demonstration platform and tools, the demonstrated SESAR Solutions, and the test site. The execution of all the tests (real-time

simulations and flight trials) involved licensed air traffic controllers and pilots to operate the scenarios.

This paper focuses on the results of flight trials concerning Exercise #5 to demonstrate solution #113 from SESAR 1 "Optimized low level instrument flight rules (IFR) routes for rotorcraft". The following elements of the solution were demonstrated: optimized low level IFR routes (LLR), point-in-space (PinS) procedures and simultaneous non-interfering (SNI) operations. The demonstration scenario included flying under IFR to/from a PinS in the proximity of the landing/departure site using a very high required navigation performance (RNP) of RNP 1.0/RNP 0.3. The segment joining the PinS and the landing/departure site (FATO - final approach & take-off areas) were flown visually. Demonstration of Solution #113 also involved fixed wing traffic in order to demonstrate SNI operations [2].

The objective of the demonstration was to show the flyability of the designed LLRs as well as the designed PinS procedure. The flight trials included a LLR routing from Braunschweig's urban area to a helipad at Braunschweig-Wolfsburg airport (see Figure 8).

The flight trials were supported by slightly modified guidance displays compared to what was used within the real-time simulations (see Figure 1 and Figure 2). These modifications were focused on the extension of standard to advanced PinS procedures. In contrast to standard PinS, advanced PinS procedures allow flying a radius-to-fix (RF) leg before the final approach fix (FAF). The final approach began at the FAF. The final approach segment was a localizer performance with vertical guidance segment (LPV) with a fictitious threshold point located such that the glide path was intersected with the ground exactly at the helipad. Vertically, 4.4° ILS lookalike guidance was provided by the European geostationary navigation overlay service (EGNOS), a satellite-based augmentation system (SBAS). The minimum descent altitude was 628ft MSL (350ft GND). Thereafter, the visual segment started. In case of a missed approach, the pilot had to initiate a climb to 2200ft MSL and followed the prescribed track as depicted in Figure 3. Upon crossing the missed approach point (MAPt) a left turn was followed to WP4. For advanced PinS, this leg was coded as a RF to WP4 with a radius of 1NM. After WP4, a 1.5NM straight leg was followed to WP6. After WP6 the leg from WP6 to WP7 was coded as RF with a radius of 2.75NM. After WP7, the aircraft returned to waypoint LELUH with a track to fix of length 5.1NM. The missed approach procedure was designed to reduce the aircraft noise impacting the downtown of Braunschweig. It took course along the city's tangent motorway. More details about advanced PinS procedures can be found in [6] and [7].

Although the procedures were designed for IFR in instrumental meteorological conditions (IMC), the flights were conducted in visual meteorological conditions (VMC) to ensure visual separation from traffic and obstacles during the trials.



Figure 1: Primary flight display (PFD) with course deviation indicator (CDI)

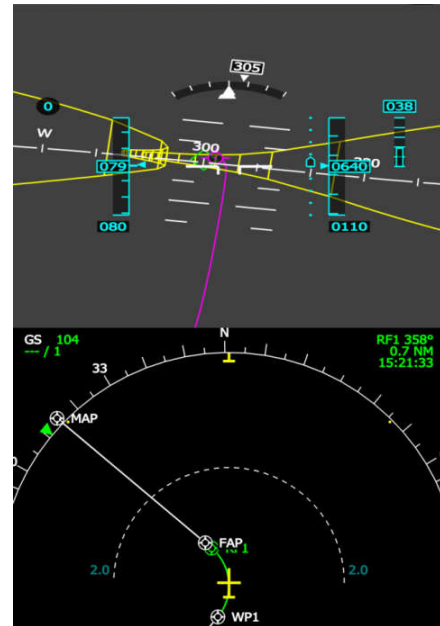


Figure 2: Tunnel-in-the-sky guidance display

## 2. FLIGHT TRIALS

### 2.1. Participants

Many experts from different fields were involved in the preparation of the flight trials:

- ⇒ Four technical experts / engineers (prototype implementation, flight trials preparation, and demonstration day technical preparation and presentation)
- ⇒ Three test pilots from the German Aerospace Center (DLR) (same pilots who carried out the real-time simulation campaign in fall 2018)
- ⇒ One human factors expert

In addition to flight data recordings (see chapter 2.2.4), a set of

- ⇒ Eight NASA-TLX and one procedure weighting table [5]
- ⇒ Eight 3D SART [9]
- ⇒ One de-briefing questionnaire

was filled in per pilot.

### 2.2. Experimental Design

#### 2.2.1. DLR's Research Helicopter ACT/FHS

The flight trials were conducted with DLR's research helicopter Active Control Technology/Flying Helicopter Simulator (ACT/FHS). This helicopter is based on a standard Eurocopter EC 135, which has

been extensively modified for use as a research and test aircraft.



Figure 3: DLR's EC 135 FHS experimental research helicopter

Due to regulatory restrictions during the flight trials, the pilot was not supported by any stabilizing assistance functions (e.g. stability augmentation system (SAS)), but rather operated in basic control mode.

### 2.2.2. Hardware Prototype

At the end of 2016, DLR has designed an experimental graphics computer called JCONV2 for high performance graphics calculations and presentations on a helmet mounted display system. As part of the GRADE project, the ability of this computer has been extended to allow additional information to be displayed on the evaluation pilot's head-down display at the same time.



Figure 4: Experimental computer systems including the JCONV2 hardware (top left)

### 2.2.3. Display Prototypes

Figure 4 and Figure 5 show the different display variants developed by DLR for these flight trials: the navigation display (Figure 5 (left) and Figure 6 (left)), the deviation guidance for the PFD during en-route and LPV approach (Figure 5 (right)), and an additional tunnel-in-the-sky guidance display (Figure 6 (right)) to increase situational awareness (SA) and reduce workload especially during the RF leg. For the

real-time simulation and flight trials, the standard PFD display was complemented by a course deviation indicator (CDI) and so-called bugs for desired speed, barometric altitude, and heading. The final approach fix (FAF) defined the position where the display of the PFD is switched from RNP/Vertical Navigation (VNAV), green) to angular deviation of the LPV (magenta).

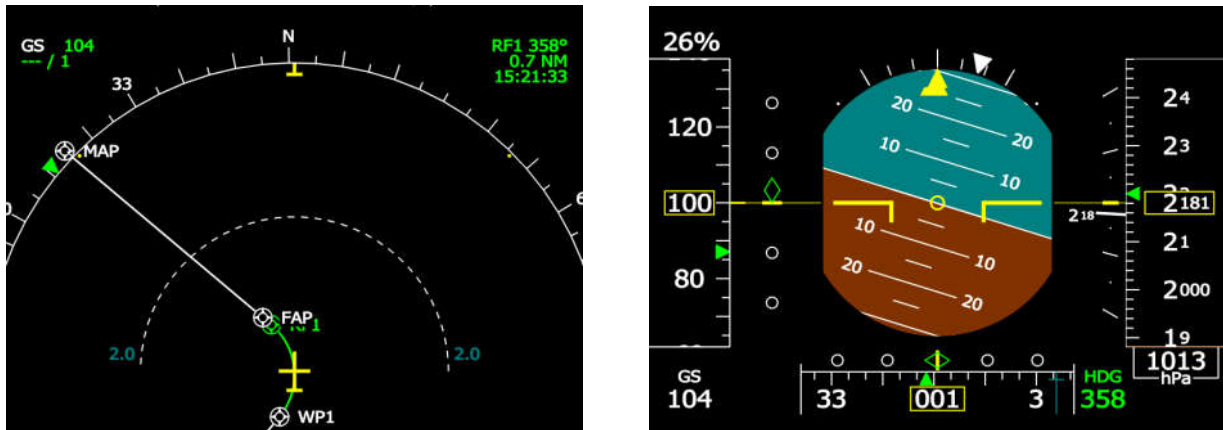


Figure 5: Navigation display with RF guidance between WP1 and FAP for advanced PinS procedure (left) and PFD with CDI requirements (right)

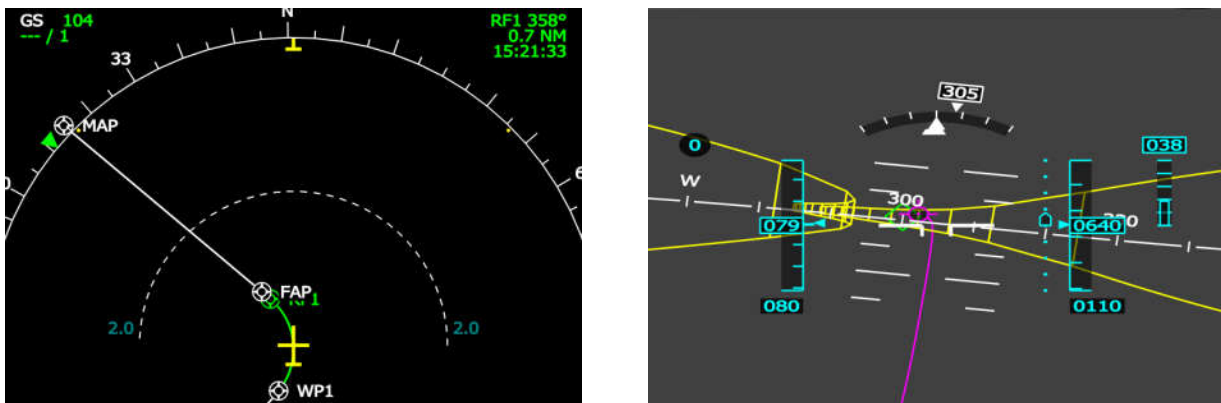


Figure 6: Navigation display (left) and tunnel guidance display (right)

In contrast to the real-time simulation version of the navigation display, the version that was used during flight trials has been complemented by additional guidance information for the curved legs between the straight segments of the procedure. This led to a transformation from a standard to an advanced PinS procedure. A tunnel-in-the-sky guidance display was implemented as an alternative to the conventional PFD. To minimize the cross-track error especially in curved segments, a predictive flight path marker and a flight director complemented the tunnel display and helped the pilot during turns.

The DLR navigation receiver complies with radio technical commission for aeronautics (RTCA) DO229D. The following is an excerpt from said document [8]:

“... document contains minimum operational performance standards (MOPS) for airborne navigation equipment (2D and 3D) using the global positioning system (GPS) augmented

by SBAS. The standards define minimum performance, functions and features for SBAS-based sensors that provide position information to a multi-sensor system or separate navigation system. They also address SBAS-based area navigation (RNAV) equipment to be used for the en-route, terminal, and lateral navigation (LNAV) phases of flight. These standards are based upon a nominal allocation of the aircraft-level requirements in RTCA/DO-236B, minimum aviation system performance standards: Required Navigation Performance for area navigation, accounting for the unique issues associated with SBAS and global navigation satellite system (GNSS) and minimizing the need for pilot training. These standards also define performance, functions and features for equipment that satisfies the requirements for LNAV/VNAV, localizer performance without vertical guidance (LP), and LPV instrument

procedures. The standards cover SBAS-based equipment that is designed to serve combinations of the above phases of flight.”

### 2.2.4. Flight Data Recording

Flight data was sent by the data management computer as a UDP IPV4 P2P stream to the JCONF2 which was generating the display content.

As described in Table 1 each of the 3 test pilots conducted 4 runs per sortie with 2 different display conditions (tunnel-in-the-sky guidance display and PFD with CDI). The approach and missed approach were recorded separately by incrementing the run number when conducting the missed approach which resulted in 48 data recordings for evaluation.

### 2.3. Scenario Description

At present, operational procedures include helicopter and slow GA traffic with all other aircraft under IFR. Therefore, GA including rotorcraft under IFR have to fly at the minimum radar vectoring altitude or above. Air traffic control (ATC) provides separation by assigning different altitudes or speeds to the aircraft, but as a regulatory limitation ATC cannot assign a speed lower than 150kts. At Braunschweig airport (EDVE), there is a single runway with instrument approaches to both runway ends. Since there is no dedicated rotorcraft instrument procedure, helicopters have to fly the approaches designed for fixed wing aircraft. Standard separation values are applied between all vehicles by air traffic control and approaching rotorcraft and general aviation are sequenced and separated by ATC according to the rule applicable for IFR. Traffic will fly instrument approach procedures separated in time, i.e. only one aircraft is allowed on the approach at a given time. When slow aircraft have to be merged into the traffic flow, the capacity will drop for the time of the approach just because the aircraft need a much longer time to execute the approach. In certain conditions this will

Table 1: Overview of flight trials including approaches and Missed Approaches

Pilot	Run number (each Approach - Missed Approach)	Tunnel-in-the-Sky (TiS) / PFD	Visibility (km)	Cloud base (ft)	Coverage	Wind	Time
B	2-5	TiS	>10	4600	Overcast	220° 08kt	04.09.19 12:11 pm - 12:32 pm
B	6-9	PFD	>10	4600	Overcast	220° 08kt	04.09.19 12:41 pm - 13:02 pm
B	2-5	TiS	>10	No clouds	No clouds	260° 11kt	10.09.19 09:17 am - 09:36 am
B	6-9	PFD	>10	No clouds	No clouds	260° 11kt	10.09.19 09:44 am - 10:06 am
C	2-5	TiS	>10	No clouds	No clouds	230° 13kt	11.09.19 12:03 pm - 12:23 pm
C	6-9	PFD	>10	No clouds	No clouds	230° 13kt	11.09.19 12:33 pm - 12:54 pm
C	3-6	TiS	>10	3500	Few	260° 11kt	12.09.19 01:38 pm - 01:58 pm
C	7-10	PFD	>10	3500	Few	260° 11kt	12.09.19 02:07 pm - 02:29 pm
A	3-6	TiS	>10	3600	Broken	290° 10kt	18.09.19 08:23 am - 08:46 am
A	8-10, 12	PFD	>10	3600	Broken	290° 10kt	18.09.19 08:55 am - 09:18 am
A	17-20	TiS	>10	3200	Scattered	280° 09kt	18.09.19 11:42 am - 12:04 pm
A	21-24	PFD	>10	3200	Scattered	280° 09kt	18.09.19 12:12 pm - 12:32 pm

introduce additional holdings and delays for all approaching aircraft.

The introduction of a low-level route network allowed to circumvent the problem of merging rotorcraft and fixed wing traffic or in general slow traffic with fast traffic. The rotorcraft followed a LLR network from one hospital to another or to the local airport under IFR. At the airport, the rotorcraft conducted a PinS procedure which was designed to be non-interfering with fixed wing aircraft approaching at the same time on conventional RNP or ILS approach. Final approach separation for the rotorcraft on the PinS was assured by proceeding visually to a dedicated helipad on the apron. If visual reference was not established at the PinS, the rotorcraft executed a non-interfering missed approach procedure. The PinS was designed such, that all separation limits were respected. The low-level route was designed at an altitude below the Minimum Radar Vectoring

Altitude (MRVA). ATC surveillance was provided and the flight path was monitored by a controller. The use case of urgent medical transport was just one of many, but for the demonstration LLR and SNI served as the driving use case.

During the real-time simulation event several weather conditions were demonstrated. For the real flight demonstration, VMC was required due to the experimental nature of the flights. In the alternate solution scenario, the execution of a missed approach was conducted in visual conditions by both the rotorcraft and the GA airplane. It was shown that SNI missed approaches were possible and safe. In order to save time and reduce complexity, the design of the missed approach was altered slightly to allow continuous approach and missed approach segments.

### 2.3.1. Low-Level Route Network

For the flight trials, a LLR network was designed for Braunschweig airport EDVE for the active runway direction 26. The network connected all hospitals in the area with each other as well as with the local airport (see Figure 7, [1]). With this network it would have been possible to transport patients to whatever hospital required under IMC. In detail, there were six hospitals, a federal police heliport and the airport EDVE which were connected with this network. The design altitude for all segments was 2200ft. For the approach and departure phase at the hospitals there is the need to implement a precision approach and departure alike or similar to the PinS concept, e.g. enabled by SBAS/GBAS.

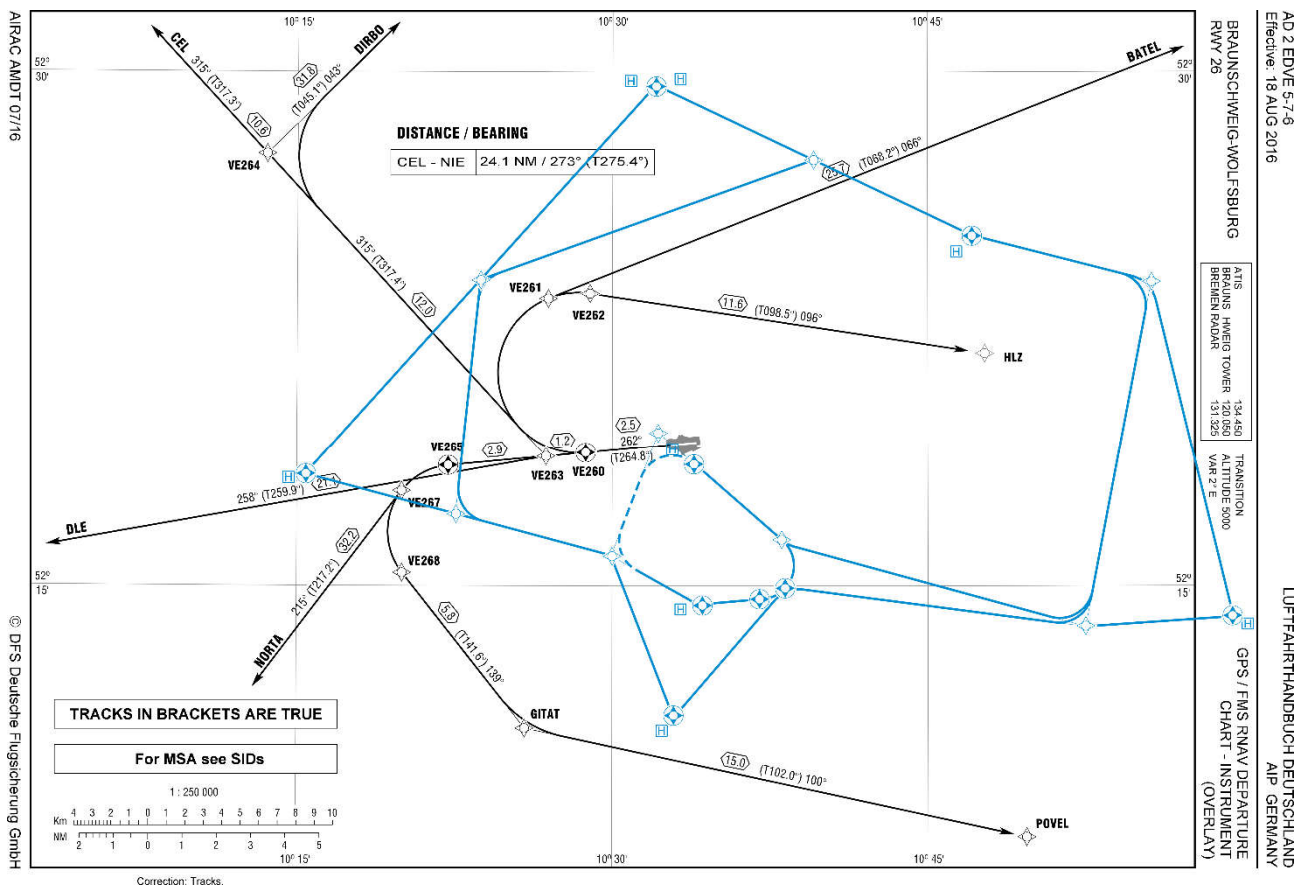


Figure 7: Example of a low level route network in a departure chart for EDVE

### 2.3.2. Initial and Intermediate Approach

The approach procedure commenced at point LELUH near the Wolfenbüttel General Hospital. It was coded as RNP0.3 (see Figure 8). Then, after 5 miles on the track, it reached WP1. Since the procedure was coded as advanced PinS for the flight

trials, the next leg was a radius to fix leg with one nautical mile radius terminating at the FAF.

### 2.3.3. Final Approach

The final approach began at the FAF. The final approach segment was an LPV segment with a fictitious threshold point (FTP) located such that the

glide path intercept point GPIP was exactly at the helipad west. Vertical guidance was a 4.4° ILS lookalike guidance provided by the SBAS system. Minimum descent altitude was 628 ft MSL (350 ft GND), thereafter proceeded visually. For the Braunschweig airport (EDVE) this visual leg would not have been flown straight, but to the north with the last descent along the taxiway in order to avoid buildings and other obstacles.

guidance. For the flight testing, the maximum allowed IAS on the approach was altered as well.

## 2.4. Exercise Plan

For Exercise #04 and #5 one demonstration day was planned for September 12, 2019, when one sortie and five additional sorties were performed, plus one shakedown sortie [3]. The three pilots had to perform four approach and missed approach cycles per sortie for a total of 24 evaluation runs. The design of the evaluation was to fly the approach beginning at LELUH, at 2200 ft, and to continue down to the MAPt. At the MAPt, the pilots conducted the missed approach procedure after acknowledging “proceed visually” and flew back to LELUH. For depiction of the procedure refer to Figure 8.

The evaluation was performed in a standardized way to minimize differences in performance due to environmental conditions. All pilots were involved in the design phase of the procedure and used the simulator to fly the pattern in preparation of the evaluation and additionally have taken part in the real-time simulation campaign. The sortie started with a briefing of approximately 30 minutes where mainly the flight conditions were briefed, followed by a safety briefing and test matrix briefing along with the flight test cards briefing. At the demonstration day the sortie was performed together with the crew of the Cessna 172N.

Each sortie was conducted the same way. Pilots did fly to LELUH and started the first pattern while using the tunnel-in-the-sky guidance display as primary flight display. Thereafter they repeated the pattern with the same configuration. After that the configuration was changed to standard PFD with CDI and repeated once. After each run the pilots were asked to fill-in a NASA TLX [5] and a 3D SART questionnaire [9]. The safety pilot was flying a holding while the evaluation pilot was filling in the questionnaires. After landing they were asked to weight the TLX parameter and filled a de-briefing questionnaire. See Table 2 for the complete test matrix.

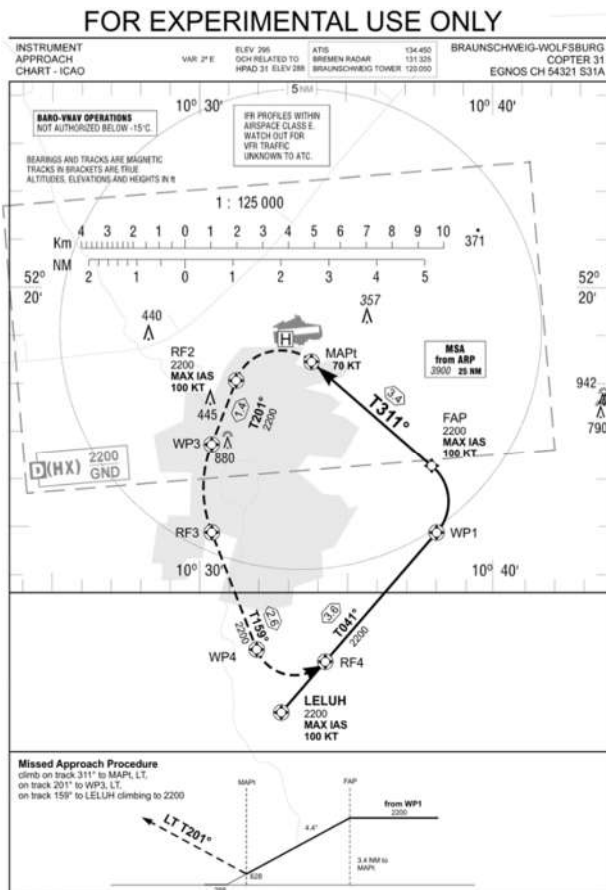


Figure 8: Slightly modified approach and missed approach procedure used for the flight trial.

### 2.3.4. Missed Approach

The missed approach commenced upon abortion of the approach procedure. The pilot had to initiate a climb to 2200ft MSL and followed the track as depicted. Upon crossing the MAPt, a left turn followed to RF2. For advanced PinS, this leg was coded as radius to fix to RF2 with a radius of 1 NM. After RF2 a 1.5 NM straight leg followed to WP3. After WP3 the leg from WP3 to RF3 was also coded as radius to fix with a radius of 2.75 NM. After RF3, the aircraft returned to LELUH with a track to fix of length 5.1 NM. The missed approach was designed to reduce noise of the downtown of Braunschweig and oriented itself on the track of the city tangent motorway. For the flight test an additional RF leg from WP4 to RF4 directed the helicopter onto the approach track to ensure continuous RNP 0.3

Table 2: Test matrix for all sorties

Run number	Test Point / Display setup
1	Reference Hover
2	Departure to LELUH
3	1. Approach with TiS
4	1. Missed Approach with TiS
Q	NASA TLX and 3d SART questionnaire
5	2. Approach with TiS
6	2. Missed Approach with TiS
Q	NASA TLX and 3d SART questionnaire
7	3. Approach with PFD
8	3. Missed Approach with PFD
Q	NASA TLX and 3d SART questionnaire
9	4. Approach with PFD
10	4. Missed Approach with PFD
Q	NASA TLX and 3d SART questionnaire
11	Approach RWY 26
12	Reference Hover

### 3. RESULTS

The following Figure 9 and Figure 10 depict the recorded lateral and vertical profile for all runs with the RNP 0.3 limits and a second limit of RNP 0.1. Figure 11 shows a continuous calculated cross-track error for all flights. It can be seen that all pilots managed to stay within the RNP 0.3 limits regardless of the guidance display type. During the LPV approach between FAF and the MAPt two runs under PFD with CDI configuration show deviations larger than the LPV allowed. In both cases the pilots managed to capture the localizer again. One can see that in general, all flights under PFD with CDI configuration pilots tend to react later to deviations from the route. With tunnel-in-the-sky guidance the lateral accuracy was always way better than RNP 0.1 except for two flights close to the start of the

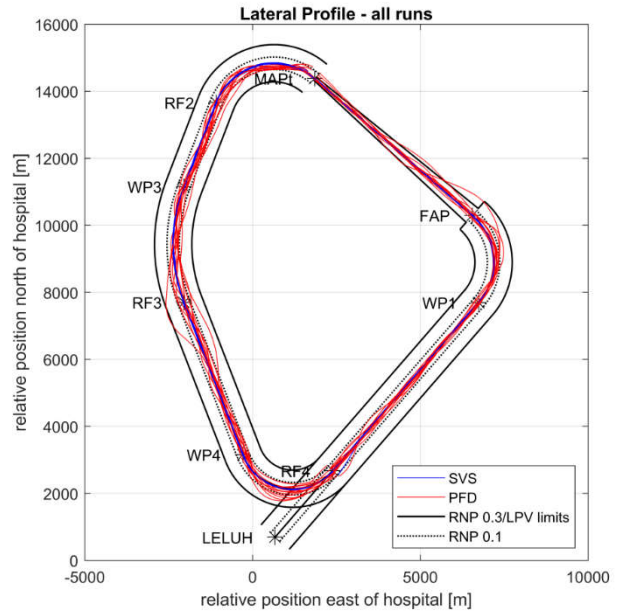


Figure 9: Lateral profile of all runs per display type with RNP limits

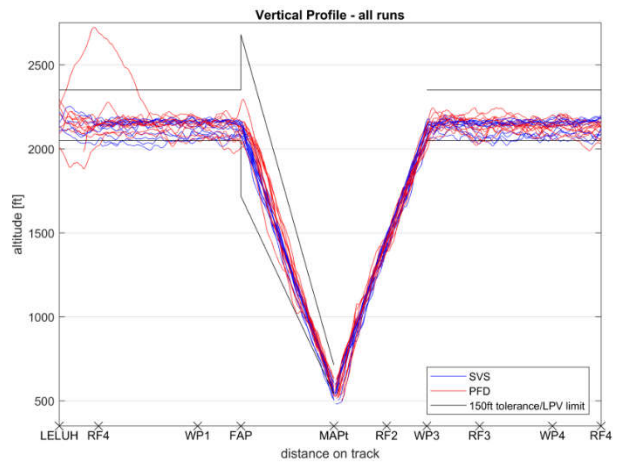


Figure 10: Vertical profile of all runs with tolerance and limits per display type

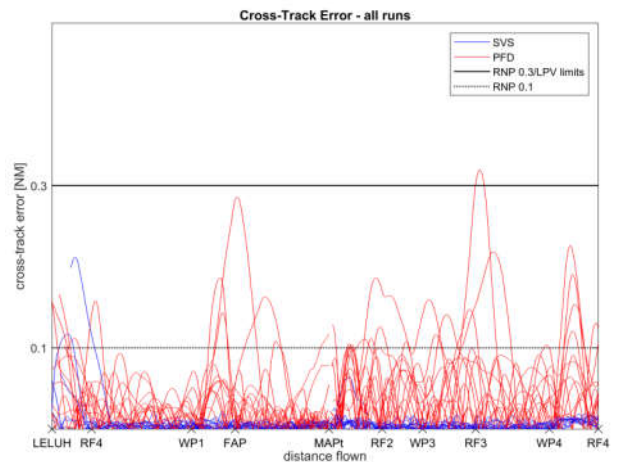


Figure 11: Calculated continuous cross-track error per display type

procedure (see Figure 11). This can be explained by the flight test procedure. The evaluation pilot had to fill in questionnaires after each missed approach and the safety pilot had to take over the helicopter to do so. The safety pilot did fly holdings over LELUH and once the evaluation pilot finished the questionnaires he did take over the helicopter again re-intercepting the route. Therefore, any deviation before RF4 is excluded from the deviation analysis.

Figure 10 shows the vertical profile of all runs. The depicted limits are 150ft above and below the nominal 2200ft cruise altitude during the level segments of the procedure and the  $\pm 1.1^\circ$  angular limits for LPV approaches during the descent phase.

Table 3: Flight time within RNP limits during the approach phase in percent

	PFD	Tunnel-in-the-sky guidance display
$X \leq \text{RNP } 0.1$	95.50%	99.81%
$\text{RNP } 0.1 < X \leq \text{RNP } 0.3$	4.50%	0.19%
$X > \text{RNP } 0.3$	0.00%	0.00%

Table 4: Flight time within RNP limits during the missed approach phase in percent

	PFD	Tunnel-in-the-sky guidance display
$X \leq \text{RNP } 0.1$	89.20%	100.00%
$\text{RNP } 0.1 < X \leq \text{RNP } 0.3$	10.60%	0.00%
$X > \text{RNP } 0.3$	0.20%	0.00%

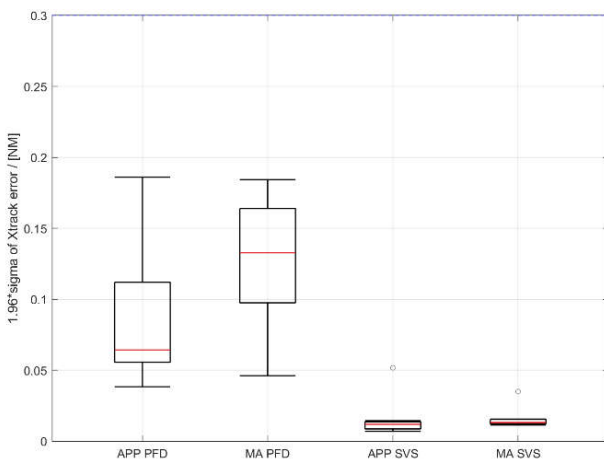


Figure 12: Boxplot per segment and display type of the 95% confidence interval ( $1.96 \cdot \sigma$ ) from the standard deviation of the cross-track error

Table 3 and Table 4 show the percentage of flight time within or outside the lateral RNP 0.1 or RNP 0.3 limits. It can be seen that during the approach phase more than 95% of the flight time the performance was at least RNP 0.1 for both guidance options. During the missed approach segment the performance was 6% worse for the PFD guidance and constantly good for the tunnel-in-the-sky guidance.

The boxplot in Figure 12 shows the difference in lateral navigation performance between the PFD and tunnel-in-the-sky guidance display: While absolute cross track error and thus also mean value and standard deviation are rather high for the PFD guidance the mean error is much lower for tunnel-in-the-sky guidance and the standard deviations diminish to nearly a single line. To emphasize again, the boxplot is calculated from the 95% confidence interval ( $1.96 \cdot \sigma$ ) of the standard deviation from each run per display type. It can be stated that the tunnel-in-the-sky guidance allowed a constant performance where PFD with CDI guidance provoked different but good enough performance.

Figure 13 through Figure 17 show the pilot ratings of the de-briefing questionnaire. It needs to be pointed out that one of the three pilots rated the immediate left turn in the missed approach to be rather not acceptable. The ratings of the PFD with CDI guidance were consequently worse than the tunnel-in-the-sky guidance. That the ratings show ratings up to “strongly disagree” rather reflect the pilots’ opinion to prefer the tunnel-in-the-sky guidance display over the PFD. The performance was good with both display types. This well-known workload related issue with simple guidance concepts, e.g. CDI, are reflected by the pilot ratings. Similar results were obtained for fixed wing aircraft in [4]. Independent from the display type, pilots stated that this type of procedure needs additional training. On top of that, the PFD CDI guidance is rated to be very demanding.

Visual and optical issues mostly applied to the glare effect of the display surface. The position and size of the navigation display was smaller than needed but due to the single display area this could not be prevented. As a result, the size of the navigation display was reduced and barely readable. From pilots’ feedback this did not influence the PFD/tunnel-in-the-sky guidance display usability. They also reported that when using the tunnel-in-the-sky guidance display they only occasionally looked on the navigation display, whereas they checked the navigation display more regularly when using the PFD.

No relevant experimental issues other than fatigue were observed. This was caused by flying the approach four times in a row, which was much longer than a regular approach. The fact that the research

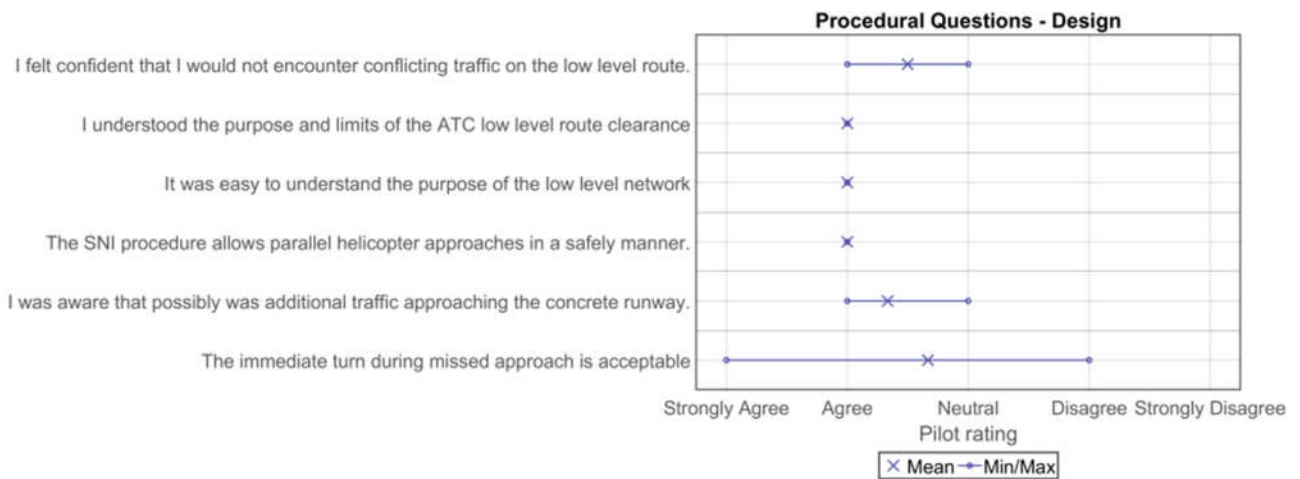


Figure 13: De-briefing questionnaire – procedural questions about design

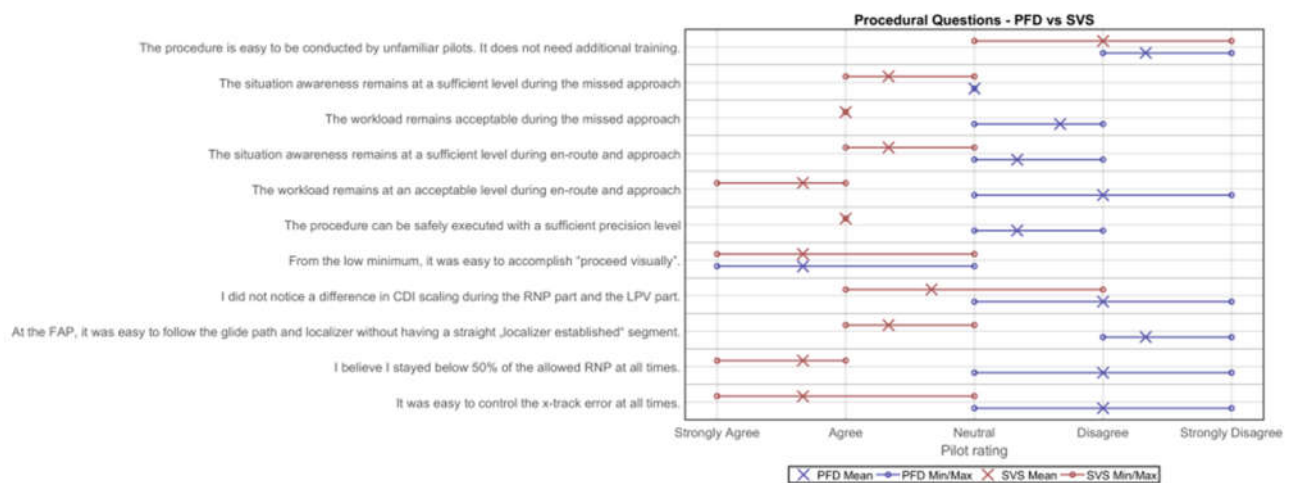


Figure 14: De-briefing questionnaire – procedural questions per display type

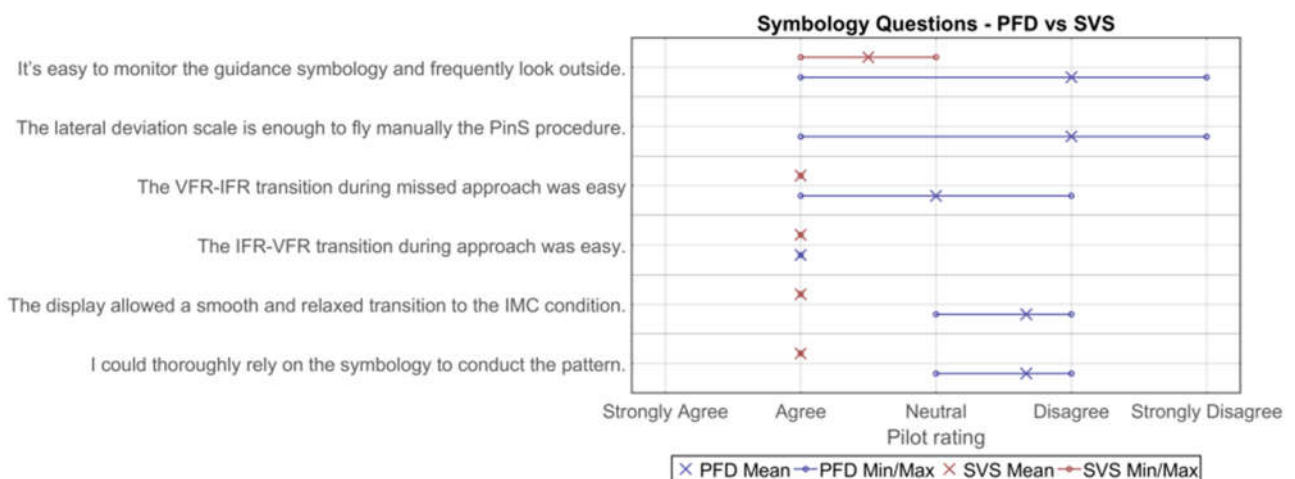


Figure 15: De-briefing questionnaire – symbology questions per display type

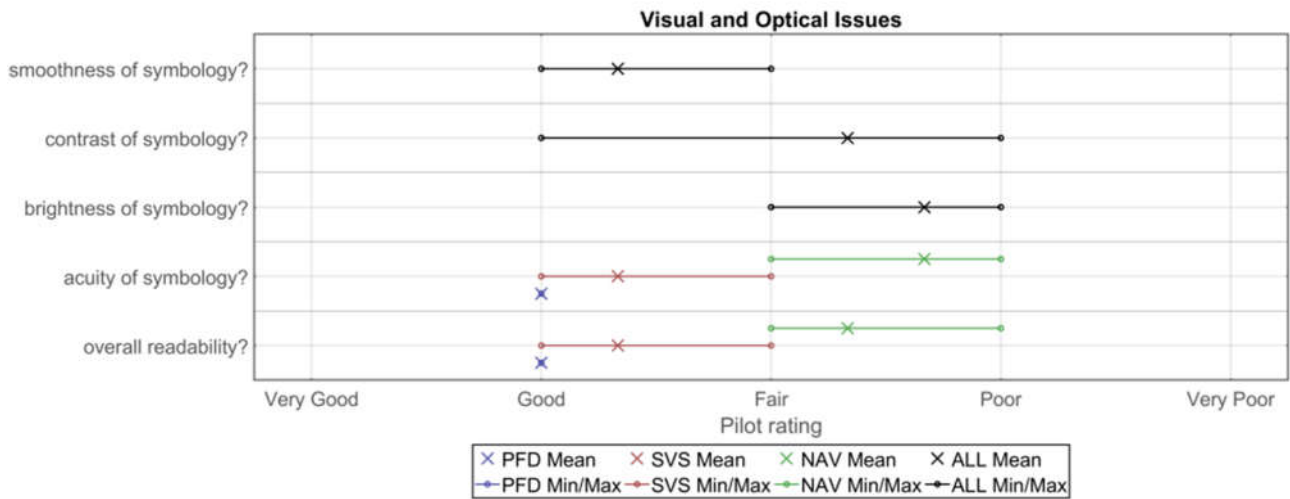


Figure 16: De-briefing questionnaire – visual/optical issues experienced per display

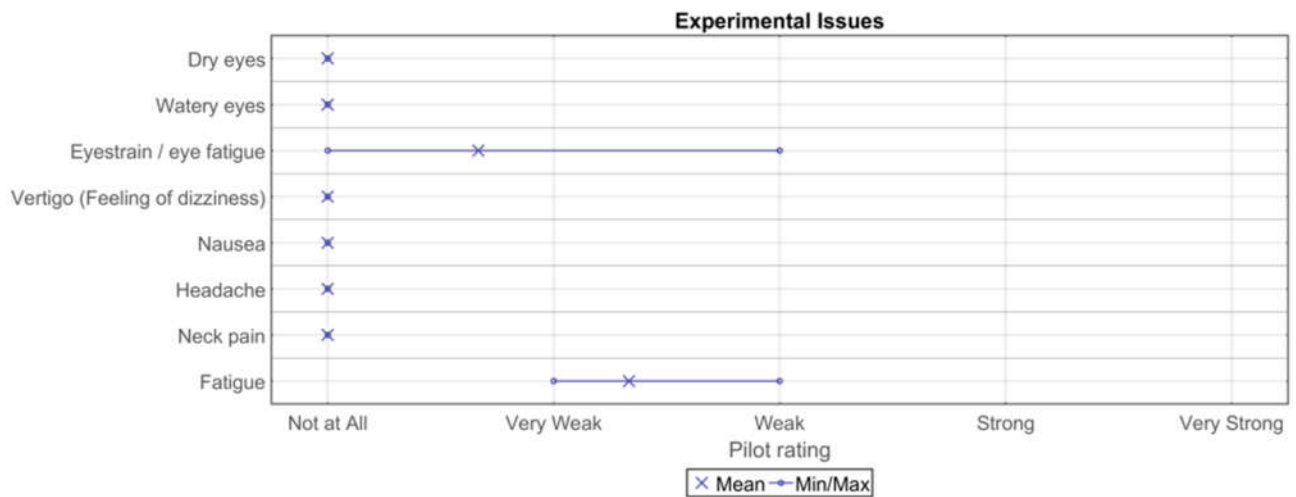


Figure 17: De-briefing questionnaire – experimental issues experienced

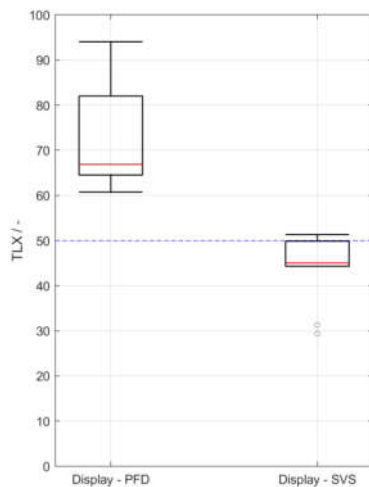


Figure 18: NASA-Task Load Index – absolute index per display type

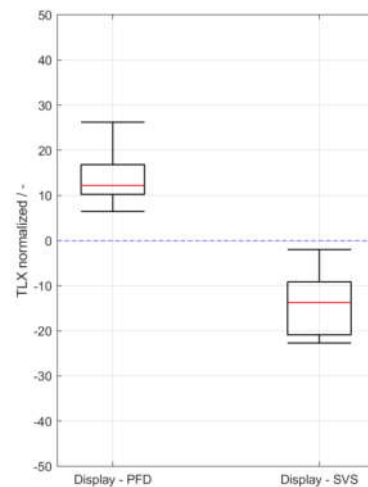


Figure 19: NASA-Task Load Index – relative index normalized for each pilot per display type

helicopter was operated in basic control mode without any stabilization (not even SAS) added workload to the task and consequently led to fatigue.

Figure 18 through Figure 21 show the boxplot from the NASA-TLX and 3D SART questionnaires per display type. The PFD provoked much more workload for the pilots than the tunnel-in-the-sky guidance. Nevertheless, the variation of the ratings for the PFD were very high. To allow a better relative view on the ratings, a normalized boxplot per display is also available. It depicts the relative rating of each pilot, that is the difference of the PFD and tunnel-in-the-sky guidance rating from the mean rating per pilot. One can see for the task load index that the tunnel-in-the-sky guidance display has a nominal and balanced workload rating whereas the PFD shows a much higher workload.

The ratings for the SA barely showed enough SA for the PFD and fair ratings for the tunnel-in-the-sky guidance display. It can be argued that, in comparison with the tunnel-in-the-sky guidance display, pilots felt much less aware of their situation and what pilots stated as being “behind” the helicopter. This states the fact that with CDI guidance pilots always have to reduce an already build up deviation. It was much easier with a tunnel-in-the-sky guidance display to prevent a deviation to build up at all.

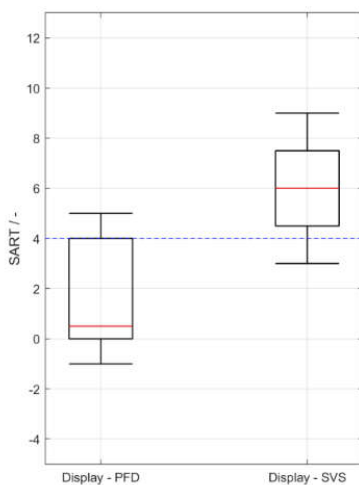


Figure 20: 3D Situation Awareness Rating Technique – Absolute score per display type

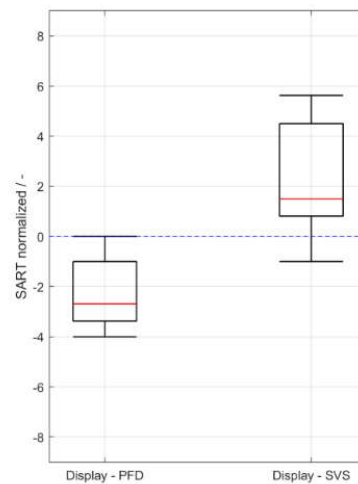


Figure 21: Situation Awareness Rating Technique – relative score normalized for each pilot per display type

#### 4. CONCLUSION

The test procedures and Exercise #05 flight trials have been carried out from August 20 until September 18, 2019.

The flight trials showed that SNI missed approaches were possible and safe. In order to save time and reduce complexity, the design of the missed approach was altered slightly to allow continuous approach and missed approach segments.

In SESAR2020, PJ.02-05 developed new PinS procedures with new technologies in order to implement and perform the expected assessments of SNI operations. It was not the goal of GRADE to validate the SNI concept, but rather to use this concept as a final flight phase of a low level route network to demonstrate conflict-free, time-parallel approaches for helicopter and fixed-wing aircraft.

Subsequently the LLR was demonstrated in the foreseen combination with SNI at local airports. The concept of LLR allowed rotorcraft to operate under IMC en-route conditions as an operational enabler for e.g. helicopter emergency medical service (HEMS) missions. It has to be pointed out that for approaches and departures at or from unprepared landing sites there is still the need for either a mobile precision approach concept or VMC condition to be met at the landing site. For the precision approach concepts there are already technological solutions available to implement a take-off to touchdown IFR operational concept, but up to now no such concept has been fielded.

Finally, it can be summarized that the flight tests carried out as part of Exercise #5 can be flown in a standard IFR configuration, but due to the lack of stabilizing assistance functions (e.g. SAS) additional workload was imposed on the pilot. Nevertheless, the flight tests were carried out safely and with high

accuracy. Ultimately, it was found on the basis of the results that the tunnel-in-the-sky guidance display leads to an improvement in performance compared to head-down set-ups.

## 5. ACKNOWLEDGEMENT

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