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Individualized Landing Flare Training Using Both Flight Performance and Psychophysiological Measures

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INDIVIDUALIZED LANDING FLARE TRAINING USING BOTH FLIGHT PERFORMANCE AND PSYCHOPHYSIOLOGICAL MEASURES

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In this paper, we propose the analysis of various measures of eye and heart-rate data in addition to the flown trajectories and landing result, to get a better understanding of a trainee's learning phase and optimize the time spent on and exercises used for the flare training. A problem often experienced is that the trainee knows what to do and tries to a level that (s)he even believes to be doing just that, without actually doing it. Objective, visual feedback can be used to provide the trainee with tangible points to focus on, instead of the often heard comments like "a little too early" or "a little stronger". We present the outcomes of a series of experiments we carried out with students as well as experienced pilots in our fixed base flight simulator.

The landing flare is arguably the most difficult routine maneuver for pilots to learn. As a visuo-motor skill, it is generally learned through practice rather than teaching, while its timing--- just seconds before landing--- is critical and the consequences of errors can be large. A too early or too strong flare will result in floating or ballooning, with the risk of runway overrun or a go-around, while a too late or too weak flare will result in a hard landing or even a crash. To worsen things, the increasing stress (early) trainees experience just before the landing may render flare training ineffective, in particular if they are unable to focus on the necessary cues (which might vary depending on the flare method being taught).

The research presented in this paper is part of the larger "Pilot's Individualized Learning using Objective Data" (PILOD) project. In this project, subjects receive introductory flight simulator training in 6 sessions of ca. 1 hour each. During the first, fourth, and last sessions we record simulator data, eye data, and heartrate data while the subject flies a fixed set of scenarios. We provide the participants personalized feedback with an overview of their progress and suggest some specific training exercises based on the results of the data analysis. In this paper we analyze which factors are related with flare performance, and how we could use these to support trainees to master the flare.

Definitions & Background

Definitions of Glide, Flare, Floating, and Ballooning

In the final approach to landing, the pilot tries to make the airplane descend along a straight line, called the glide slope or glide path (diagonal dotted line in the bottom-left graph of Figure 1). We call this phase the '*Glide'*. If the pilot would maintain this path until hitting the runway, the sinkrate at touchdown would be too high and the pitch may be too low, causing a hard landing, nose wheel landing, or crash. Therefore, shortly before touchdown, the pilot pulls the control column (indicated with the blue triangles in Figure 1) to initiate the '*Flare*', resulting in an increased pitch angle and reduced sinkrate, followed by a smooth but not too soft touchdown.

Ideally, the flare is a smooth transition from the glide to touchdown. In practice however, and particularly in turbulent weather, we generally see one or more of the following phenomena:

- The flare is made in multiple steps (the column is not pulled once, but multiple times). This is mostly not a problem, and may even be desirable in some cases. Only if the flight becomes unstabilized (e.g., large pitch or sinkrate fluctuations due to overcompensated over-control) this is undesirable.
- The flare is somewhat strong, causing the aircraft to '*Float*' over the runway (the thick orange line segments in Figure 1). Floating increases the risk of runway overrun. In this research we define floating as a sinkrate below 100ft/min.
- The flare is too strong, causing '*Ballooning*' (the thick red line segments in Figure 1). This means the sinkrate becomes negative, and the aircraft starts climbing again. Apart from the runway overrun risk, there is a risk of stall, and a risk of hard landing or crash due to over-controlling after the pilot notices the aircraft is ballooning.

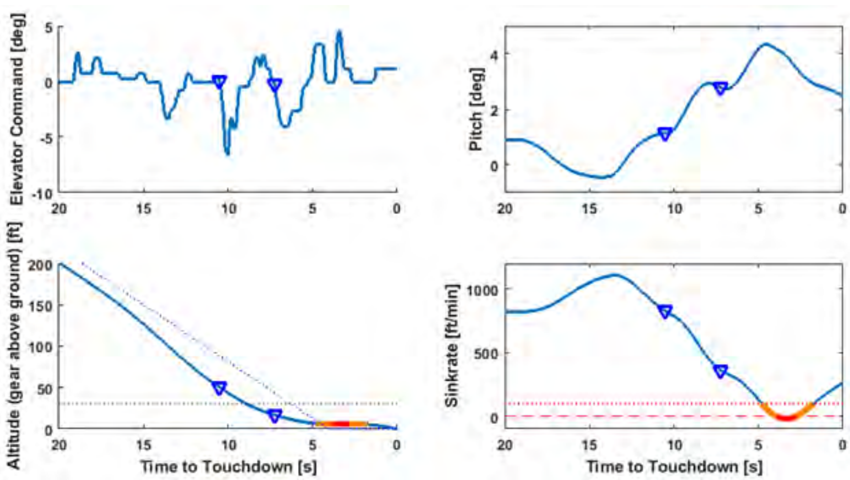


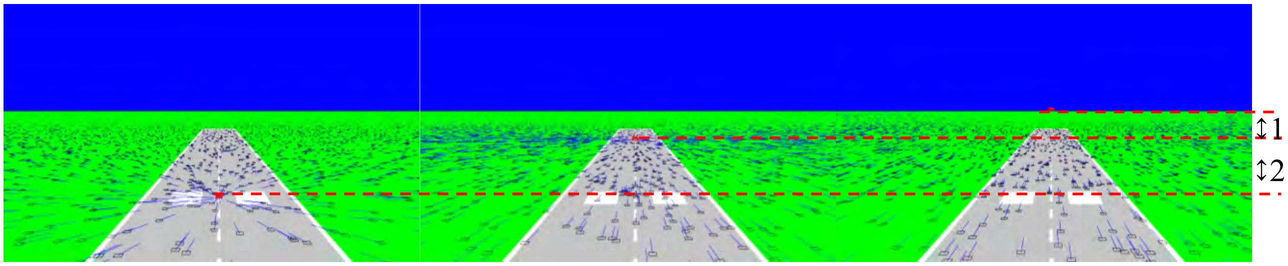
Figure 1. Example of the flare maneuver. In this case, the flare is carried out in 2 steps (the initiation points are indicated by the blue triangles). The floating and balooning regions are indicated by the thick orange and red line segments, respectively.

Cues for Flare Initiation and Guidance

For an acceptable touchdown sinkrate, the flight path should be changed from 3° to 1° or even a little bit less. The flight path can be identified from the out the window view as the center of expansion of the visual scene (Figure 2). If the aircraft is stabilized, it will be the only point in the visual scene which seems motionless. We will call the process of identifying this point and controlling the aircraft to make it coincide with the desired flight path direction `*Aiming*'.

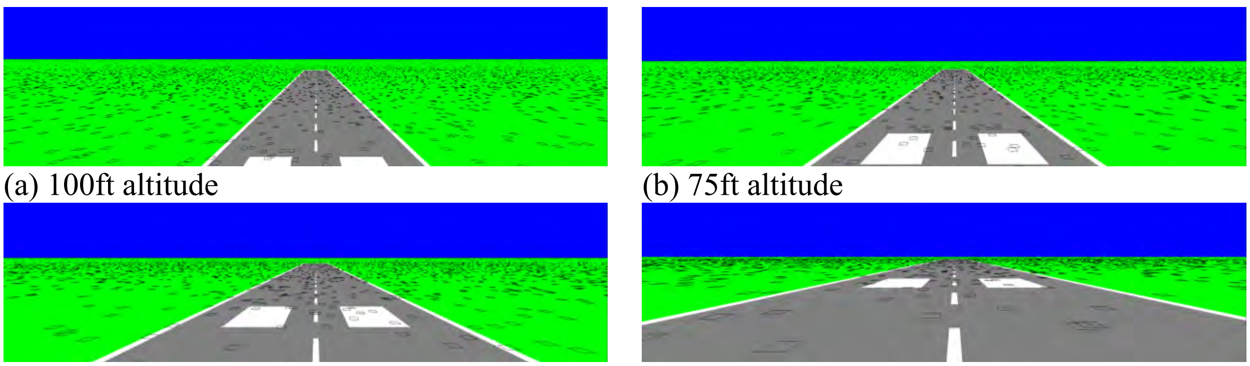
Although the aiming method tells us what to do, it does not tell us when to start doing it, nor how fast to do it. Training manuals generally mention a certain altitude (10~20ft for general aviation, or ±30ft for jet airliners) to start the flare initiation, often with a remark that this should be adapted based on several factors, most importantly the sinkrate. This brings us to the question how to determine altitude (and sinkrate) during the final seconds before touchdown.

A study by Benbassat (2005) showed that the "shape of the runway or runway markings", the "end of the runway or the horizon" and "peripheral vision" are the most commonly used visual cues to determine their altitude above the ground level. Even though the questionnaire covered a relatively homogeneous population at 2 schools, these results seem to be in line with other literature (for an overview, see Entzinger (2010)). Interestingly, the importance of "peripheral vision" is mainly noticed by expert pilots, and almost never mentioned by novices.



(a) 3° path (b) 1° path (c) 0° path (level flight)

Figure 2. The center of expansion of the optical flow field proides a visual cue of the flight path. In the glide phase the pilot should control the aircraft such that the center of expansion coincides with the aiming point markers. In the flare, the pilot should control the aircraft such that center of expansion shifts to a position near the far end of the runway.



(a) 100ft altitude (b) 75ft altitude

(c) 50ft altitude (on glide slope) (d) 25ft altitude

Figure 3. Visual cues to altitude are provided by the runway shape (apparent angle between the sidelines), the apparent vertical distance between the far runway end and the horizon, and the relative size of nearby texture. (All frames are taken at the same longitudinal position.)

Experiments

Overview & Hypotheses

We consider the following 4 flight performance parameters for the evaluation of the flare: sinkrate at touchdown, amount of floating, amount of ballooning, and longitudinal position of the tochdown point. The last one is largely affected by glide slope deviations, floating, and balloning, and therefore only an indirect objective for training.

There are several reasons to measure not only flight performance, but also a pilot's psychophysiological factors. These factors can help explain *why* the trainee could not achieve a good performance. On the other hand, if a good performance was obtained, they can indicate whether it was due to skill or luck; important additial knowledge considering the limited number of trials we usually get to analyze.

The heart rate (HR) is related to stress and arousal (Roscoe, 1992), while the heart rate variability's power spectrum density (PSD) in the frequency band from 0.06 to 0.14 Hz is said to be suppressed in cases of high mental effort (ME) (Aasman, Mulder, & Mulder, 1987; Vicente, Thornton, & Moray, 1987). Low ME during the flare can indicate panic (if accompanied by a high HR) or giving up (if accompanied by a decreasing HR). We hypothesize that high ME in the flare phase will lead to better flare performance.

The pupil diameter can be used as a measure for cognitive and memory workload (Beatty, 1982; Simpson & Hale, 1969). Recently it has also been shown that the pupil dilates when looking at a peripheral drift motion illusion (Beukema, Olson, Jennings, & Kingdom, 2017). We have seen pupil dilation in pilots and some of the trainees. We hypothesize that a significant increase in pupil diameter during the flare phase will lead to better flare performance. We also hypothesize pupil dilations will be larger when the subject uses peripheral vision.

Subjects

For the main analysis, we use the data of 22 university students, of which 21 male and 1 female. Some of them had flight experience in a glider or hanglider, or played flight simulator games. None had significant experience with the large jet simulator used in the experments.

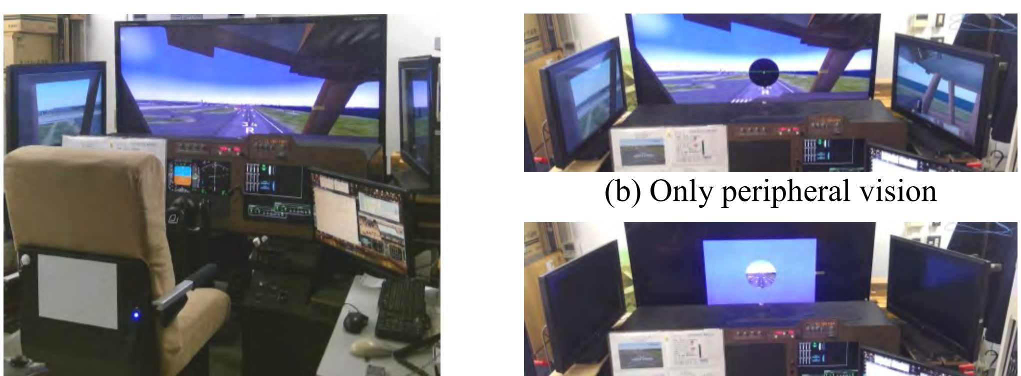
Five subjects took part in an additional experiment to clarify the effect of peripheral vision use on pupil dilation. One was a retired B747 captain pilot, another one was a student with extensive experience in our simulator, and the other 3 subjects just finished the introductory course of the main experiment.

The experiment protocol was approved in advance by the ethics committee of The University of Tokyo's School of Engineering. Each subject provided written informed consent before participating.

Materials & Methods

The experiments were carried out in the fixed-base Boeing 747 flight simulator at The University of Tokyo (Figure 4). The visuals are generated by Microsoft Flight Simulator 2004, but custom software is used to simulate the dynamics. The simulator states are logged at 20Hz. All approaches were simulated landings to Tokyo Haneda airport runway 34R, starting trimmed and on glide slope. We recorded eye-data at 30 Hz using the Takei TalkEyeLite eye-mark recorder and removed artifacts and outliers. The increase of pupil diameter was calculated as the slope of a straight line fit of the pupil diameter vs. time for the altitude interval 50~10ft.

Electrocardiograms (ECG) were recorded at 250Hz using the ParamaTech EP-301. We then calculated the instantaneous heart rate (HR) and the mental effort (ME) was calculated over a 16s sliding window.



(b) Only peripheral vision

(a) Basic setup with good visual conditions

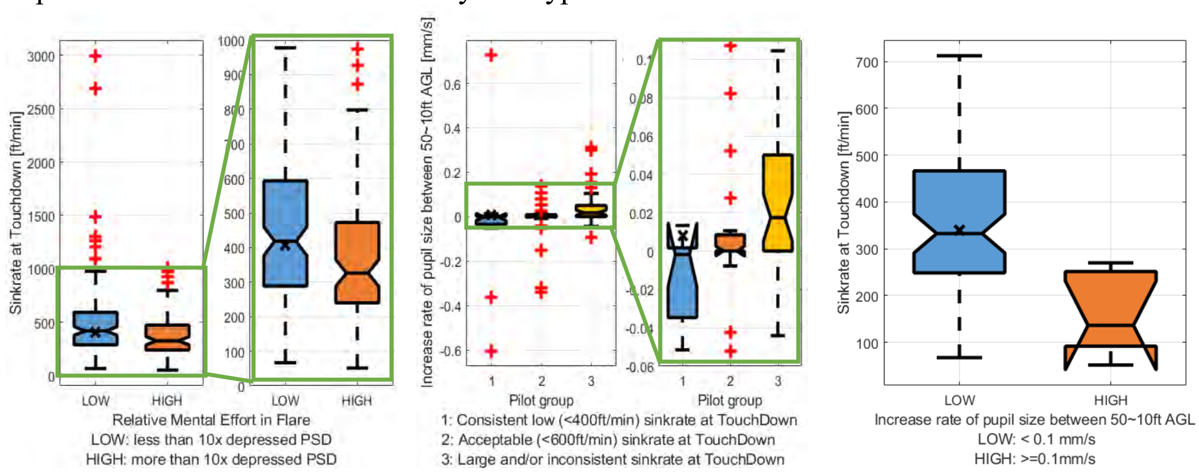
(c) Only foveal vision

Figure 4. The B747-400 simulator at The University of Tokyo and specific test conditions.

Results

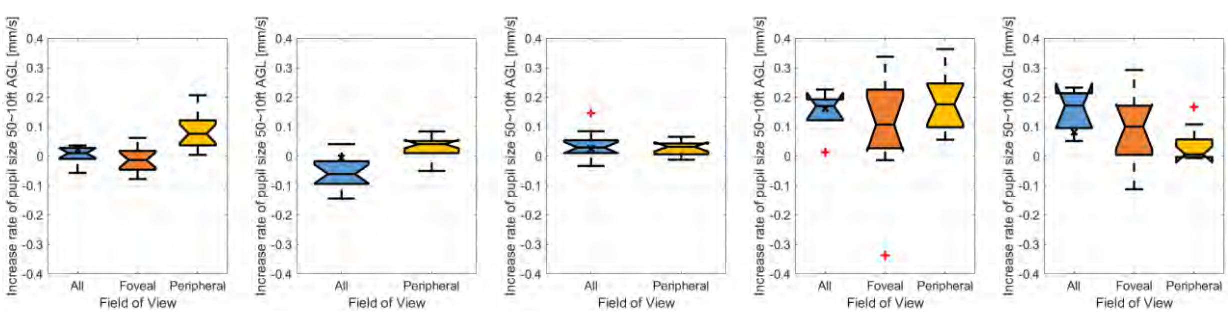
As expected, we saw strong training effects on the flare performance parameters. The sinkrate at touchdown, amount of floating, and touchdown location improved significantly at 1% level and the amount of balooning at 5% level. Figure 5(a) shows that high mental effort results in significantly lower sinkrates at touchdown, as we expected. For the effect of pupil size increase on tochdown sinkrate, we could not find general trend. However, interestingly, there seems to be an oppisite effect before and after training. Subjects who were able to touchdown at consistently low sinkrates before training actually showed a decrease in pupil diameter (Figure 5 (b)). After training, trials with in which a strong pupil size increase was observed had a significantly lower sinkrate at touchdown (Figure 5 (c)).

The additional experiment with different fields of view showed an stronger increase of pupil size during the flare when using only peripheral vision then when everything was visible, but only for the experienced subjects (Figure 6). Subject SRE showed an opposite effect. More experiments will be needed to verify the hypothesis.



(a) Mental effort. (b) Pupil size before training (c) Pupil size after training

Figure 5. Main experiment analysis results. Boxes span from the 25th to the 75th percentile. Box plots whose notches do not overlap have different medians at the 5% significance level. Red + marks indicate outlier values (outside 1.5 times the interquartile range).



(a) Retired airline pilot (b) Intensively trained subject (c) Subject SSY finished basic training (d) Subject SRD finished basic training (e) Subject SRE finished basic training

Figure 6. Experienced subjects show significantly larger pupil size increases when using only peripheral vision, while this effect is not observed for less experienced subjects.

Discussion

Psychophisiological parameters such as heart rate variability based mental effort and pupil dilation short before touchdown seem to be related to flare performance. These could be used to identify a trainee's needs, such as starting with a simple rule of thumb if mental effort is low, or practicing the use of peripheral vision if pupil dilation is weak. In addition, the results suggest aiming practice may be more useful for beginners, while using peripheral vision to estimate altitude and sink rate may help more experienced subjects to further hone their skills.

Acknowledgements

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