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Glideslope perception during aircraft landing

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Abstract

Ideally, when a pilot approaches a runway on their final approach for landing, they must maintain a constant trajectory, or glideslope, of typically 3°-4°. If pilots misperceive their glideslope and alter their flight path accordingly, they are likely to overshoot or undershoot their desired touch down point on the runway. This experiment examined the accuracy of passive glideslope perceptions during simulated fixed-wing aircraft landings. 17 university students were repeatedly exposed to the following four landing scene conditions: (i) a daylight scene of a runway surrounded by buildings and lying on a 100 km deep texture mapped ground plane; (ii) a night scene with only the side runway lights visible; (iii) a night scene with the side, center, near end and far end runway lights visible and a visible horizon line; or (iv) a night scene with a runway outline (instead of discrete lights) and a visible horizon line. Each of these simulations lasted 2 seconds and represented a 130 km/hr landing approach towards a 30 m wide x 1000 m long runway with a glideslope ranging between 1° and 5°. On each experimental trial, participants viewed two simulated aircraft landings (one presented directly after the other): (a) an ideal 3° glideslope landing simulation; and (b) a comparison landing simulation, where the glideslope was either 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, or 5°. Participants simply judged which of the two landing simulations appeared to have the steepest glideslope. As expected, the daylight landing scene simulations were found to produce significantly more accurate glideslope judgments than any of the night landing simulations. However, performance was found to be unacceptably imprecise and biased for all of our landing simulation scenes. Even in daylight conditions, the smallest glideslope difference that could be reliably detected (i.e. resulted in 75% correct levels of performance) exceeded 2º for 11 of our 16 subjects. It is concluded that glideslope differences of up to 2° can not be accurately perceived based on visual information alone, regardless of scene lighting or detail. The additional visual information provided by the ground surface and buildings in the daytime significantly improved performance, however not to a level that would prevent landing incidents.

Keywords

Glideslope, perception, during, aircraft, landing

Disciplines

Arts and Humanities | Life Sciences | Medicine and Health Sciences | Social and Behavioral Sciences

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Glideslope Perception During Aircraft Landing

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Abstract. Ideally, when a pilot approaches a runway on their final approach for landing, they must maintain a constant trajectory, or glideslope, of typically 3°-4°. If pilots misperceive their glideslope and alter their flight path accordingly, they are likely to overshoot or undershoot their desired touch down point on the runway. This experiment examined the accuracy of passive glideslope perceptions during simulated fixed-wing aircraft landings. 17 university students were repeatedly exposed to the following four landing scene conditions: (i) a daylight scene of a runway surrounded by buildings and lying on a 100 km deep texture mapped ground plane; (ii) a night scene with only the side runway lights visible; (iii) a night scene with the side, center, near end and far end runway lights visible and a visible horizon line; or (iv) a night scene with a runway outline (instead of discrete lights) and a visible horizon line. Each of these simulations lasted 2 seconds and represented a 130 km/hr landing approach towards a 30 m wide x 1000 m long runway with a glideslope ranging between 1° and 5°. On each experimental trial, participants viewed two simulated aircraft landings (one presented directly after the other): (a) an ideal 3° glideslope landing simulation; and (b) a comparison landing simulation, where the glideslope was either 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, or 5°. Participants simply judged which of the two landing simulations appeared to have the steepest glideslope. As expected, the daylight landing scene simulations were found to produce significantly more accurate glideslope judgments than any of the night landing simulations. However, performance was found to be unacceptably imprecise and biased for all of our landing simulation scenes. Even in daylight conditions, the smallest glideslope difference that could be reliably detected (i.e. resulted in 75% correct levels of performance) exceeded 2º for 11 of our 16 subjects. It is concluded that glideslope differences of up to 2° can not be accurately perceived based on visual information alone, regardless of scene lighting or detail. The additional visual information provided by the ground surface and buildings in the daytime significantly improved performance, however not to a level that would prevent landing incidents.

1. INTRODUCTION

It has long been noted that the approach and landing phases of aircraft flight are the most critical and demanding for pilots [7]. In order to land safely, pilots should ideally maintain a constant glideslope of 3° (or 4°, depending on the aircraft) in order to touch down at their desired aimpoint (usually located approximately 1,000ft from the runway threshold). If a pilot makes an approach that is too steep, they are likely to undershoot their aimpoint. Conversely, by making an approach that is too shallow, they are likely to overshoot their aimpoint. In principle, pilots can use a range of visual cues to perceive and control their glideslope during landing. These include the form ratio of the runway (the ratio of the apparent width of the far end of the runway to the apparent length of the runway), the H-angle (the visual angle between the runway aimpoint and the horizon) and optic flow (the gradient of optical velocities of scene features generated by the aircraft's motion). In the case of the latter cue, Gibson, Olum and Rosenblatt (1955) noted that the focus of expansion of the pilot's optic flow always coincided with the aircraft's heading direction. Despite this variety of visual cues, pilots appear to have a lot of difficulty accurately perceiving glideslope during landing. In particular, the high incidence of landing accidents at night [4], [12] suggests that these "black hole" landing situations do not provide adequate visual information for glideslope perception and control.

1.1 Form Ratio

Pilots could maintain a constant glideslope during landing by keeping the ratio of the optical width of the far end of the runway to the apparent length of the runway constant. However, to perceive the appropriate form ratio for a particular runway, the pilot would need to be familiar with it's physical dimensions, [3], [11]. Form ratio perception is also dependent on the geographical slant of the runway. Errors/biases will likely occur when landing on unfamiliar runways, with different physical dimensions and/or slants, for the first time. Mertens and Lewis (1982) and Lintern and Walker (1981) both found support for the form ratio as a cue for glideslope control. In their research, transferring pilots from their familiar runways to longer, narrower runways was found to produce lower approaches compared to transfers to shorter, wider runways. However, these results are not definitive, and form ratio alone can not always produce accurate glideslope control.

1.2 H-Angle

H-angles are invariant cues to glideslope, meaning that as long as the glideslope is held constant, the H-angle will remain constant. If the glideslope varies, the H-angle will vary. A high visible horizon increases the explicit H-angle, while a low visible horizon decreases the H-angle [8]. Lintern and Liu

(1991) confirm the use of H-angle as a glideslope control cue. In their experiment, they artificially raised or lowered the horizon during a simulated aircraft approach, and it was found that participants made low approaches to high horizons, and high approaches to low horizons, as was predicted. However, their results could not conclude that H-angle alone can produce accurate glideslope control.

1.3 Optic Flow

The focus of expansion of the pilot's optic flow always indicates the aircraft's heading direction. However, optic flow is a theoretical construct, which is not affected by eye-movements. When the pilot fixates on and tracks another object in the scene, the focus of expansion of his/her retinal flow will coincide with the direction of fixation rather than self motion [14]. As such, before optic flow can be used a cue for heading, retinal flow must be identified. Studies by Warren and colleagues [15], [16] have shown that during terrestrial self-motions, optic flow can be used to accurately judge the direction of self-motion However, Palmisano and Gillam (2005) found that optic flow was not accurate enough to judge future touchdown point position during simulated night landings. They found passive touchdown point perceptions were significantly biased by the simulated glideslope, with shallow glideslopes being overestimated and steeper glideslopes being underestimated.

1.4 The Current Study

The present study examined whether the incidence of glideslope difference detection errors would be more likely to arise under the following aircraft approach simulation conditions: (i) night, as opposed to day conditions; (ii) with only side runway lights visible, as opposed to all runway lights visible; (iii) with all runway lines visible, rather than all runway lights; and (iv) with no visible horizon, as opposed to with a visible horizon.

2. METHOD

2.1 Participants

The participants were 17 psychology undergraduates at the University of Wollongong, comprising 13 females and 4 males. All had either normal or adjusted vision and participated in the study for course credit. No participant had any flight experience.

2.2 Apparatus

This study utilized custom-built flight simulator software based on the openGL graphics library. These computer generated aircraft landing approach simulations were generated on a Macintosh G5 personal computer and presented on a Samsung Trinitron SyncMaster monitor (37cm wide x 27.5 cm high, with a pixel resolution of 1280 x 1024 and an 85 Hz refresh rate). The participant viewed the 49° wide by 37° high displays monocularly, through a square hole in a mask, that aligned the participant's eye level with the simulated location of the display's true horizon (either explicitly or implicitly represented in the scene). This mask occluded the rest of the room from view, so that only the landing simulation was visible.

2.3 Stimuli

Four experimental scenarios were tested on each participant: (1) day scene, (2) night scene with only runway sidelights, (3)night scene with all runway lights , and (4) night scene with all runway lines. Figure 1 shows two sample screen images, one of the day scene, and the other of the night scene with all runway lines. The day scene provided a clear view of the runway tarmac, surrounding ground plane and true horizon. There were also 20 visible buildings randomly placed on either side of the runway in each trial. The night scene with only runway sidelights provided a view of the converging left and right sides of the runway, indicated by light markers evenly spaced 60m apart. No explicit horizon information was provided. The night scene with all runway lights provided a view of the runway marked by the side lights, center lights, near and far runway edge lights and the true visible horizon. The night scene with all runway lines provided the runway outline, marked by side lines, a center line, and near and far runway edge lines, as well as the true horizon. The four experimental blocks were based on manipulation of the same aircraft approach scenario. The runway dimensions were 840m x 30m in each scenario, and the starting height of each trial was 50m. The speed of the approach was 130km/hr, and each trial lasted for 2 seconds. Each block consisted of either 9 experimental conditions. In each of these conditions, participants viewed two simulated aircraft landings (one presented directly after the other):): (a) an ideal 3° glideslope landing simulation; and (b) a comparison landing simulation, where the glideslope was either 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, or 5°. Participants simply judged which of the two landing simulations appeared to have the steepest glideslope.

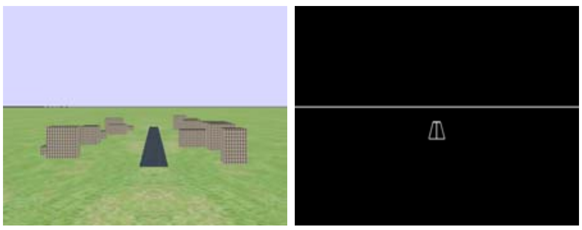

Figure 1. Screen images from day scenario and night scenario with horizon and all runway line visible

2.4 Procedure

Participants were informed that they would be viewing pairs of simulated aircraft landings, and their task was to select which simulated approach was steeper. Testing consisted of four 10-15 minute experimental sessions presented contiguously on the same day, in a different random order for each participant. When the participant had selected an option, the next trial would begin. The entire testing process took approximately 1 hour for each participant to complete.

3. RESULTS

3.1 Quantitative Results

We performed a 4x5 (scenario x glideslope difference) repeated measure ANOVA on the percent correct data. The means and standard deviations are presented in Table 1.

We found a significant main effect of scenario on the percentage of correct responses ($F_{3,\ 48}$ = 4.698, p = .006). Surprisingly there was no significant effect of glideslope difference either with the extra comparison (p = .218) or when it was excluded (p = .294). There was also no significant interaction between scenario and glideslope difference with the extra condition (p = .563) or when it was excluded (p = .257). Figure 2 demonstrates the relationship between scenario and glideslope difference.

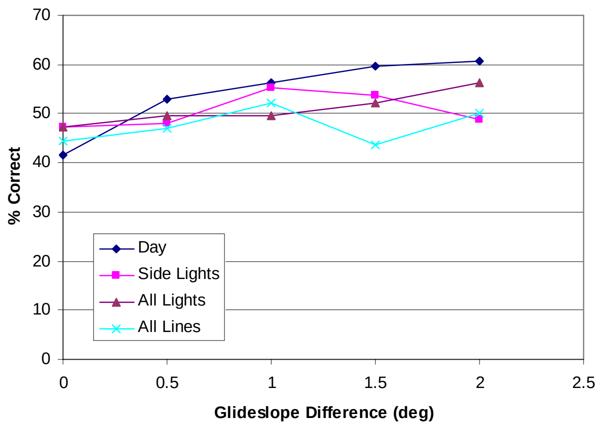

Figure 2. Mean % correct values as a function of glideslope difference.

3.2 Quantitative Results

For each participant's data, the 75% correct glideslope detection threshold was determined. Scenario conditions with a threshold of above 3.5° were counted as invalid trials, and given a value of 0. Conditions with a threshold below this criterion were given values of 1. A Pearson chi-square analysis was conducted on this qualitative data to determine whether there was a significant difference in the likelihood of valid trials between the 4 different scenarios. The results indicated a near significant effect of scenario (r = 7.257, p = .064), supporting the quantitative ANOVA findings. After conducting a non-parametric binomial test on the data, we found that all of the night scenarios had significant differences between observed values of valid (24% of trials) and invalid (76% of trials) trials, indicating that invalid trials were more likely to occur in night landing scenarios than valid trials (p = .049; i.e. if we assume there is an equal likelihood of the occurrence of valid and invalid trials, this pattern of results would be obtained only 4.9% of the time). The day scenario did not have a significant difference between valid (53% of trials) and invalid (47% of trials) results (p = .629), indicating that valid and invalid responses were equally likely to occur. These results tentatively suggest that the day scenario produces more accurate perception of glideslope differences than any of the night scenarios.

4. DISCUSSION

In the present aircraft landing simulation study, we found that glideslope difference detection was unacceptably imprecise. Performance failed to reach a 75% correct detection threshold for any of the landing scenarios tested. However, we did find that glideslope difference detection was significantly more accurate that any of the night landing scenarios tested. This finding can be explained by the presence of additional visual cues in these day scenes that were not available in the night landing situations. The day scene contained both H-angle and runway form ratio information. In addition, day scenes provided a texture mapped ground plane and 20 visible buildings surrounding the runway, which provided more optic flow and 3-D scene layout information than any of the night scenes. While H-angle and form ratio information was present in two of the three night time scenarios (those with either all possible runway lights or all possible runway lines), these scenes lacked detail of a ground plane or 3D objects. Thus, performance in these night conditions was likely to succumb to the featureless terrain illusion, in which the height above ground is misperceived, and the consequent approach angle is also misperceived [4]. Calvert (1950) describes an illusion in which runway lights, in the absence of visible surface texture, appear to "float in space" or "stand on end". Longuet-Higgins (1984) has shown that when only the runway lights are available, the pattern of moving lights projected onto the pilot's retina could be either correctly perceived as an oblique landing approach

Table 1. Means and Standard Deviations of Threshold Levels

Glideslope Diff.	Day		Side Lights		All Lights		All Lines	
	M	SD	M	SD	M	SD	M	SD
0	41.67	25.77	47.22	18.52	47.22	16.27	44.44	21.75
0.5	52.94	10.15	48.16	11.85	49.63	12.97	47.06	13.09
1	56.25	14.32	55.15	15.51	49.63	14.06	52.21	13.25
1.5	59.56	11.29	53.68	15.94	52.21	17.81	43.75	11.05
2	60.66	17.08	48.90	14.70	56.25	16.97	50.00	20.73

toward a horizontal ground plane, or misperceived as pure descent relative to an almost vertical plane. The appearance of the runway lights and runway lines in the night scenarios used here likely produced the same illusion, even when the visible horizon was present.

Another surprising finding was that the night scenario with only runway sidelights did not differ significantly from either of the other night scenarios, despite the absence of strong form ratio cues and any explicit visible horizon. This suggests that participants were not exclusively using the form ratio or H-angle cues in scenarios where these cues were available. The presence of a surface texture and buildings was therefore likely to have been responsible for the improved performance observed during the day conditions (this extra detail appears to have increased the effectiveness of either the optic flow or scene layout information).

Our failure to find a significant effect of glideslope difference was surprising. It was expected that a glideslope difference of 2° would be easier to detect than a glideslope difference of 0.5°. However, our results suggest that a deviation of 2° from an ideal glideslope could not reliably be detected. If true, this could have devastating consequences when piloting an aircraft. If a glideslope of 1° was incorrectly perceived as 3° at a height of 50m above ground level, the pilot would overshoot the aimpoint by approximately 1900m.

Previous research suggests that there are significant correlations between performance in flight simulators and performance in actual flight [1], [6]. The use of non-pilots in the present study limits our ability to generalise the results of this experiment to real world situations. It is possible that experienced pilots would be better able to detect glideslope differences based on the information available in our displays (i.e. compared to non-pilots). However, in actual landing situations, a pilot has many factors to consider, for example crosswinds, aircraft speed, and flare timing. The current task involved passive viewing of predetermined landing approaches. This method was considered ideal in this situation, as the student participants had no piloting experience. In future, it is possible that we might find improved performance by either increasing the size of our sample of student participants or by instead utilizing certified pilots as participants.

5. CONCLUSION

In conclusion, this experiment has demonstrated that the additional visual information provided by the ground surface and buildings in the daytime significantly improves glideslope perception, however not to a level that would prevent landing incidents. While results from day conditions were found to be significantly more accurate than any night condition, there was no significant difference between night conditions with different lighting patterns. The observed difference between day and night conditions in this simulation study were attributed primarily to the use of better optic flow and/or scene layout information.

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