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Caron, Julius; van Paassen, M.M.; Landman, H.M.; Stroosma, O.; Mulder, Max

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Description:

A view of the Wright Model A Flyer
in flight with a passenger onboard.

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PERIPHERAL AIRSPEED INDICATION FOR MANUAL APPROACH

J. Caron, M. M. (René) van Paassen, Annemarie Landman*, Olaf Stroosma, Max Mulder
Aerospace Engineering – Delft University of Technology
Delft, The Netherlands, * also TNO, Soesterberg, The Netherlands

Maintaining proper speed control is critical in visual approach procedures. Currently, pilots need to to switch between the outside visual scene and the aircraft instruments. In this project we investigate the possibility to use a low cost display in the peripheral view to indicate deviation from the aircraft's approach speed. An off-the shelf light bar is installed in a full motion flight simulator (SIMONA Research Simulator, TU Delft), and configured to show speed deviation. In an experiment, approach path and speed performance are evaluated during approaches in a high and low turbulence condition. A condition with conventional instrumentation will be compared to conditions with the new speed deviation indicator with two different scaling factors for the speed indication. An eye tracker (Pupil labs Core) is used to quantify differences in visual switching in the different conditions. We expect to find a reduction in workload, better speed and path performance, and reduced visual switching (final results are pending).

Introduction

While automation has improved efficiency and safety, take-off and landing remain the most critical flight phases with over 50% of aircraft accidents in 2014-2023 happening here (International Air Transport Association, 2023; Schmid & Stanton, 2020). A significant proportion of these accidents are caused by unstable approaches (14% of accidents between 2011-2020) and the International Air Transport Association (IATA) names pilot fatigue and other demanding cognitive factors as main contributors, among others (IATA, 2016, 2022). One potentially contributing factor to unstable approaches is the increasing use of automation, as this has led to reduced manual flying practice, potentially eroding pilots' skills and raising concerns about pilot workload (Feng et al., 2018; Veillette, 1995). Research highlights the role of visual processing and attentional focus in manual landing performance and its effect on workload (Lefrançois et al., 2021). While existing studies have explored various cockpit display solutions to reduce workload during the landing phase, few have focused on using peripheral vision (PV) to improve performance in this phase (Fox et al., 1996; Robinski & Stein, 2013; Ziv, 2016). Previous research on this (Hasbrook & Young. E., 1968; Vreeken, 2013), has shown the potential benefits of peripheral cueing, particularly for aircraft attitude and other flight parameters, suggesting improved performance and reduced mental workload. Schaudt et al. (2002) and Bulkley et al. (2009) proposed to use the periphery directly for processing speed and flight path information intuitively than using a standard, cognitively more demanding, numeric display. Despite showing a statistically significant increased manual flying performance, the experiments were conducted with 8-12 participants without flying experience, and in a low-fidelity simulation setup. Their findings raised further questions regarding the translation of these results to more realistic flight scenarios in a high-fidelity simulator with licensed pilots.

The main contribution of this paper is to further explore the use of a Peripheral Vision Display (PVD) for airspeed indication to increase manual flying performance in pilots, reduce workload, and analyze the impact on gaze behavior. This is done by performing an experiment on flight path management during visual approaches in a high-fidelity full-flight simulator with General Aviation (GA) pilots. Many airports are equipped with advanced landing aids, but this equipment is not cost-effective for smaller airports (Gonçalves et al., 2009). In GA, visual navigation with manual control is more abundant in approach and landing, so a low-cost PVD could contribute to safety. Additionally, GA pilots have sufficient flying experience and a lower risk of being biased in their expertise with standard airspeed indication, such that a PVD becomes redundant.

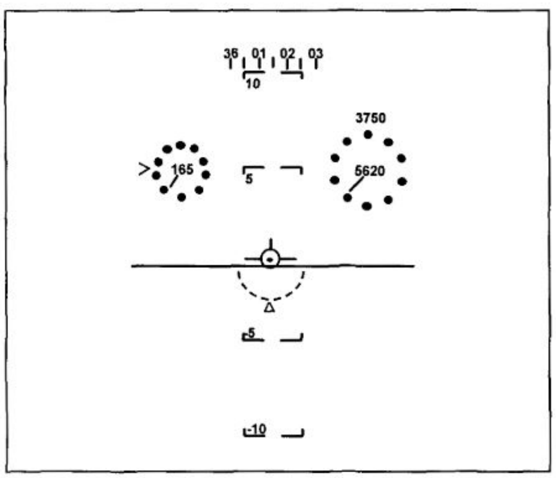
Background

Pilot gaze on final approach

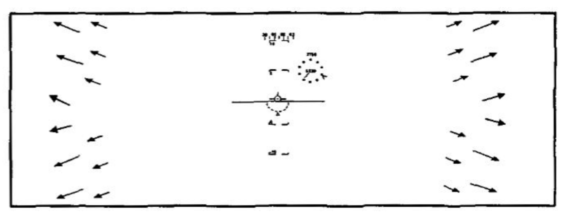
Pilot visual information processing is still one of the most important factors contributing to flight safety. This is reflected in multiple reviews on eye tracking studies in aviation where visual scanning patterns of pilots have been seen to influence flight performance (Peißl et al., 2018; Ziv, 2016), showing most fixations on the airspeed indicator and outside the cockpit windows during approach. The Federal Aviation Administration summarizes the most vital aspects of visual approaches as being adequate altitude and airspeed management (Federal Aviation Administration, 2021). Monitoring and adjusting for speed variations due to turbulence or wind, as well as scanning the runway for alignment are essential for a stable manual approach (Flight Safety Foundation, 2000). This is seen in the distribution of pilot gaze on airspeed compared to other instruments, as the results of Harris et al. (Harris et al., 1986) show.

Peripheral vision cueing

As part of the human visual sensory system, peripheral vision is characterized by a lower acuity, lower sensitivity to color and a higher overall light sensitivity (Pinel, 2011). Peripheral vision is used for monitoring the environment and detecting changes to plan a potential future fixation point (Vater et al., 2022). In aviation, pilots use peripheral cues for monitoring the different sources of information received from different instruments and outside view, and even suffer from a worse flight performance when their peripheral vision is blocked (Fox et al., 1996). Using the periphery to cue flight information like aircraft roll angle has shown improved flight performance and lower perceived workload (Hasbrook & Young. E., 1968). Schaudt et al. (2002) tested a peripheral vision display with airspeed cues instead of a dial speed indicator to see the effect on a speed and altitude tracking task under turbulence. They included eye tracking to validate whether peripheral cues were not processed through fixations in foveal vision. Cues were displayed from an eccentricity of 30 degrees laterally onward. The MIL-STD-1787B HUD display was altered to show moving arrows in the periphery representing the magnitude and direction of speed error from a target speed, as shown in Figure 1. This display was tested in a low-fidelity flight simulation, including a simple aircraft model, two displays, and basic flight controls. Their results and recommendations are from the foundation of using a Peripheral Vision Display (PVD) for airspeed indication and testing this in a high-fidelity approach scenario in a full-motion simulator.



(a) MIL-STD-1787B



(b) Altered MIL-STD-1787B

Figure 1: HUD displays used by Schaudt et al.Schaudt et al., 2002

Workload

Current research on peripheral cueing suggested it may reduce workload compared to numeric displays (Hasbrook & Young. E., 1968). Workload is defined as the cognitive demand of a task on the limited mental resources of a human (Wickens, 2008). Peripheral vision can be exploited for monitoring flight information like airspeed, leaving more resources available for other cognitive tasks. This research aims to test a PVD in different workload conditions as well as examine the indicated workload by pilots in the presence or absence of cues in the PV. Mental workload is often manipulated by varying the task load in the experiment (Wang et al., 2024). For instance, manipulating visibility in the flight scenario, or adding a secondary arithmetic task, as well as manipulating wind and turbulence conditions (Mohanavelu et al., 2020; Vivaldi, 2004).

Methodology

Participants

The aim is to have a sample size of 24 pilots. A power analysis for a repeated-measures ANOVA with four conditions indicated that 24 participants would be sufficient for detecting medium effect sizes (f = 0.25) with alpha = 0.05 and beta = 0.8. Flying experience has been linked to a more effective use of peripheral cues (Fox et al., 1996; Robinski & Stein, 2013), however, a consultation with a professional test pilot concludes that experienced commercial pilots are not likely to use the PVD in combination with standard speed indication due to flying habits and lower adaptivity. Therefore PPL pilots will be asked to participate in this study. Despite not all being certified for a twin-jet aircraft, the short flight duration is deemed sufficient to still obtain valid representable data.

Apparatus

Flight simulator The SIMONA Research Simulator at Delft University of Technology will be used with a Cessna Citation-II flight model. The flight controls include a control stick with pitch trim, rudder pedals, and throttle control. Flaps and landing gear control are available, however, the aircraft will be initialized fully configured for landing. The simulation includes a turbulence model based on Von Dryden Spectra. Turbulence intensity is variable per simulation run. Wind components are included in the body velocity components of the state vector of the aircraft model and are added based on magnitude and direction.

Peripheral Vision Display A low-cost Peripheral Vision Display is developed using off-the-shelf components for a 2-pilot set-up in a full flight simulator and tested with a single pilot to present flight information in the peripheral visual field. The display consists of 4 WS2812B LED strips mounted on metal frames with a diffusion cover, controlled by a Teensy 4.1 controller. The strips are mounted just above the PFD on both sides of the cockpit, symmetrically so it can be used in a 2-person cockpit. The cue eccentricity ε starts at 30 degrees and runs into the far peripheral field as depicted in Figure 2.

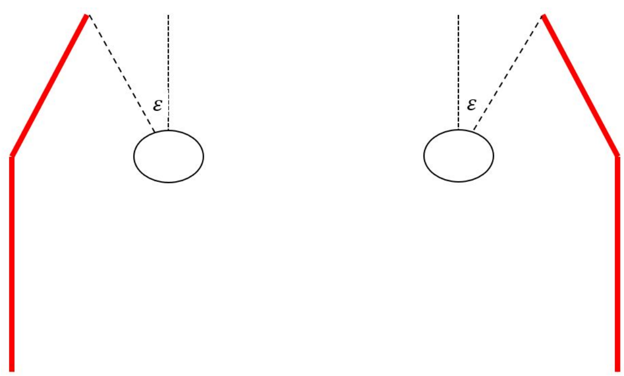


Figure 2: Two-pilot flight deck top-view of the proposed PVD

The PVD is designed to show the airspeed deviation from the target speed in the flying task as described in section . The error is sent in real time from the flight model to the Teensy controller, which will convert the error signal into a visual peripheral cue. Three tentative cue types are proposed for testing, of which one is chosen for the final PVD design. For all cues, the left and right half of the display are mirrored. The cue designs are described in Table 1 and illustrated in Figure 3. Cue 1 is closely related to the design used by Schaudt et al. (2002) showing promising results but adapted for an LED-based PVD. Cues 2 and 3 are designed to exploit the light sensitivity characteristics of the peripheral visual field by changing brightness to indicate error magnitude.

In all cues, the error direction indication uses an ego-centric perspective of the pilot, such that when flying too fast or too slow, the cues show where the target speed is. Like in Figure 3 the cues show stimuli oriented coming towards the pilot and to the back of the airplane, indicating that the aircraft is flying faster than the target speed. In this way, the cue direction also provides a stimulus for the control input required to overcome the error. The cue error magnitude indication will follow a quadratic relation with the error, as bigger deviations from the target speed are

Table 1: *Peripheral vision cue options*

Cue Number	Name	Description	Indication of magnitude of speed error	Indication of direction of speed error
1	Stream	Display filled with equidistant blocks of light moving through display. Brightness fades out over block.	Block move speed	Block fade & movement direction.
2	Dim	Two static light blocks front and back. Blocks alternate in activation and brightness	Block brightness	Front or back blocks active
3	Arrow	Full display forms static fade from begin to end of bar	Arrow brightness	Arrow fade direction

highly undesirable. In extreme situations when the speed limits are exceeded, the cues change from color from green to red.

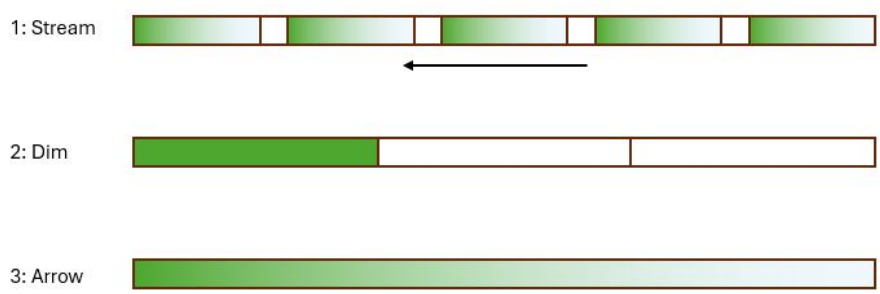


Figure 3: Illustration of left half of PVD with different cue designs, all showing a situation with overspeed; the arrow for cue 1 indicates the movement direction of the lights.

Eye tracker To check whether the PVD would allow participants to look more outside, the Pupillabs Core eye tracker will be used. The areas of interest that are important for the results of the experiment are: 1. Head-up outside view 2. instruments (primary display and engine display) 3. As a check for the PVD to ensure no fixations on peripheral cues take place. Besides gaze, pupil dilation and blink detections throughout the experiments is recorded as a measure of mental workload.

Experimental setup

Design The research objective of this study will be achieved through experiment sessions with Private Pilot License (PPL) pilots as participants. They will be testing a peripheral vision display under different workload conditions in a VFR approach flight scenario, flown in a full-motion simulator. The experiment had a 2x2 experimental design with two within-subject factors: workload (low, high) and display (baseline, PVD). Next to this, an event scenario is tested, where the effect of using the PVD in a high workload wind shear scenario. The effect of this on flight performance, indicated workload and gaze behavior will be analyzed.

Tasks Participants were instructed to fly 12 manual visual approaches and landings of the same scenario, lasting about five minutes each. The scenario started with the aircraft fully configured for landing (gear down, flaps land) at pitch-trimmed with a flight path angle corresponding to a 3-degree flight path, at an altitude of 1000ft. The initial position of the aircraft was aligned with the runway. Thrust setting N1 was set at 62% and the aircraft had an airspeed V_{ref} of 105kts. The participant was tasked with flying a 3-degree flight path on visual PAPI inspection and verbally report the PAPI status every 30 seconds. In airspeed management, participants were asked to keep a constant Final Approach Speed (FAS) of $V_{ref} + 5[kts]$ until an altitude of 200ft is reached, upon which they could continue to land or opt for a go-around if deemed necessary. Per participant, data was collected in one session of a maximum of 2 hours in the simulator. Before a session, all participants were briefed and trained extensively. The training was used for participants to practice and perform the approach and landing task sufficiently, despite having no twin-jet aircraft certification. After this proficiency check, the PVD was introduced and participants trained scenarios with the PVD present as in the experiment, as well as sole means of speed perception.

For the scope of this research and with available resources, VFR approaches are flown with the Cessna Citation-II model, to ensure out-of-window gaze by the pilot in flight. With standard airspeed indication, a look down into the cockpit is required for speed management, while with PVD a constant gaze outside can be achieved. Even though a VFR approach is less operationally realistic for this aircraft model, the flight task is flying the final approach of a VFR circuit. Starting fully configured for landing at 1000ft altitude and flying until landing, during which participants are allowed to opt for a go-around at any moment. The PVD is configured to provide cues when the indicated airspeed varies from the target approach speed ($V_{ref} + 5[kts]$). When flying too slow, the PVD is active immediately. For flying too fast there is a margin of three knots upon which the PVD will activate.

Conditions To create a low and high workload condition, turbulence and wind conditions are manipulated. The experiment conditions are as follows as shown in Table 2 The Rating Scale Mental Effort (RSME) is used after

Table 2: *Experiment workload conditions*

Workload	PVD	Code	Turbulence	Wind
Low	No	L0	Low	No
Low	Yes	L1	Low	No
High	No	H0	High	Yes
High	Yes	H1	High	Yes

every run as a manipulation check of the high and low workload condition. Apart from testing different workload conditions, the effect of how quickly a wind shear is detected is investigated by using a high turbulence condition where a vertical wind shear is introduced. This is tested with the classical speed indicator as well as the PVD.

Dependent Measures

Flight performance The flight performance is evaluated through speed and path tracking. The task instructs participants to follow a 3-degree flight path with a constant FAS. The error between flown FAS and target FAS is compared across experiment conditions. The flight path management is measured through a comparison of flown altitude and the ideal 3 degree flown path for the glide slope section between 1000 and 200 ft above ground level.

Eye tracking The eye tracker is used to verify whether dwell times on the instrument display and times spent on the out-of-the window view change.

Workload A simple workload metric (Rating Scale for Mental Effort, (Zijlstra, 1993)) is used to verify the effect of the workload manipulation, through turbulence intensity variation, and possibly detect effects from the instrument condition on experienced workload.

Preliminary results

Due to various circumstances, the full flight simulator experiment had to be postponed. Preliminary evaluation, with a test pilot, has resulted in a number of recommendations for the final experiment; specifically to use an asymmetric criterion for indicating speed boundaries, based on the insight that underspeed is more critical than overspeed, and a small margin overspeed has been added to the indication. Another preliminary conclusion is that a ”dark cockpit” concept is to be preferred, and that the PVD should not emit light when the correct speed is flown. Experiment completion is currently expected in June, with results following soon after.

References

Bulkley, N. K., Dyre, B. P., Lew, R., & Caufield, K. (2009). A peripherally-located virtual instrument landing display affords more precise control of approach path during simulated landings than traditional instrument landing displays. *Proceedings of the Human Factors and Ergonomics Society*, *1*, 31–35.

Federal Aviation Administration. (2021). Approaches and Landings. In *Airplaneflyinghandbook* (pp. 1–7). FAA.

Feng, C., Wanyan, X., Yang, K., Zhuang, D., & Wu, X. (2018). A comprehensive prediction and evaluation method of pilot workload. *Technology and Health Care*, *26*, 65–78.

Flight Safety Foundation. (2000). *Tool Kit Flight Safety Foundation Approach-and-landing Accident Reduction* (tech. rep.). Flight Safety Foundation.

Fox, J., Merwin, D., Marsh, R., McConkie, G., & Kramer, A. (1996). Information Extraction during Instrument Flight: An Evaluation of the Validity of the Eye-Mind Hypothesis. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *40*(2), 77–81.

Gonçalves, T. F., Azinheira, J. R., & Rives, P. (2009). Vision-based autonomous approach and landing for an aircraft using a direct visual tracking method. *ICINCO 2009 - 6th International Conference on Informatics in Control, Automation and Robotics, Proceedings*, *2 RA*, 94–101.

Harris, S., R. L., Glover, B. J., & Spady, J., A. A. (1986). Analytical techniques of pilot scanning behavior and their application.

Hasbrook, A., Howard, & Young. E., P. (1968, February). *Pilot response to peripheral vision cues during instrument flying tasks* (tech. rep.). FAA.

IATA. (2016). *Unstable Approaches Risk Mitigation Policies, Procedures and Best Practices 2nd Edition*.

IATA. (2022). *Examining Unstable Approaches-Risk Mitigating Efforts Unstable Approach-Safety Analysis Project Team* (tech. rep.). IATA.

International Air Transport Association. (2023). *IATA Annual Safety Report Executive Summary and Safety Overview-60th Edition Safety Overview* (tech. rep.). IATA.

Lefrançois, O., Matton, N., & Causse, M. (2021). Improving airline pilots' visual scanning and manual flight performance through training on skilled eye gaze strategies. *Safety*, *7*(4).

Mohanavelu, K., Srinivasan, P., Ravi, D., Singh, P., Mahajabin, M., K., R., Singh, U., & Jayaraman, S. (2020). Cognitive Workload Analysis of Fighter Aircraft Pilots in Flight Simulator Environment. *Defence Science Journal*, *70*, 131–139.

Peißl, S., Wickens, C. D., & Baruah, R. (2018, October). Eye-Tracking Measures in Aviation: A Selective Literature Review.

Pinel, J. P. (2011). Biopsychology. In *Biopsychology* (8th ed., pp. 131–140). Pearson.

Robinski, M., & Stein, M. (2013). Tracking visual scanning techniques in training simulation for helicopter landing. *Journal of Eye Movement Research*, *6*(2).

Schaudt, W. A., Caufield, K. J., & Dyre, B. P. (2002). *Effects of a virtual air speed error indicator on guidance accuracy and eye movement control during simulated flight* (tech. rep.). University of Idaho.

Schmid, D., & Stanton, N. A. (2020, April). Progressing Toward Airliners' Reduced-Crew Operations: A Systematic Literature Review.

Vater, C., Wolfe, B., & Rosenholtz, R. (2022, October). Peripheral vision in real-world tasks: A systematic review.

Veillette, P. R. (1995). Differences in aircrew manual skills in automated and conventional flight decks. *Transportation Research Record*, (1480), 43–50.

Vivaldi, B. E. (2004). The effect of crosswind and turbulence in mental workload and pilot tracking performance. *The effect of crosswind and turbulence in mental workload and pilot tracking performance*.

Vreeken, J. (2013, December). *Nationaal Lucht-en Ruimtevaartlaboratorium Helicopter Flight in a Degraded Visual Environment* (tech. rep.). National Aerospace Laboratory NLR. Amsterdam.

Wang, P., Houghton, R., & Majumdar, A. (2024, June). Detecting and Predicting Pilot Mental Workload Using Heart Rate Variability: A Systematic Review.

Wickens, C. D. (2008, June). Multiple resources and mental workload.

Zijlstra, F. R. H. (1993). *Efficiency in work behaviour : A design approach for modern tools*. Delft University Press.

Ziv, G. (2016, October). Gaze Behavior and Visual Attention: A Review of Eye Tracking Studies in Aviation.

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