IN-FLIGHT EVALUATION OF PILOT GAZE DURING SHIP DECK LANDINGS

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Abstract
The Ship Deck Landing (SDL) is one of the most challenging missions for helicopter pilots. Adverse weather conditions with a small and constantly moving deck platform as well as turbulence and an obstacle environment makes the SDL a demanding task. Therefore, it requires a lot of training to not compromise flight safety. As the training in a real environment is expensive, requires a lot of organizational effort and is restricted in emergency procedures, a simulator with realistic cues could be a solution to optimize the SDL training. In this work the use of eye tracking is proposed to find out the correct visual cues, which are necessary for a realistic training simulation environment of the SDL. A training campaign with 17 SDLs was recorded and analyzed using logging devices and eye tracking glasses. The results show that eye tracking can be a suitable tool to find significant visual cues for the SDL task. Multiple outside and cockpit visual cues and differences in gaze behavior between approach and takeoff were identified.

1. ACRONYMS

AOI	Area of Interest
AVES	Air Vehicle Simulator
F/A	Fore/Aft
FTD	Flight Training Device
GNSS	Global Navigation Satellite Systems
HEDELA	Helicopter Deck Landing Assistance
HEMS	Helicopter Emergency Medical Service
HUMAN	Using Helicopters to Support Maritime Emergencies (Hubschraubereinsätze im Rahmen der maritimen Notfallvorsorge)
IOR	ITC/OTW Ratio
ITC	Inside-the-Cockpit
OTW	Out-the-Window
SDL	Ship Deck Landing
SHOL	Ship Helicopter Operation Limits
TOI	Time of Interest

2. INTRODUCTION

Due to their versatile vertical flight capabilities, helicopters are used in a wide range in the maritime environment. In military and police operation, helicopters are typically used for transport of personnel and material, defense, surveillance and reconnaissance. As stationary landing pads are rarely available in open seas, those tasks require the helicopter to operate from and to the deck of a ship. The takeoff and landing procedure on ships, as shown in Fig. 1 is known as SDL, which includes landings on aircraft carriers and medium class warships such as frigates or corvettes.

Figure 1 EC155 of the Flight Service of the German Federal Police during SDL

The maritime operation of helicopters and especially the SDL task is very demanding for the pilot and the helicopter technology. Inclement weather situations such as precipitation, low visibility, high wind speeds makes flying in the maritime environment difficult. In the vicinity of the ship, high turbulence with strong rotational and translational components caused by the ship's superstructure can be expected. Due to spray coming from breaking waves in high sea states the visibility might be very low [1]. Depending on the sea state, the ships relative speed to the waves and the ships damping capabilities, a high ship motion in pitch, roll and heave can lead from challenging up to impossible conditions for both the helicopter and the pilots. Human or technical errors in the maritime environment, such as an One Engine Inoperative (OEI) situation, may require an emergency ditching connected with an increased risk of death [2]. To find a safe flight envelope in this environment, the operational limits in wind speed and ships rotational motion, also known as Ship Helicopter Operation Limits (SHOL), are typically determined using flight testing [3].

Within the scope of DLR's project partners, the training of helicopter pilots for the SDL is mainly performed in the real environment, which has three major disadvantages. Firstly, a ship with fully trained crew for ship operations and a helicopter suitable for maritime operation has to be provided, which causes huge costs and requires a lot of organization. Secondly, the training is only possible during good weather conditions. Considering the organizational effort for the ship, crew and the availability of the helicopter, the available training slots are even more limited. Thirdly, emergency maneuvers and borderline weather conditions with high ship movements and strong turbulence can only be trained to a very limited amount, as otherwise flight safety might be compromised.

A solution to optimize the SDL training is to use Flight Training Devices (FTDs) with a realistic environment. Previous works have already addressed the simulation environment for SDL. In a simulation campaign investigating visual cueing effects in Good Visual Environment (GVE) and Degraded Visual Environment (DVE) conditions pilots stated the importance of visual details such as the horizon bar and deck bum-line [4]. An accurate ship wake as well as a correct motion cueing was determined as significant elements of a realistic ship-helicopter dynamic interface simulation [5, 6]. Even the ships engine exhaust was found to have an influence on the simulated helicopter performance [7]. It was found in a simulator study, that especially in higher wind conditions the motion cues have an influence on the task performance during SDL [8]. Three studies already analyzed the pilots gaze strategy during simulated SDL. The first study found the gaze of pilots focusing almost exclusively on the ship [9], the second study discovered significant differences between student pilots and instructors [10] and the third study identified the paramount importance of line-up and positional information [11]. A previous study in the Air Vehicle Simulator (AVES) simulator found the main focus of pilots during approach and landing being at Out-the-Window (OTW) cues [12]. During a further study with interviews of ten navy pilots various lights, deck markings and the horizon reference bar were identified as the main external visual cues for a successful completion of the SDL [13].

As the results from previous research works show, it is crucial to know the main visual cues which pilots use during the ship deck operation for creating a realistic simulation environment. The research question, which this work addresses, is whether eye tracking is a suitable approach for identifying these cues and which metrics are suitable for validating the visual simulation environment.

In this paper the analysis of a SDL training campaign by the Flight Service of the German Federal Police is presented, which was accompanied and analyzed to optimize the SDL training. Eye tracking glasses in combination with flight state data acquisition units on board of the ship and the helicopter were used to record relevant data. Various fusion and analysis algorithms were used to evaluate the recorded data. The data of one pilot flying 17 approaches and 16 takeoffs were taken into account for the evaluations.

This paper is structured as follows. In Sec. 3 the previous work in the projects Helicopter Deck Landing Assistance (HEDELA) and Using Helicopters to Support Maritime Emergencies (HUMAN) is presented. Sec. 4 contains a detailed description of the experimental setup and the analysis methodology. The results of the analysis are shown in Sec. 5. A final conclusion and an outlook is presented in Sec. 7.

3. PREVIOUS WORK

Prior to the work in this paper, several maritime projects and eye tracking studies were conducted at the Institute of Flight Systems at the DLR. This includes simulator fidelity optimizations as well as piloted campaigns in the AVES simulator and DLR's Bo105 helicopter.

3.1. Project HEDELA and HUMAN

The goal of the DLR-internal financed projects HEDELA and HUMAN is to increase maritime safety by enabling helicopters and crew to operate in adverse weather conditions. While the focus of the research activities during the already completed project HEDELA was on flight safety during SDL, the running project HUMAN is focused on helicopter operation during maritime emergencies. A maritime simulator scenario including the ship environment consisting of visual elements and a wake turbulence simulation was integrated into the AVES during HEDELA. Three assistance systems were evaluated and an eye tracking analysis was conducted in the simulation environment during multiple SDL approaches in a piloted simulation campaign. All three participating pilots in this campaign showed an OTW focus during the approaches with an ITC/OTW Ratio (IOR) between 20% and 40%. Furthermore the Airspeed Indicator (ASI), Altitude Indicator (ALT) and Attitude Indicator (ATT) were identified as most significant Inside-the-Cockpit (ITC) cues. The results of the evaluations are presented in [12].

3.2. Helicopter In-Flight Eyetracking

During the past years, various piloted campaigns in helicopter cockpits were conducted at DLR. First trials using eye tracking during ship deck landing simulation showed the share of attention of helicopter pilots in the simulated maritime environment [12]. An analysis of hover flights with eye tracking glasses using DLR's Bo105 helicopter showed the influence of the visual environment to the gaze behavior of the pilots and a first approach to identify gaze strategies [14]. The difference in eye gaze patters in simulated and real flight was addressed in a comparison of takeoff and landing maneuvers in DLR's Bo105 and the AVES [15]. Results of the work showed a change of gaze behavior between real and simulated flight which is assumed to be a cause of simulator deficiencies. The first steps of the integration of an eye tracking system into DLR's research helicopter ACT/FHS with connection to the avionics and real time data analysis are described in [16]. In this work the requirements for using eye tracking glasses in the helicopter were defined and the airworthiness of the glasses was assured. With the preparation of those previous works, it was possible to use the eye tracking glasses during this campaign without compromising flight safety.

4. METHODOLOGY

This section describes the experimental set-up of the study as well as the performed maneuver and the used algorithms for the analysis.

4.1. Vehicles, Weather and Pilot

The Flight Service of the German Federal Police operates 90 helicopters, of which 24 are used in Helicopter Emergency Medical Service (HEMS) or training operation [17]. In maritime and ship deck operation mostly AS 332 L1 and H215 Super Puma as well as EC155 helicopters are used due to their advantages regarding payload, performance and maritime suitability. For the experiments described in this paper, an EC155, as shown in Fig. 2, equipped with emergency flotation system, retractable landing gear and rescue hoist was used. Since the flights were categorized as training flights, only two pilots and two scientist were on board. The landings were performed on a Potsdam class corvette, as shown exemplary in Fig. 3. The Potsdam ship class has a length of 86.2 m, a width of 13.4 m, a maximum speed of 21 kt and is, among other features, equipped with a roll damping system and a landing deck supporting helicopters up to a maximum size of the Airbus H215 or the NHIndustries NH90 [17]. As assistance systems to support SDL during day and night operations various lighting systems as well as a Visual Landing Aid (VLA) and Horizontal Reference System (HRS) are installed.

Figure 2 EC155 of the Flight Service of the German Federal Police (Source: Helicopter Travel Munich (HTM))

Figure 3 Potsdam class corvette of the German Federal Police (Source: Bundespolizei)

During the training flights, the cloud coverage varied between scattered and broken cloud layers above a height of 3500 ft with a visibility of 10 km or more as reported by the nearest airport. The wind was measured by the ships control station as coming from 220° - 230° with a speed of 25 kt - 30 kt. The Outside Air Temperature (OAT) was measured by the ship at 18°C and the air pressure at 1005 hPa at sea level.

The pilot flying the experiment was in the age of 40-50 with 3000 flight hours on various medium twin engine helicopters. The pilot regularly flies offshore missions including SDL.

4.2. Mission Profile

The flights were planned as training flights for both the helicopter and the ships crew. As approach and landing procedure, the port lateral approach was defined in advance, as shown in Fig. 4 [18]. This approach is also known as Fore/Aft (F/A) procedure. The flight course during all approaches and take-offs was set to 240°, which means a relative wind of RED 10° - 20° on the deck during the training. Due to the high wind speed and restrictions in the SHOL the ships speed was set to 3.5 kt Speed Over Ground (SOG).

4.3. Eyetracking

The technology of eye tracking is used in multiple industries, as for example neuroscience, marketing, automotive or aviation. It enables researchers to get an insight about a subjects gaze behavior, points of visual attention and cognitive processes [19]. Typical eye tracking recording devices can be categorized as remote or head-worn devices.

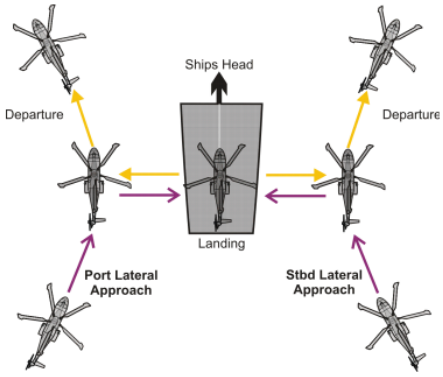

Figure 4 Port/Starboard Lateral Approach (Source: [18])

While remote devices have the advantage of a higher accuracy, head-worn devices offer the possibility of using them in a flexible environment without any modifications. This makes head-worn devices suited for the use in larger environments or in aviation cockpits.

From the raw gaze data recorded by an eye tracking device, fixations and saccades can be identified using different filtering approaches, such as Tobii's velocity threshold filter [20]. A fixation is a localized stationary gaze typically during an information processing period and the fast movement between two fixations is called saccade. In the further analysis process, the identified fixations can be mapped to Area of Interest (AOI), which are predefined relevant areas in the visual scenery, such as indicators in an aircraft. In the aviation context, ITC AOIs are all areas inside the cockpit and OTW AOIs all elements in the outside view.

As an eye tracking system, the Tobii Pro Glasses 3 wearable eye tracker was used, as shown in Fig. 5. The system consists of a wearable glasses unit connected to a recording unit. The eye tracking glasses use the Pupil Centre Corneal Reflection (PCCR) eye tracking technique via 4 cameras and 16 infrared LEDs. The eye tracking system provides a sampling rate of 50 Hz, a Field-of-View (FoV) of 95° horizontally and 63° vertically with an accuracy of 0.6° and features an additional scene camera and audio recording [21]. The data is stored on a SD card in the recording unit but can be shared with other devices with minimal lag using the built-in WiFi capability. To use the eye tracking glasses aviation compliant as Personal Electronic Device (PED), as defined in [16], the WiFi functionality was deactivated. The deactivated transmission of the device in this configuration was previously experimentally verified in DLR's Electromagnetic Compatibility (EMC) chamber [16].

As the glasses are usually controlled using a tablet or mobile phone connected via WiFi, in the aviation compliant mode an ethernet cable had to be connected temporarily to start and stop the eye tracking recordings.

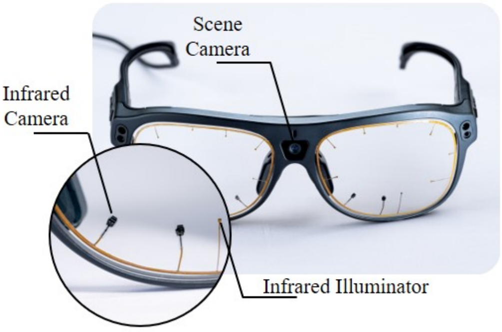

Figure 5 Tobii Pro Glasses 3 (Source: DLR)

4.4. Vehicle State Data Recording

As attitude and position recordings of both the helicopter and the ship were not available, self-assembled measurement units were positioned on board of the helicopter and the ship. Both units were equipped with a CubePilot Cube Orange flight controller combined with a Here2 Global Navigation Satellite Systems (GNSS) sensor, which was used to record the helicopter state data. The units were powered by a 10.000 mAh powerbank and were housed waterproof in a PeliCase box. The measurement unit on board the helicopter, as shown in Fig. 6, was positioned on the longitudinal axis of the helicopter, approximately 0.5 m behind the center console. The measurement unit on board the ship, as shown in Fig. 7, was attached to a structure on the starboard side close to the bridge, with a distance of 40 m to the center of the helicopter deck.

The CubePilot Cube Orange is a flight controller and multi-sensor platform designed for the use in Unmanned Aerial Vehicles (UAV). Among other hardware features it is equipped with two barometric pressure sensors, two 9-axis Inertial Measurement Unit (IMU) sensors featuring accelerometer, gyroscope and magnetometer (compass) and one 6-axis IMU sensor featuring accelerometer and gyroscope. The IMU data was recorded in 200 Hz and the barometric data in 5 Hz.

The used Here2 sensor is, among other hardware, equipped with a u-blox M8 GNSS sensor. The sensor supports the GPS, GLONASS, BeiDou and Galileo GNSSs and the EGNOS SBAS systems in Europe. The GNSS data was recorded in 2 Hz.

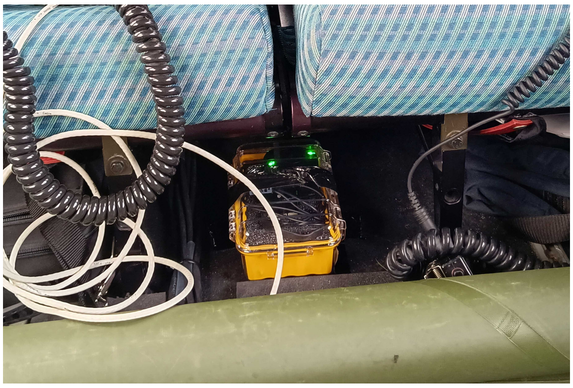

Figure 6 Measurement unit on board the EC155 (Source: DLR)

Figure 7 Measurement unit on board the ship (Source: DLR)

The operating system PX4, stable release 1.13.3 from March 2023, was used on both flight controllers.

4.5. Eye Tracking and Vehicle Data Analysis

While the data from the eye tracking glasses were analyzed using a two-step process in the Tobii Pro Lab software and MATLAB the recordings from the PixHawk vehicle state data recorders were analyzed using MATLAB. The simplified process of the analysis is shown in Fig. 8.

4.5.1. Vehicle State Data

The logging data is stored in the PX4 firmware in a ULog file format. Those logging files were in a first step converted into comma-separated files and the data from the ship and helicopter were fused into one mutual array. As the sensors were recorded in different recording rates, a time series alignment of the sensor data coming from both vehicles was performed.

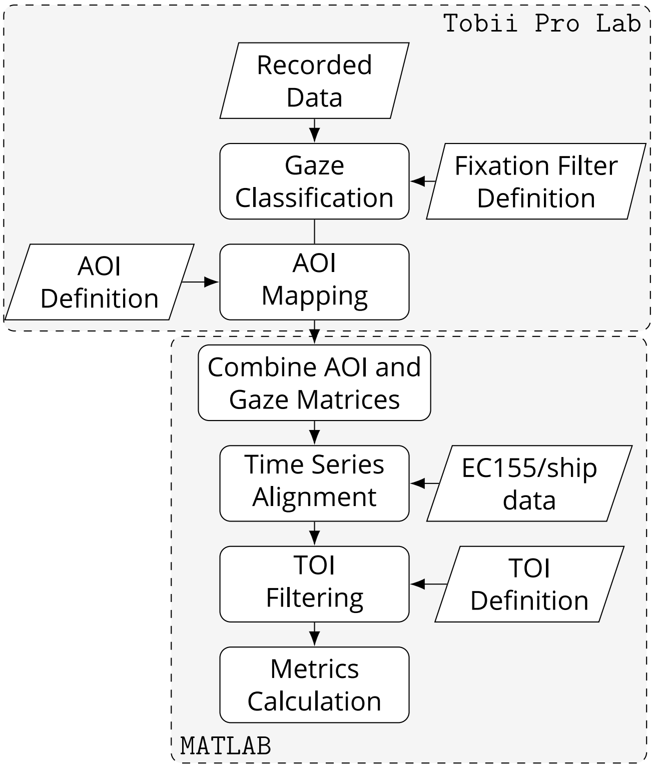

Figure 8 Post-processing toolchain

A comparison of the internally fused IMU and GNSS position showed a poor position accuracy, why only the GNSS data was used in the further process. As a next step, approach and takeoff start and end time stamps for the Time of Interest (TOI) definition were extracted manually from the position and altitude data. The manual selection of the timestamps followed the following criteria. Plotting the helicopter altitude over the position, it could be noticed that the final approach with a constant descent rate typically began after a left turn at a distance d of 1000 - 1500 m to the ship, why $d_{Approach,start} = 1000$ m was selected. As distance d the slant distance between helicopter and ship deck was used. The approach end point was selected as the data point where the distance d between ship and helicopter was constant at approximately 40 m, which is the distance between the PixHawk sensor and the midpoint of the deck. The takeoff start point was set to the point where the marshal gave the takeoff signal to the pilots. To have consistent sequence diagrams for approach and takeoff and to be able to compare IOR during both flight phases, the takeoff end point was set at $d_{Takeoff,end} = 1000$ m. The time intervals between approach and takeoff start and end point are the relevant TOIs for the analysis.

4.5.2. Eye Tracking Data

The first steps of the eye tracking analysis were performed with the Tobii Pro Lab software. Within the software, the raw eye movement data was classified as saccades and fixations using the integrated I-VT filter algorithm [20].

The identified fixations were in the next step mapped to manually defined AOIs. The selected ITC AOIs are shown in Fig. 9 and listed below:

- Primary Flight Display (PFD): ASI, ALT/Vertical Speed Indicator (VSI), ATT
- Central Instrument Panel: First-Limit Indicator (FLI), Vehicle and Engine Monitoring Display (VEMD), Central Warning Panel (CWP), Multi-function Display (MFD) with fuel quantity indicator, moving map, autopilot
- Navigation Display (ND), center console instruments

The identified fixations could be mapped partially automated on the ITC AOIs using the assisted mapping functionality. The assisted mapping functionality uses the homography based Real World Mapping (RWM) algorithm to compare the current gaze snapshot with a predefined picture and is able to automatically map the subjects gaze onto the picture, when a specified similarity level is reached [22].

Figure 9 AOI selection for the EC155 cockpit

The following significant features during the SDL were defined as OTW AOIs:

- Shipboard personnel: Marshal, other crew members
- Ship features: Ship general, roll-up-door, VLA, Deck buildings and other features
- Deck features: Line-up line (lateral axis), lateral position line (longitudinal axis), other lines

- Sea, Sky, Horizon

As due to changing outside view parameters no similarity was given between the gaze snapshot and a static picture of the ships deck, those OTW AOIs had to be mapped manually.

Fig. 10 shows the pilot view with the OTW AOIs marshal, line-up line and lateral position line highlighted.

Figure 10 Pilot view during approach on the ship deck with OTW AOIs marshal (1), line-up line (2) and lateral position line (3) highlighted

The resulting AOI and gaze matrices from the Tobii Pro software were processed further in multiple MATLAB scripts. To be able to define the correct TOIs in the gaze data, the eye tracking matrices were fused with the vehicle state data. Each element in the gaze matrices was mapped to a UTC time-wise matching element from the vehicle state data matrix. While the vehicle state data matrices were time series re-sampled before the fusion using interpolation, the eye tracking matrices were not manipulated to avoid unintended modifications of the gaze data. With the fused data matrices, the approach, landing and takeoff TOIs could be marked and the distance between the helicopter and the ship could be calculated for each element. The calculated distance was verified at each landing via the recorded video from the eye tracking glasses.

The IOR plots shown in Sec. 5 are calculated using the formula shown in Eq. 1. The TOI in this case is one of the approaches or takeoffs.

(1)

$$\mathrm{IOR} = \frac{\sum_{n=t(TOI,Start)}^{t(TOI,End)} \Delta t_{\mathrm{Fixation,n}}(\mathrm{ITC})}{\sum_{n=t(TOI,Start)}^{t(TOI,End)} \Delta t_{\mathrm{Fixation,n}}(\mathrm{ITC,OTW})}$$

5. RESULTS

The results of the analysis of the vehicle state data and eye tracking analysis are presented here. The methodology of the analysis within the eye tracking software Tobii Pro Lab and MATLAB are described in Sec. 4.5.

5.1. Flight Profile

The complete flight path of the helicopter and the ship as considered in this analysis is shown in Fig. 11.

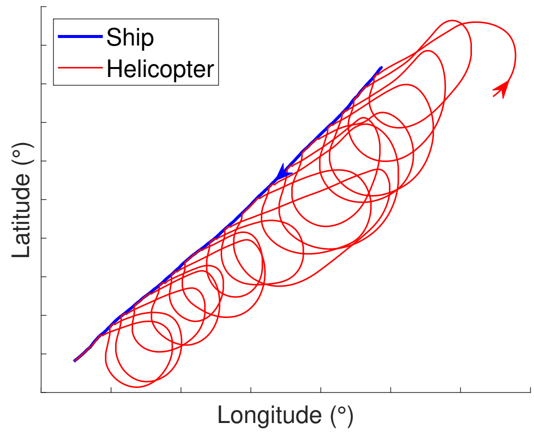

Figure 11 Complete helicopter (red) and ship path (blue) with 17 landings and 16 takeoffs

One training segment took between 4 - 5 min with the helicopter flying to a maximum altitude of 400 - 500 ft, as shown in Fig. 12. After three landings the helicopter was lashed to the deck to train the lashing team on board the ship.

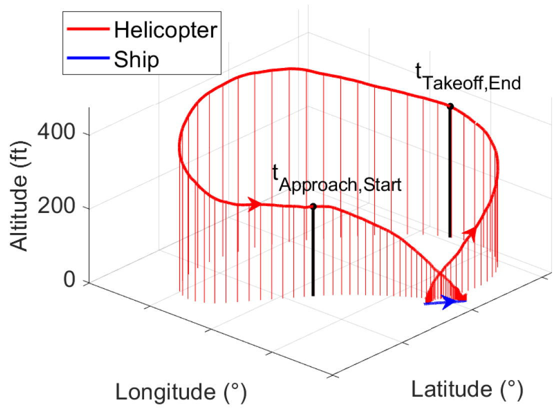

Figure 12 Training segment with the TOI for approach and takeoff marked

In Fig. 13 all approaches beginning from a distance of 1000 m are shown. It can be seen that with the exception of approach 5 all approaches were conducted at a narrow altitude range of 100 ft starting between 180 - 280 ft at the distance of 1000 m. As the flights were also used to train the ship's crew, the pilot varied the altitude during several approaches, which explains the variance.

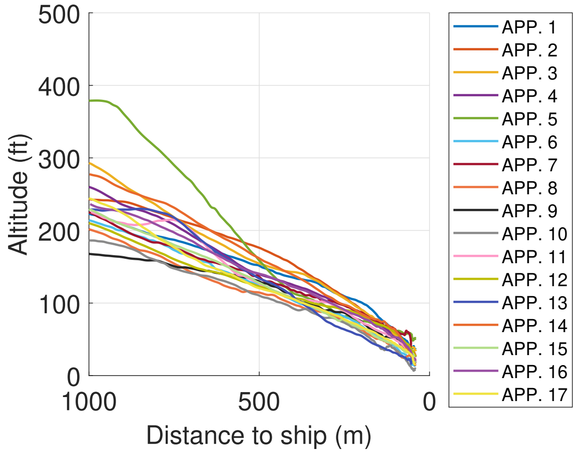

Figure 13 All 17 approaches plotted over distance to the ship deck

The takeoff altitude characteristics are even more scattered as the approach characteristics, as Fig. 14 shows. The altitude at 1000 m distance to the ship varies in this plot from 200 - 450 ft. It can be noted, that takeoffs 9, 10, 12, 13, 14 and 15 were conducted in a very narrow altitude range of 10 ft while there is a variance of 200 ft during the other takeoffs. This variance can be explained as the pilot performed takeoffs 9, 10, 12, 13, 14 and 15 for training reasons under Instrument Flight Rules (IFR) using mainly cockpit instruments and the other takeoffs under Visual Flight Rules (VFR). In Fig. 15 the IFR takeoffs are represented with a high ITC percentage and the VFR takeoffs with a low ITC percentage.

Both plots show a scatter of the helicopters altitude close in the vicinity of the deck in between 8 - 50 ft. An assumption is that this scatter is due to a poor GNSS position accuracy caused by multipath effects.

5.2. Eye Tracking

The data quality of the recorded eye tracking data was with 92% (landing 1), 96% (landings 2-10) and 91% (landings 11-17) recorded gaze samples very good, as between 5-10% of gaze samples are typically lost due to blinking [23]. As a first step in the eye tracking analysis, the IOR was calculated for all approaches and takeoffs, as show in Fig. 15.

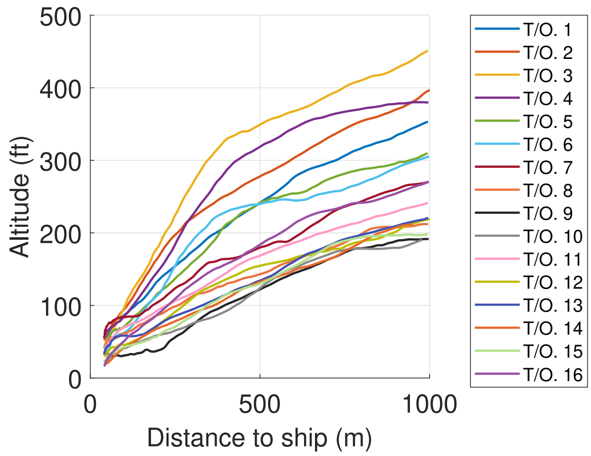

Figure 14 All 16 takeoffs plotted over distance to the ship deck

For the fixations during the approaches, the median is at $\mathrm{IOR}_{\mathrm{Approach}} = 1.6\%$ with a very little spread, as the box plot shows. Those results are generally consistent with the results of an earlier SDL simulation campaign but differ in the exact range of values [12]. For the takeoffs the median lies at $\mathrm{IOR}_{\mathrm{Takeoff}} = 28\%$ with a wide variability and a significant variation. This result can be interpreted that the SDL approach and landing is an "eyes-out" task, where the pilot concentrates almost exclusively on outside cues. With the takeoffs a high spread ranging from 10% to 60% in the IOR can be seen, as the whiskers of the box plot in Fig. 15 show. This can be explained on the one hand with the IFR and VFR takeoffs mentioned in Sec. 5.1 and on the other hand by the assumption, that the takeoff task requires both ITC as well as OTW cues.

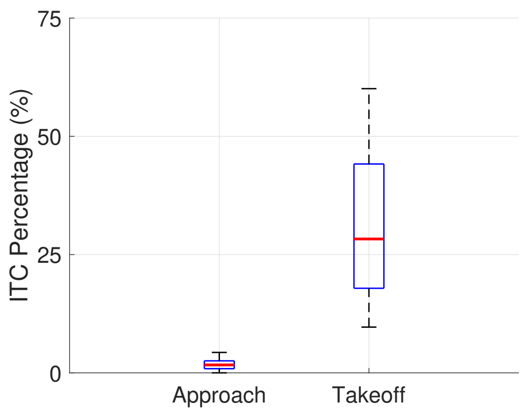

Figure 15 Box plot of IOR for all approaches and takeoffs showing the median value (red), the interquartile range (box) and the complete data range (whiskers)

As Fig. 15 shows, only a small number of ITC fixations was registered during the approaches. The average number of all ITC fixations per approach is 5.5, which is further broken down for the most significant cockpit indicators in Fig. 16. This plot shows the average number of hits of fixations on the ASI, ALT/VSI, ATT, FLI, the fuel indicator, moving map and ND during the approach phase. The number of fixations on the ND was explained by the pilot with the relevance of the GPS speed, which is displayed on the ND. The data plotted in Fig. 16 can be interpreted as no relevant ITC information is needed by the pilot during the day SDL approach, with the exception of the GPS speed in the ND.

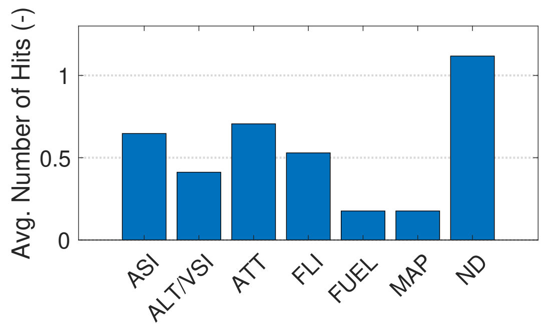

Figure 16 Average number of hits on cockpit indicators during approach

A further analysis of the ITC and OTW cues used by the pilot was carried out using sequence plots, as shown in Fig. 17 - 20. In the sequence plots, each fixation on the previously defined AOIs is plotted over the corresponding time stamp. It was established during the analysis, that for the SDL case, using the time stamp distorts the sequence plots and makes a comparison challenging. This effect is illustrated in Fig. 17 and 18, which show the same data plotted over the time and the distance. The reason for that is that the time the helicopters hovers over or next to the deck varies a lot. To avoid this effect, the distance to the ship was used as reference metric for the sequence diagram.

The relevant OTW AOIs during the SDL approach are shown in Fig. 19 exemplary for approach 13. Although the approach start point was defined at 1000 m, the plot starts at a distance of 300 m between the helicopter and the ship. The reason for this is that the individual AOI data points would be compressed to much in the plot representation shortly before the landing. In the approach phase between 1000 m and 300 m the pilot focuses mostly on the ship and occasionally on the sea. Up to a distance of approximately 150 m it is not possible to distinguish between individual details, which explains the fixations on "Ship General" in the plot.

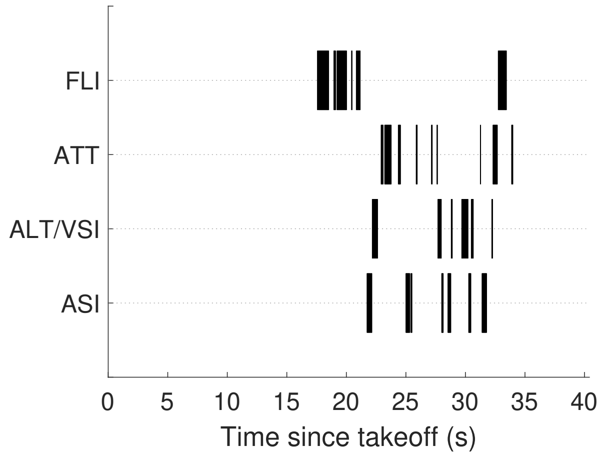

Figure 17 Sequence diagram for takeoff 15 with fixations plotted over time

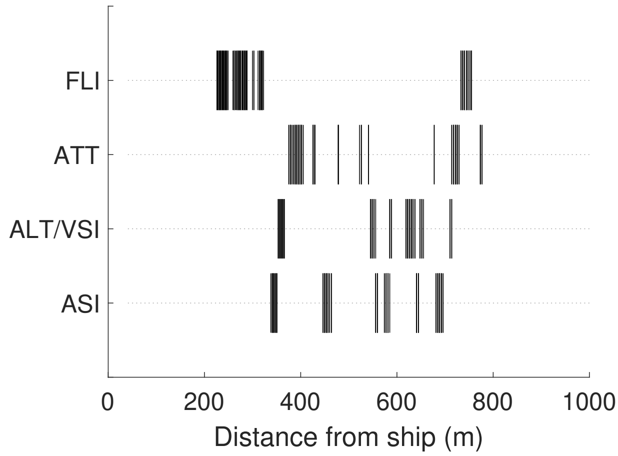

Figure 18 Sequence diagram for takeoff 15 with fixations plotted over distance from the ship

Starting at a distance of 50 m, the pilot mainly focuses the marshal, line-up and lateral position line as well as other ship features (mainly elements on the superstructure of the ship).

The relevant OTW and ITC AOIs during the takeoffs are shown in Fig. 18 and 20. Up to a slant distance of approximately 150 -170m the pilot concentrates on the OTW AOIs marshal and other ship features (mainly the ships superstructure in front of the deck). After this distance, his focus changes to ITC features and the sea as well as few fixations on the horizon and the airspace. Fig. 18 shows the cockpit instruments, which are relevant for the pilot to achieve a stable cruise flight condition (FLI, ATT, ALT/VSI and ASI).

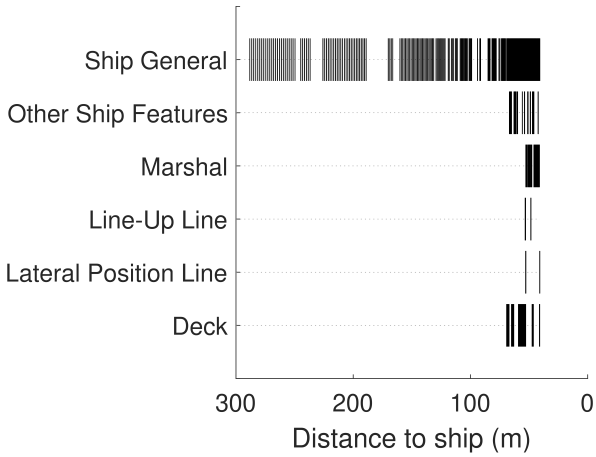

Figure 19 Sequence diagram for approach 13 with OTW fixations plotted over distance

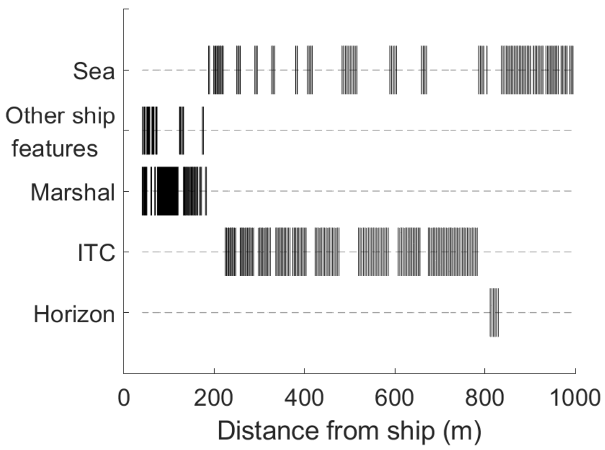

Figure 20 Sequence diagram for takeoff 15 with OTW fixations plotted over distance from the ship

6. DISCUSSION

During this campaign, the proposed method of using eye tracking to get insights about significant visual cues during SDL was carried out with only one pilot in daylight conditions. Therefore all evaluations, analysis and conclusions are specific to this pilot. To get generally valid statements, additional campaigns in day- and nightlight conditions would have to be conducted with additional pilots. However, the general method proved successful and some results as the approach and takeoff IOR suggest a general character as they are consistent with other research works.

It was expected during the campaign, that the internal fusion of IMU and GNSS in the PixHawk vehicle state data logger brought better results as just the GNSS sensor. The analysis unfortunately showed a poor accuracy of the fused data, why only the GNSS sensor data was used. A troubleshooting is necessary to resolve this issue and to obtain highly accurate vehicle state data with a high recording rate through the IMU and GNSS data fusion.

A major drawback of the eye tracking technology is the missing feature of recording the peripheral vision. During this and past campaigns, pilots reported that they intensely used their peripheral vision to track or monitor objects. For this work this means that the full extend of the visual gaze behavior cannot be tracked and not all visual cues could be captured.

7. CONCLUSIONS AND OUTLOOK

The focus of this investigation was to evaluate whether eye tracking is a suitable approach to identify gaze behavior for optimizing the simulation environment for SDL. To answer this question, a flight campaign with a total of 17 approaches was accompanied. The purpose of the flights was to train the ship's and the helicopter crew, why some approaches and takeoffs varied from the standard procedures. The eye tracking data was recorded using a head-worn eye tracker and the vehicle state data of the ship and the helicopter was captured using PixHawk-based logger. A data analysis toolchain was developed using the Tobii Pro Lab software and MATLAB and the data matrices from the different sensors were fused to define the approach and takeoff TOI. After the ITC and OTW AOIs were mapped in a manual and partially automated process, several metrics could be calculated and signification visual cues were identified.

From the analysis of the vehicle state and eye tracking data, the following conclusions could be drawn:

1. The results from the analysis flights propose that eye tracking is a good tool to identify important visual cues during SDL. It is possible to distinguish between various ITC and OTW cues and to identify different gaze patterns in approach and takeoff. It can be derived from the results which visual cues are particularly important and have to be considered in the simulator.
2. The IOR evaluation shows the importance of the outside view during the SDL. Furthermore it provides a metric that allows a comparison between different mission elements or configurations, e.g. between the real flight and a simulator.

3. The used setup for recording eye tracking and vehicle state data has proven to be easy to realize from a technical point of view and with regard to airworthiness certification, and provides an acceptable level of accuracy. However, the position accuracy could have been even better with a functioning internal fusion. The subsequent fusion with the eye tracking data using the UTC for a temporal data alignment proved to be very suitable.

4. The sequence plot is a good visualization tool to show the temporal dependence of certain fixations and can also be used to analyze gaze patterns of other mission profiles.

5. The analysis of the eye tracking data showed the relevance of OTW cues during approach and both OTW and ITC cues during takeoff. The main OTW cues during approach and takeoff are the marshal, the line-up and lateral position line, the deck and other ship features, such as the superstructure of the ship close to the deck. Those results are consistent with findings from previous studies as summarized in Sec. 2. The main ITC cues especially during takeoff are the instruments necessary to achieve a stable flight, which are in this case the FLI, ATT, ALT/VSI and ASI.

In future campaigns, this analysis should be repeated with other pilots in a day and night configuration to gain additional insights and to confirm or disprove a general character of the results. As a next step in this project, the identified visual elements will be implemented with varying visual quality into into the AVES simulator. In a simulator study with similar vehicles and mission profile and eye tracking it shall be investigated whether this can improve the simulator fidelity and if this results in an increased training efficiency.

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9. ETHICS STATEMENT

This study involving human participants was reviewed and approved by the Ethics Committee of the German Aerospace Center (DLR). The participating pilot was informed prior about all recorded data and gave his written consent to participate in the study.

REFERENCES

[1] Bruce R Lumsden, Colin H Wilkinson, and Gareth D Padfield. Challenges at the helicopter-ship dynamic interface. In *24th European Rotorcraft Forum (ERF)*, 1998.

[2] European Union Aviation Safety Agency. Notice of Proposed Amendment 2020-16: Helicopter ditching and water impact occupant, RMT.0120 (2729.008).

[3] NATO Research and Technology Organisation. Helicopter/ship qualification testing.

[4] Yaxing Wang, Mark White, Ieuan Owen, Steven Hodge, and George Barakos. Effects of visual and motion cues in flight simulation of ship-borne helicopter operations. *CEAS Aeronautical Journal*, 4(4):385–396, 2013. ISSN 1869-5582. doi: 10.1007/s13272-013-0085-9.

[5] James S. Forrest, Seven J. Hodge, Ieuan Owen, and Gareth D. Padfield. Towards fully simulated ship-helicopter operating limits: The importance of ship airwake fidelity. *American Helicopter Society 64th Annual Forum*, 64, 2008.

[6] I. Owen, M. D. White, G. D. Padfield, and S. J. Hodge. A virtual engineering approach to the ship-helicopter dynamic interface – a decade of modelling and simulation research at the university of liverpool. *The Aeronautical Journal*, 121(1246):1833–1857, 2017. ISSN 0001-9240. doi: 10.1017/aer.2017.102.

[7] Paul Scott, Mark D White, and Ieuan Owen. Unsteady CFD modelling of ship engine exhaust gases and over-deck air temperatures, and the implications for maritime helicopter operations. In *71st American Helicopter Society International annual forum 2015*, Red Hook, NY, 2015. Curran. ISBN 9781510803787.

[8] Wajih A. Memon, Mark D White, Ieuan Owen, and Sophie Robinson. Preliminary progress in establishing motion fidelity requirements for maritime rotorcraft flight simulators. *American Helicopter Society 74th Annual Forum*, 74, 2018.

[9] John K. Tritschler, John C. O'Connor, James A. Pritchard, and Ryan Wallace. Exploratory investigation into rotorcraft pilot strategy and visual cueing effects in the shipboard environ-

ment. In *Journal of the American Helicopter Society (JAHS)*, volume 65, pages 1–13. 2020. ISBN 2161-6027. doi: 10.4050/JAHS.65.022003.

[10] Maxi Robinski and Michael Stein. Tracking visual scanning techniques in training simulation for helicopter landing. *Journal of Eye Movement Research*, 6(2), 2013. doi: 10.16910/jemr.6.2.3.

[11] James A. Pritchard, Ryan D. Wallace, John K. Tritschler, John C. O'Connor, and David R. Arteche. Characterization of pilot strategy for simulated shipboard approaches with realistic ship motion. In *AHS 72nd Annual Forum & Technology Display*, 2016.

[12] Malte-Jörn Maibach, Christian Walko, and Arti Kalra. Evaluation of a head-mounted display and advanced flight control laws for helicopter ship deck landing. In *48th European Rotorcraft Forum (ERF 2022)*. 2022. ISBN 9781713870296.

[13] Martin Tušl, Giuseppe Rainieri, Federico Fraboni, Marco de Angelis, Marco Depolo, Luca Pietrantoni, and Andrea Pingitore. Helicopter pilots' tasks, subjective workload, and the role of external visual cues during shipboard landing. *Journal of Cognitive Engineering and Decision Making*, 14(3):242–257, 2020. ISSN 1555-3434. doi: 10.1177/1555343420948720.

[14] Daniel Heinrich Greiwe and Maik Friedrich. A comparison of helicopter pilots' gaze movements during hover flight in a real helicopter and a full flight simulator. In *Deutscher Luft- und Raumfahrtkongress 2023*, 2023.

[15] Daniel H. Greiwe and Maik Friedrich. Gaze movements of helicopter pilots during real and simulated take-off and landing maneuvers. *MDPI Aerospace*, 11(6):429, 2024. doi: 10.3390/aerospace11060429.

[16] Malte-Jörn Maibach, Daniel Heinrich Greiwe, and Mario Müllhäuser. Helicopter in-flight eye tracking: System integration aspects and first results. In The Vertical Flight Society, editor, *The Future of Vertical Flight*. Curran Associates Inc, Red Hook, NY, 2023. ISBN 9781713874799.

[17] Bundespolizei. Zahlen, Daten, Fakten, 2024. URL `https://www.bundespolizei.de/Web/DE/05Die-Bundespolizei/07Daten-Fakten/Daten-Fakten_node.html`.

[18] NATO STANDARDIZATION OFFICE. Helicopter operations from ships other than aircraft carriers (HOSTAC).

[19] Andrew T. Duchowski. *Eye tracking methodology: Theory and practice*. Springer, London, 2 edition, 2007. ISBN 978-1-84628-608-7.

[20] Anneli Olsen. The Tobii I-VT Fixation Filter: Algorithm description.

[21] Tobii AB. Tobii Pro Glasses 3, 2024. URL `https://www.tobii.com/products/eye-trackers/wearables/tobii-pro-glasses-3#specifications`.

[22] Tobii AB. Assisted mapping in Tobii Pro Lab, 2024. URL `https://connect.tobii.com/s/article/Assisted-mapping-in-Tobii-Pro-Lab`.

[23] Tobii AB. Tobii Pro Lab User Manual.