

Precision Approach Procedures with General Aviation Aircraft and Helicopter at Braunschweig Research Airport



T. Feuerle, T. Rausch, T. Lueken, and S. Schmerwitz

Abstract The European funded project “GNSS Solutions for Increased GA and Rotorcraft Airport Accessibility Demonstration—GRADE” is a very large demonstration (VLD) project within the SESAR2020 program. In the context of this VLD, several SESAR solutions are demonstrated in simulation and real flight test campaigns. This paper presents the demonstration and evaluation of capabilities of a common used general aviation (GA) aircraft, namely Cessna 172N, performing different precision approach procedures. In parallel, an EC135 helicopter is demonstrating the possibilities of point in space (PINs) approaches. The project team consists of European partners representing different stakeholders involved in air traffic. Initially, fast time simulations took place where air traffic controllers were confronted with aircraft approaching on curved approaches paths using performance-based navigation (PBN) procedures. A flight test campaign has been conducted in July and September 2019 in Braunschweig. The two project partners TU Braunschweig (TUBS) and German Aerospace Centre (DLR) conducted several approaches in parallel using a GA aircraft (TUBS) and a research helicopter (DLR) in order to demonstrate a simultaneous non-interfering (SNI) approach to the Braunschweig airport.

Keywords Precision approach procedures · General aviation · Demonstration of novel SESAR approach procedures

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1 Introduction

In the coming decades, general aviation (GA) aircraft and rotorcraft, especially the small ones for personal transportation, will have an increasingly important role in air traffic. These vehicles usually have basic on-board equipment, only some of them are equipped for instrument procedures like the instrument landing system (ILS). Therefore, in the terminal phases of the flight, they often fly according to visual flight rules and perform non-precision approaches, significantly affecting the operations of the other airspace users. As already done for better equipped commercial aircraft, the exploitation of Global Navigation Satellite System (GNSS) for navigation during instrument approach and landing could allow GA aircraft and rotorcraft to improve their navigation (guaranteeing the required performance) and to increase tasks automation (thus reducing pilot workload), while ensuring higher levels of safety. For the application, the availability of affordable flight deck displays and decision support tools is necessary. Consequently, it will facilitate the integration of such aircraft in future air traffic scenarios and systems [1, 2].

Moreover, the exploitation of GNSS navigation procedures will allow the definition of more flexible approach procedures, providing benefits in terms of minimizing the interference with commercial aircraft for landing on congested airports and the avoidance of sensitive zones (e.g. due to obstacles, security and noise constraints) for landing on small airports placed, e.g. in urbanized area.

One of the aims of the “*GNSS Solutions for Increased GA and Rotorcraft Airport Accessibility Demonstration* (GRADE)” project is to demonstrate the capability of GA aircraft, equipped with SBAS (space-based augmentation system) as well as GBAS (ground-based augmentation system) receivers, to perform precision curved approaches with required navigation performance (RNP) below 0.3 NM [3–5]. A general overall overview of the project can be found in [6].

The project demonstration itself includes two steps, the first one consists of real-time simulations (RTS) with human and hardware in the loop and the second one of flight trials (FT) [7]. The paper [7] analyses the results of the first demonstration step for fixed-wing GA aircraft, aimed at the fine adjustment up of the prototype systems to be integrated in the flying test beds.

This paper summarizes the trials conducted in Braunschweig. Due to the nature of the very large demonstration (VLD) project, the focus was laid on the demonstration of the technological achievements of previous SESAR projects. A detailed explanation of the setup and the results will be given herein.

2 Experimental Setup

This paper focusses on the flight trials at Braunschweig research airport (EDVE). The two project partners TU Braunschweig (TUBS) and German Aerospace Centre (DLR) have conducted several approaches with a GA aircraft (Cessna 172N) and a helicopter (EC135). The procedures which have been flown will be explained in more detail in Chap. 5.

The C172N is equipped with several high performance GNSS navigation equipment, namely a prototype of a ground-based augmentation system (GBAS) receiver for GA, a commercial off-the-shelf (COTS) space-based augmentation system (SBAS) receiver, a GNSS reference unit and a prototype system of a human-machine interface (HMI). The objective of the flight trials is the demonstration of different SESAR solutions for GA from a technical perspective as well as the collection of pilot feedback, i.e. collection of operational feedback. Procedures to be covered will be SESAR 1 solution #51 “Enhanced terminal operations with LPV procedures”, #55 “Precision approaches using GBAS CAT II/III based on GPS L1” and solution #103 “Approach procedure with vertical guidance”.

The operational scope of the flight test campaign in Braunschweig was the demonstration of the feasibility and benefits of the execution of the SESAR 1 solution Sol#113 “Optimized Low-Level IFR routes for rotorcraft”, which covers the demonstration of standard point in space (PinS) helicopter procedures as well as low-level IFR routes for helicopters. In addition, it has been demonstrated, that the PinS procedure can be conducted independently from approaching fixed-wing traffic resulting in a simultaneous non-interfering (SNI) operation. The same guidance tools as used in the real-time simulation have been integrated into DLR’s research helicopter active control technology / flying helicopter simulator (ACT/FHS). This included head-down display prototypes of an enhanced primary flight display with course deviation indicator (CDI), as well as a navigation display for presenting guidance information to the pilot.

3 Research Aircraft Cessna C172N

The research aircraft is a standard Cessna C172N (see Fig. 1). It has been modified with several additional sensors and antennas as well as pilot interfaces. It is certified with a permit to fly which limits the flights to daytime and visual flight conditions. Nevertheless, it can be used for experimental flight trials easily (see also [8]).

For the GRADE project and the trials described in this paper, a prototype of a GBAS receiver has been installed. It is located in the middle part of the flight deck below the GARMIN 430WAAS (see Fig. 2). Deviation indications from both devices



Fig. 1 Research aircraft cessna 172N “D-EMWF”



Fig. 2 Cockpit of cessna 172N

can be displayed on the cross deviation indicator, which is also located in the middle part of the cockpit panel. With this installation GBAS as well as SBAS approaches can be performed using standard instruments. It has been used within the project to assess the flyability and acceptability of novel approach procedures in conventional cockpit layouts. Besides these conventional instruments, a portable moving map device was installed into the aircraft as well. (Fig. 3).



Fig. 3 DLR’s research helicopter active control technology / flying helicopter simulator (ACT/FHS)

4 Research Helicopter EC135

The ACT/FHS “flying helicopter simulator” of the DLR is based on a standard Eurocopter EC 135 type helicopter, which has been extensively modified for use as a research and test aircraft. The mechanical controls, for example, have been replaced by a fly-by-wire/fly-by-light (FBW/FBL) flight control system. As a result, the control commands are transferred by electric cables and fibre optic cables instead of control rods.

The application portfolio of the FHS covers pilot training, trials of new open and closed-loop control systems, up to simulation of the flight characteristics of other helicopters under real-environmental conditions. The FHS is equipped with two engines, a bearingless main rotor and a Fenestron tail rotor as standard; its key features are notably quiet operation and high manoeuvrability and safety. The fly-by-light control system is a ground breaking new system, where, in contrast to fly-by-wire, the control signals between the controls, the flight management computer and the actuators for rotor blade control are transferred optically via fibre optic cables instead of electrically.

The advantages compared with electrical data transfer are the high transmission bandwidth, high reliability and low weight. The fly-by-light flight control system consists of a quadruple redundant computer and is designed such that the stringent safety criteria of the European aviation authorities are met in full.

FHS is the first helicopter in the world with this flight control system. The cockpit layout provides seats for a safety pilot, the test pilot and the flight trial engineer. A comprehensive equipment line-up with sensors and systems for on-board data recording and processing is used to record the data from the flight trials. This data is available to users and engineers for analysis on board and—via telemetry—on the

ground. Furthermore, additional vision systems and an experimental flight management system (FMS) can be integrated in order to generate adequate head-down symbology for PinS guidance.

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 the display of additional information to be displayed on the evaluation pilot's head-down display at the same time. To realize this capability, a cable was laid between the JCONV2 and the side panel near the flight test engineer. From there, the video signal was routed to the evaluation pilot's head-down display.

5 Procedures Flown

Two independent flight test procedures were designed: One for the fixed-wing demonstration and one for the rotorcraft demonstration. The procedures described in this chapter have been demonstrated in flights either by the Cessna 172 solely, the FHS solely, or by both aircraft simultaneously.

Flight trials for the fixed-wing demonstration exercises consist of reference scenarios (standard instrument RNAV arrival and approach procedures as published in AIP) and solution scenarios designed for the flight exercises in the GRADE project. These solution scenarios included shorter routes and additional turning points compared to the reference scenarios. The additional turning points were set to already available visual reporting points to ease the flight operations including air traffic control and other traffic. The intention was to generate curved and segmented pre-defined approaches as given in the different SESAR solutions (see Chapter 2).

Figure 4 shows, from left to right, the reference scenario for the runway 08, the solutions scenario route for runway 08, solution scenario route for runway 26 and the reference scenario for runway 26.

The pilot was supported by a GNSS-based navigation prototype on a portable display (showing a map display and a course deviation indicator) during the whole approach, and for the final approach of the solution scenarios additionally either by GBAS or SBAS information. Off-nominal scenarios like simulated GBAS outage or display outage were included in the exercises.

Flight trials for the rotorcraft demonstration exercises consist of an en-route segment of a low-level route (LLR), a PinS approach and a PinS missed approach. 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.

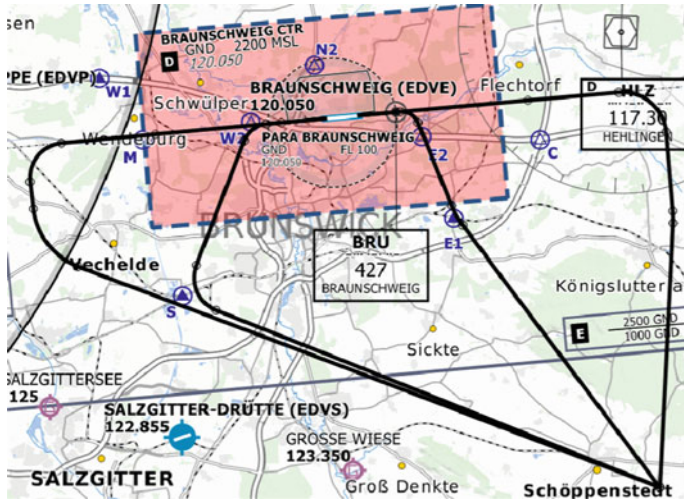


Fig. 4 Reference and solution scenario routes for the fixed-wing demonstration exercises

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 a visual procedure 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 design of the PinS ensures that all separation limits are respected according to SESAR 4.10 Deliverable 23. 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.

Figure 5 shows the LLR network for the GRADE project integrated into a departure chart for runway 26 at EDVE. The design altitude for all segments is 2200 ft, roughly 2000 ft above ground level. The approach procedure (see also Fig. 6) commences at point LELUH near Wolfenbuettel. 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 segment (LPV) with a fictitious threshold point located such that the glide path intercept point is exactly at the desired helipad. Vertical guidance is an ILS look-alike guidance provided by the SBAS system using a 4.4° glide path angle. Minimum descent altitude is 628 ft MSL (350 ft GND), thereafter proceed visually if the helipad is in sight.

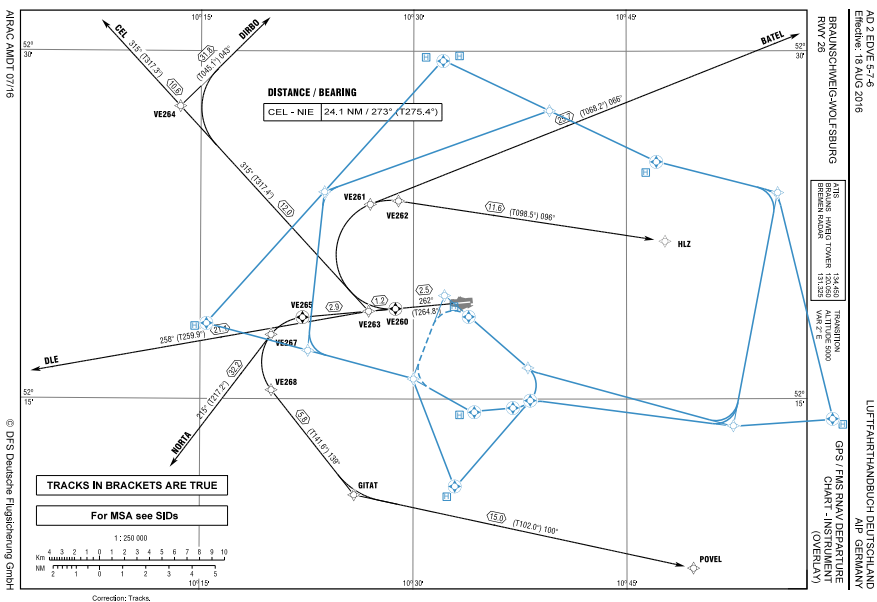


Fig. 5 Possible low-level route network

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. 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. Upon reaching WP4, a 1.5 NM 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 2.75 NM. 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 5.1 NM. We designed the missed approach track along the track of the city tangent motorway to reduce noise exposure of downtown Braunschweig.

As an example, with this network, it would be possible to transport patients from whatever hospital required to the airport under IMC. In detail, there are six hospitals, a federal police force heliport and the airport EDVE connected to this network. The rotorcraft can follow a LLR network from one hospital to another or to a local airport under IFR. This 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.

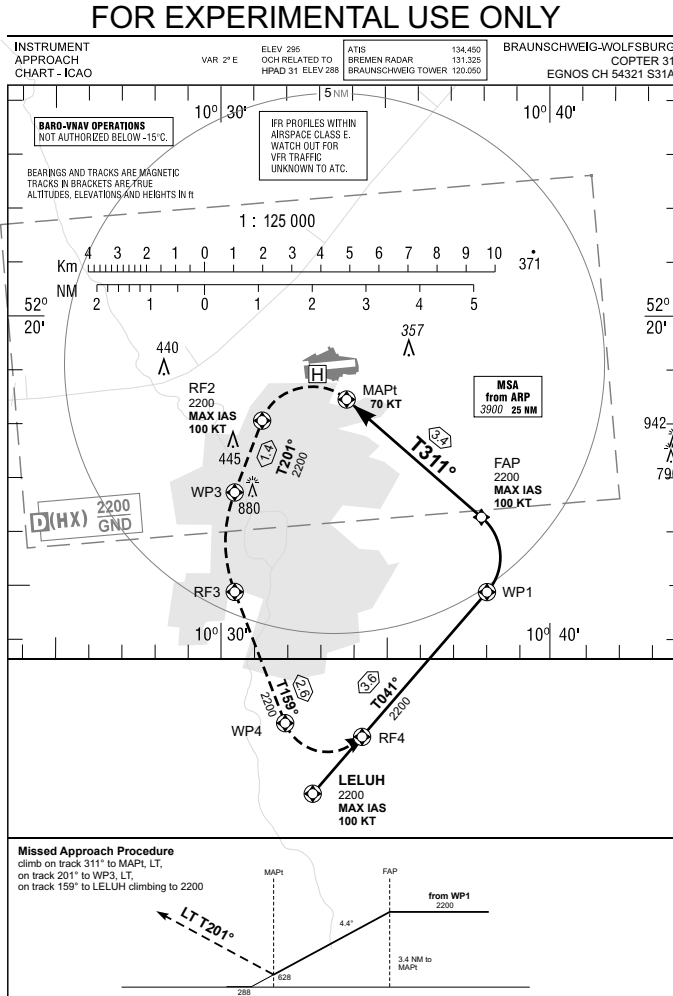


Fig. 6 Possible simultaneous non-interfering approach

6 Results and Evaluation of the Trials

The fixed-wing flights have been carried out between 18th July and 12th September 2019; three different pilots were involved. 20 approaches and a total flight time of about 7:30 h on 6 different days were executed.

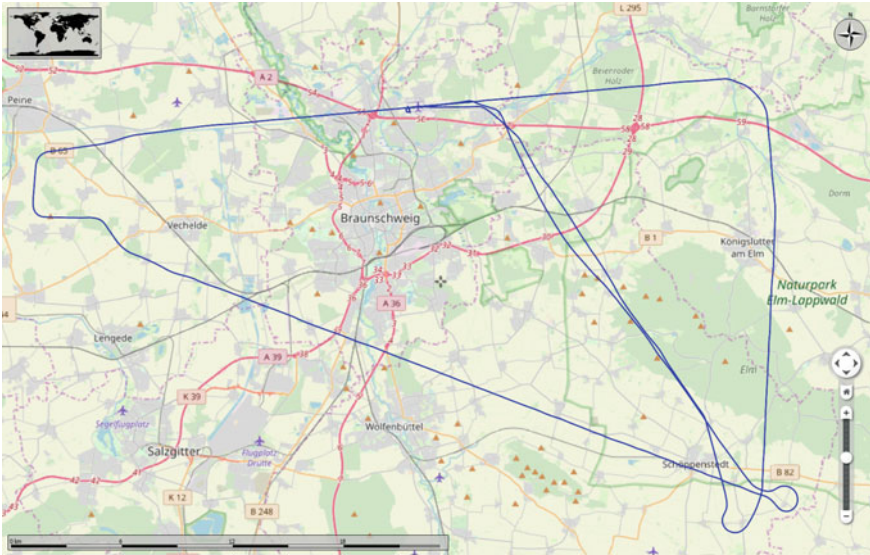


Fig. 7 Reference scenario flight path of the fixed-wing demonstration exercise (with ATC intervention during RWY08 approach)

Figure 7 shows one flight with reference scenario approaches inbound runway 26 and runway 08. The complete flight trajectory is displayed with the outbound trajectories in the middle and the approach trajectories to the right (for runway 26) and left (for runway 08). The approaches all started at the initial waypoint south east of Braunschweig airport. The approaches inbound runway 26 were flown without ATC delays. The approach to runway 08 shows a small deviation due to ATC vectoring.

Figure 8 depicts the flight trajectories of solution scenario approaches. All three approaches were flown on runway direction 26 with different length of initial approach segment. The intermediate approach segments have been flown using augmented GNSS while the final approach segment has been flown using either SBAS or GBAS (as GBAS is not available for terminal approach path procedures so far).

An inspection of the recorded flight path data showed that pilots were able to follow the defined approach path closely. In all the executed approaches, values lower than 0.3 NM for the deviation from the defined approach path were achieved.



Fig. 8 Solution scenario flight path of the fixed-wing demonstration exercise, RWY26

For human performance analyses, questionnaires have been filled out, addressing the objectives of acceptability of the tested operations by pilots, feasibility and flyability of the designed procedures (accurate and efficient completion of operations), cognitive workload (using the NASA Task Load Index (TLX) assessment), situational awareness (using the NASA Situation Awareness Rating Technique (SART) assessment), and the capability of the HMI to provide the pilot with clear and complete information to execute the landing procedures with a sufficient level of confidence and precision.

The resulting subjective total workload of the fixed-wing pilots ranges from 38% to 44%, the resulting subjective total situational awareness score ranges from 5.6 to 9.2 (on a scale ranging from -5 to 13). This shows a generally moderate workload combined with a good situational awareness.

Figures 9, 10, 11 and 12 show some further pilots' answers to the questionnaire items.

Fig. 9 Exemplary questionnaire answers for the fixed-wing flights (procedure)

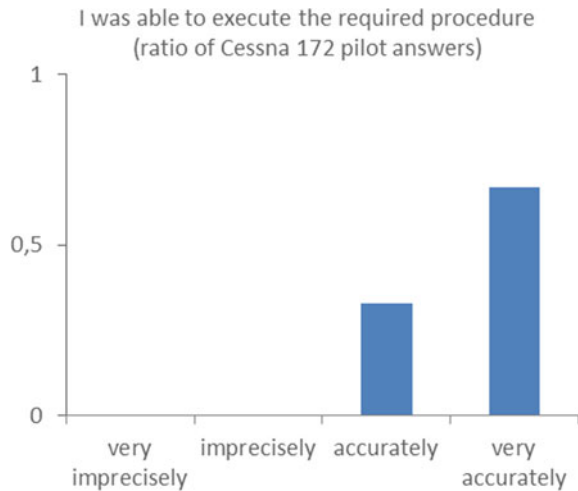
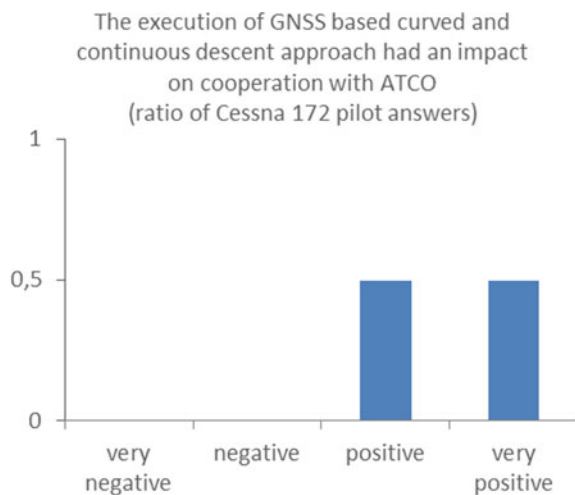


Fig. 10 Exemplary questionnaire answers for the fixed-wing flights (impact on ATCO)



Comments to the procedure layout were also collected. Beside the fact, that the final was quite short but manageable, no major findings were drawn. A rationale for this statement is the fact that the procedure has been adapted especially for relatively slow flying GA aircraft.

Regarding the helicopter flight trials, these exercises were supported by two different types of flight guidance displays (Fig. 13). The standard PFD display has been complemented by a course deviation indicator (CDI) and so-called bugs for desired speed, barometric altitude, and heading. The final approach point “FAP” defines the position where the display of the PFD is switched from RNP/VNAV (green) to angular deviation of the LPV (magenta). A tunnel-in-the-sky synthetic

Fig. 11 Exemplary questionnaire answers for the fixed-wing flights (situational awareness)

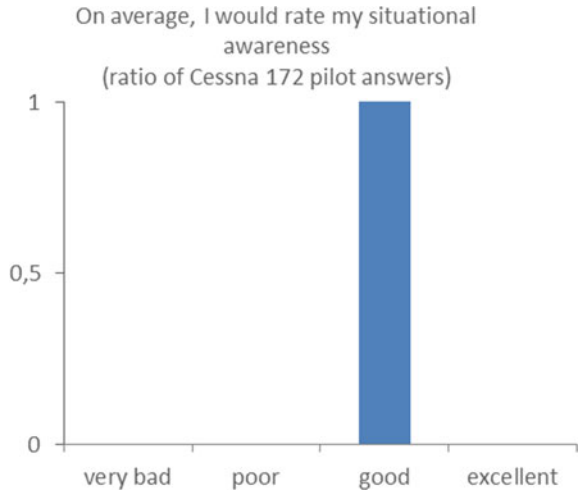
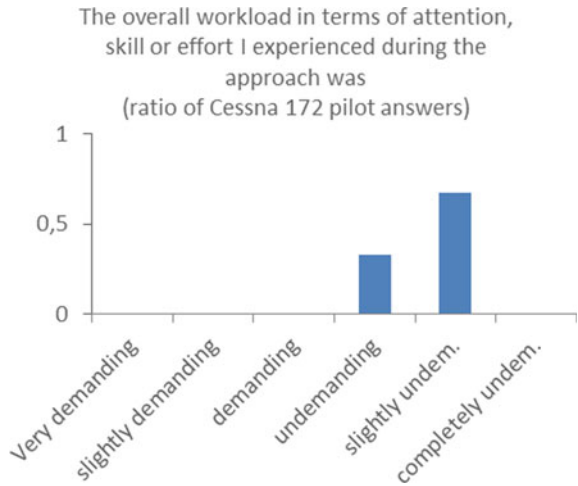


Fig. 12 Exemplary questionnaire answers for the fixed-wing flights (workload)



vision system (SVS) was implemented as an alternative primary flight display. To minimize the cross-track error especially, in curved segments, a flight path marker and a flight director as parts of the tunnel display supported the pilot during turns.

The flight trials have been carried out from 20th of August until 18th of September. With respect to the preparation of these flight trials, many different experts on different focal areas have been involved in these experiments:

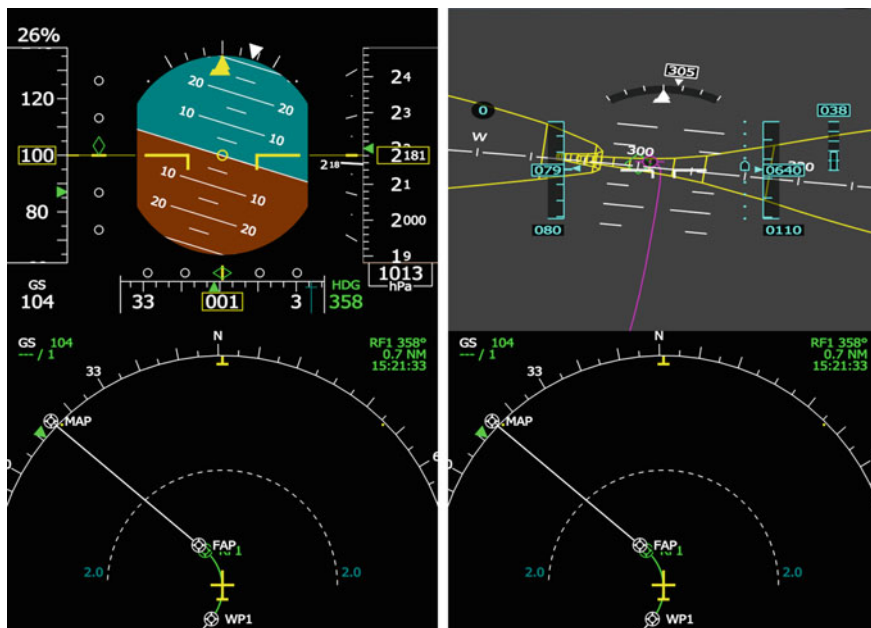


Fig. 13 Solution scenario (Sol #113) of first helicopter demonstration exercise including tunnel- (SVS), navigation- and PFD flight guidance displays.

- 4 technical experts / engineers (prototype implementation, flight trials preparation, and demonstration day technical preparation and presentation);
- 3 DLR test pilots (same pilots who carried out preceded real-time simulations in fall 2018) [9];
- 1 human factors expert.

In total, 2 shakedown runs and 24 repeated approaches during 10 h of flight time on 6 different days were conducted during the flight trials.

Flight data records were made to subsequently provide quantitative statements regarding e.g. tracking accuracy, cross-track errors, etc. For human performance analyses, questionnaires have been filled out: 8 NASA TLX, 8 3D SART, and a debriefing questionnaire by each pilot.

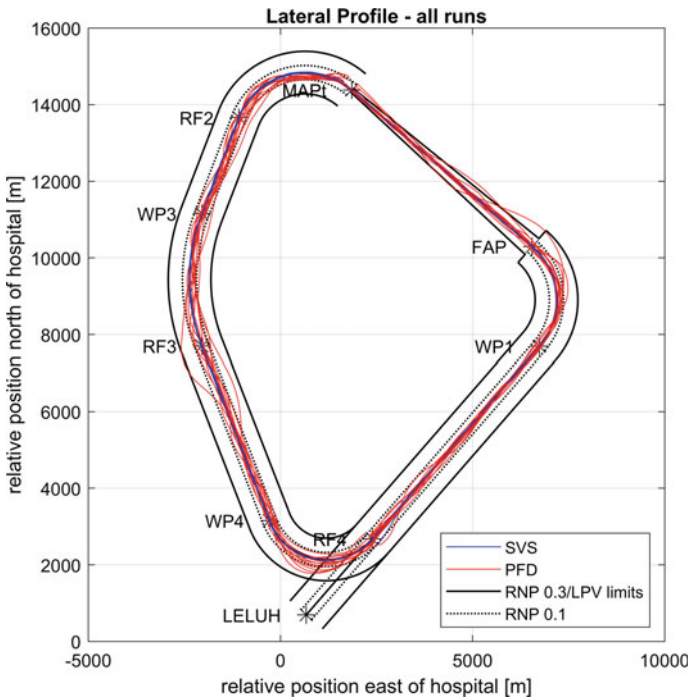


Fig. 14 Lateral profile of all runs per display type with RNP limits

Figure 14 depicts the recorded lateral profile for all runs with the RNP 0.3 limits and a second limit of RNP 0.1. It can be seen that all pilots managed to stay within the RNP 0.3 limits during the approach phase regardless of the guidance display type. During the LPV approach between FAP and the MAPt, two runs under PFD with CDI configuration show deviations larger than the LPV allows. In both cases, the pilots managed to capture the calculated localizer again. It can be observed that in general, all flights under PFD with CDI configuration pilots tend to react later on deviations from the route. With SVS guidance, the lateral accuracy was always significantly better than RNP 0.1 except for two flights close to the start of the procedure.

Table 1 Flight time within RNP limits during the approach phase in percent

	PFD (%)	SVS (%)
$X \leq \text{RNP } 0.1$	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

Tables 1 and 2 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 is 6% worse for the PFD guidance and constantly good for the SVS guidance.

Figures 15 and 16 show the box-whisker plots from NASA TLX and 3D SART questionnaire per display type. The PFD provoked much more workload for the pilots than the SVS. Nevertheless the variation of the ratings for the PFD is very high. The ratings for the situation awareness barely shows enough SA for the PFD and fair ratings for the SVS. It can be argued that in comparison with the SVS display pilots feel much less aware of their situation and what pilots state as being “behind” the helicopter. As a result, pilots with CDI guidance always have to reduce an already build up deviation. It is much easier with a tunnel-in-the-sky guidance to prevent a deviation to build up at all.

Table 2 Flight time within RNP limits during the missed approach phase in percent

	PFD (%)	SVS (%)
$X \leq \text{RNP } 0.1$	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

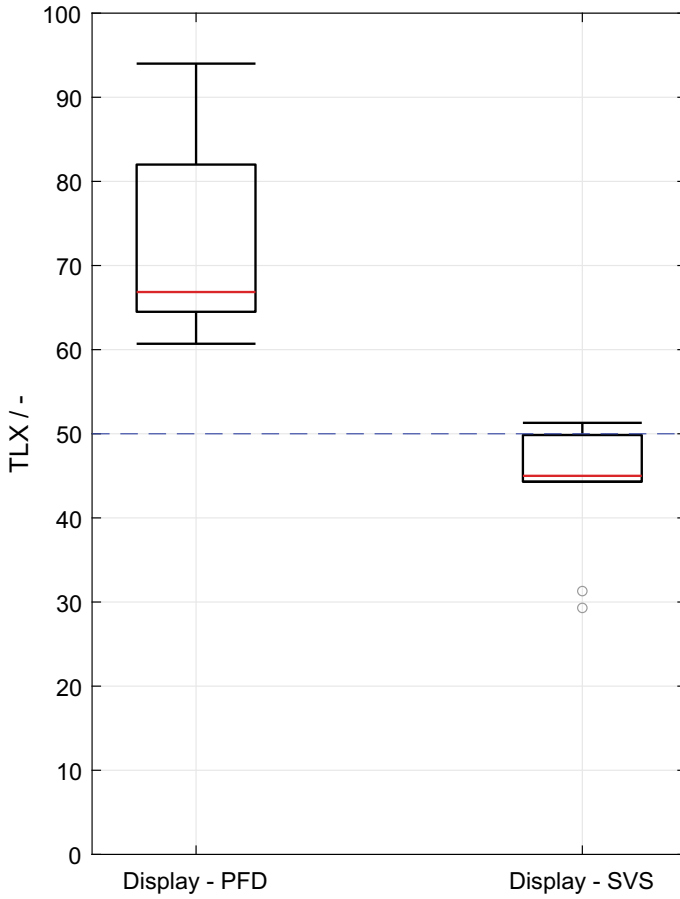


Fig. 15 NASA Task load index, absolute index per display type

More details to the results of GRADE's helicopter flight trial demonstration will be presented on 46th European Rotorcraft Forum ERF 2020 in Moscow [10].

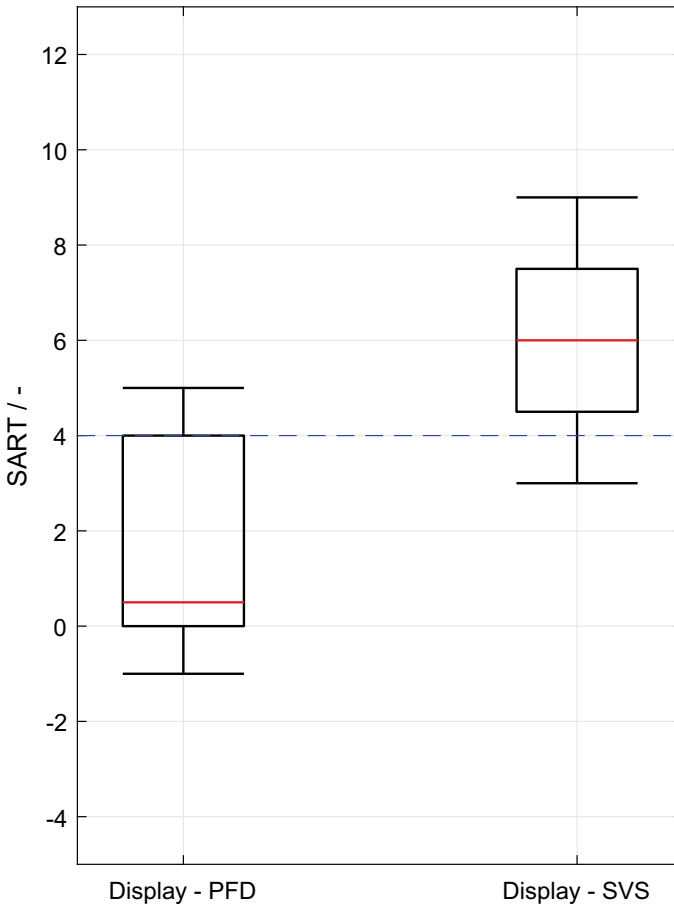


Fig. 16 3D situation awareness rating technique, absolute score per display type

7 Conclusions

The GRADE project demonstrated that GNSS-based approach procedures are well suited not only for business and transport aircraft but also for rotorcraft and general aviation aircraft. With the performed study including demonstration flights into Braunschweig research airport, the feasibility has been demonstrated. With the highly flexible GNSS procedures and the corresponding avionic equipment approaches can be flown with less impact on environment (e.g. circumnavigation of noise sensitive areas) as well as separation between different kinds of traffic.

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