Apparent Rotation of Runway Sidelines as a Cue to Flare Timing

Jorg Onno Entzinger[1] and Shinji Suzuki[2]

Department of Aeronautics & Astronautics, University of Tokyo, Tokyo, Japan
[1] (Jorg@Entzinger.nl)
[2] (tshinji@mail.ecc.u-tokyo.ac.jp)

Abstract: This paper presents experimental results regarding the timing of the landing flare initiation by airline pilots. From previous research it was hypothesized that pilots use the visual cue $\dot{\theta}$ —which denotes the speed of apparent rotation of the runway side lines— to decide the proper time to commence the flare. Experiments were carried out in a Boeing 767-300 full flight training simulator, with one Captain and one Junior pilot. Approaches were flown under calm, head, cross- and tail wind conditions, resulting in a variety of approach sink rates, without the demerit of 'unnatural' visual cues as would be the case with varying glide slopes as usually done in such experiments. Both the proposed $\dot{\theta}$ cue and several other cues suggested in literature are analyzed. Results show significant differences between the pilots with respect to the flare, while the main parameters during glide and at touch down did not. Data of the captain pilot seems to support our hypothesis, although the relatively small sample size and some outliers make it difficult to draw hard conclusions. No clear flare initiation cue could be identified the junior pilot, and and his control throughout the flare is less sophisticated as well.

Keywords: Jet Airliner Landing, Manual Flare Control, Visual Cues, Perception, Human Pilot, Psychophysics

1. INTRODUCTION

The out-the-window view provides the the main information pilots need to control the aircraft during the final phases of landing. *How* the pilot perceives and uses this information, however, is still largely unknown. The work we present here is part of a project in which we try to reveal which visual cues pilots use for their navigation and control decisions [1–5].

Applications of knowledge about visual cue use can be found in, for example,

- pilot training and evaluation,
- the development of enhanced or synthetic vision displays for bad weather approaches or remote-controlled missions,
- increasing the fidelity of flight simulators while balancing computational workload intelligently between important and less important visual elements,
- better modeling of human-machine interaction, e.g., for evaluating handling qualities in early phases of aircraft design
- the development of automatic landing systems, for example vision-based systems to increase robustness, or systems that adopt a more 'human-like' control style to simplify human-machine interaction and reduce accident risk,
- the study of visual illusions and spatial disorientation in aircraft operations. Training pilots to use the more reliable and significant cues, rather than the most salient cues could prevent dangerous situations.

In the current research we especially work towards applications in pilot training and evaluation.

The most difficult standard maneuver is the flare, which will be explained in more detail in §2.1. Timely initiation and proper execution of the flare are indispensable for safe and soft landings. However, even highly skilled pilots cannot explain their technique, so student have to learn by experience from extensive practicing.

In the work presented here we focus on the timing of the flare maneuver for medium sized jet airliners such as the Boeing B767 and Airbus A320. We will especially look at how captain pilots use the available visual cues, as these cues provide the main information in this phase of flight. Section 2 will provide some more background for readers unfamiliar with the flare maneuver, visual cues, and literature related to this topic. Section 3 introduces the hypothesis that the apparent rotation of the runway side-lines is used by pilots as a cue to flare timing. The experiments are then described in section 4, and the results in section 5. Section 6 provides a discussion of the experiment results and section 7 lists the conclusions.

2. BACKGROUND

The following subsections provide some background information for readers unfamiliar with the flare maneuver, the related visual cues, and/or previous research & literature on this topic.

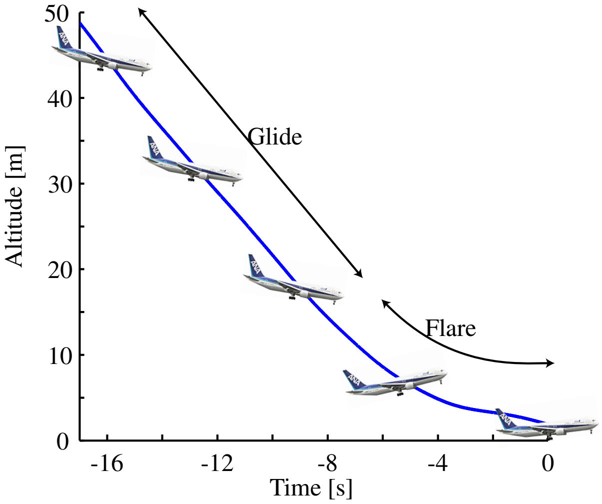
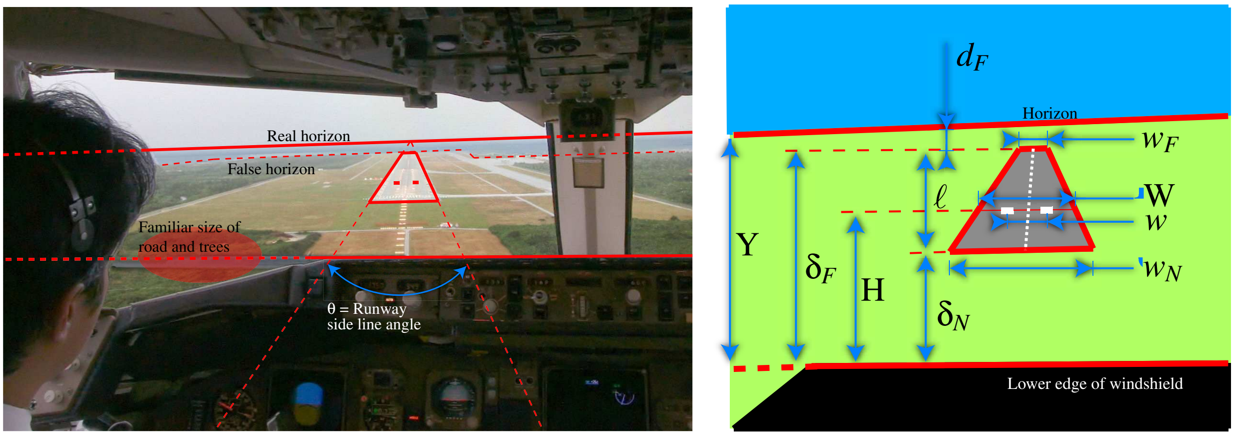


Fig. 1 In the final approach to landing, the pilot pitches up to arrest sink rate and land softly on the main gear. This maneuver is called the flare. (Pitch angles are exaggerated.)

2.1 The Flare Maneuver

The flare is a maneuver to decrease the high sink rate used during the glide phase to levels acceptable for landing (fig. 1).



(a) (b)

Fig. 2 Definition of some visual cues for longitudinal landing control. (a) A picture from the cockpit. A false horizon is visible below the real horizon due to the edge between land and sea. Familiar size can be used as a distance (altitude) cue, and the runway side line angle can also be an altitude cue. (b) Minimalistic view of the landing scene with various distances that can be used as cue. Note that the depression angle d_F=Y-δ_F; similarly, cues like d_N=Y-δ_N and d_H=Y-H (the latter being the H-distance or 'implicit horizon') could be constructed. Additionally, ratios such as ℓ/W may be used as cue.

At the same time it ensures that the plane touches down with the main gear first. This is achieved through an increase of the plane's pitch attitude by a few degrees.

It is very important that the flare is performed properly. If the flare is too late or too soft, this will result in a hard landing (which may damage the landing gear and causes passenger discomfort) or even in a crash. A too early or too strong flare on the other hand, may lead to 'floating' over the runway (leaving too little runway length for breaking), missing the runway at all and going back into the air, or even stall (sudden loss of lift).

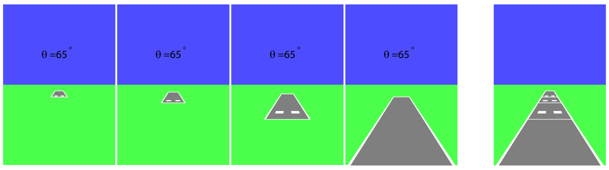
For mid-sized and large jet aircraft the flare is commenced when the landing gear reaches a height between 20 and 40 ft (6 – 12 m) above the ground and it roughly takes 4 – 8 seconds from flare initiation to touchdown. The actual values depend on the aircraft weight, descent rate, wind variations, etc. [6–8]. For these large aircraft the time lag between a pilot's control inputs and the effect on the aircraft state is in the order of 1 second. This means that pilots have to 'look ahead' and cannot easily correct once a maneuver has been started.

2.2 Visual Cues

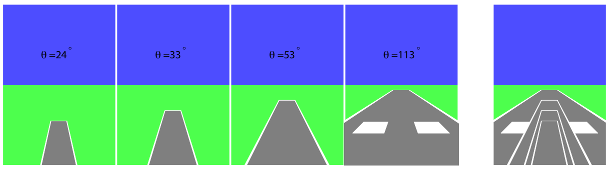
Below the 'Minimum Descent Height' or 'Decision Height' of 200 – 300 ft (60 – 90 m) the pilot must have established a visual reference. This means that he must be able to infer the aircraft state (position, orientation, speed, etc.) from the visual scene. The reason for this rule is that in close proximity to the ground, the pilot will not have enough time to read all instruments and integrate all information before making control actions. Additionally, instruments may give wrong or inaccurate information at low altitudes, while visual cues get stronger and more reliable when closing in.

Figure 2 shows a large number of variables that a pilot could use for (longitudinal) positional awareness. The way these variables change over time reveals even more information about the aircraft states. There is for example a direct relation between the distance Y (lower windshield edge – horizon) and the pitch attitude of the aircraft. It is also well known that the H-distance d_H=Y-H (aim point markers – horizon) remains constant if the aircraft is on a constant glide slope to the aim point (see also fig. 3(c)) and that this distance only depends on the glide slope angle. We provided an extensive overview of general visual cues and of research on visual cues in aircraft landing in another paper [9].

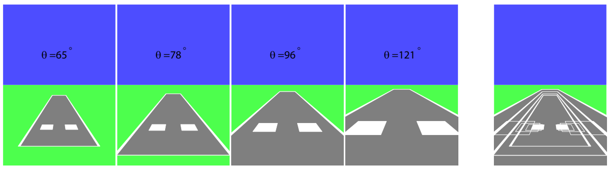
In this paper we will especially look at θ, the apparent angle between the runway side lines (fig. 2(a)). As fig. 3 illustrates, θ remains constant in level flight, while it increases with decreasing altitude.



(a) With pure forward movement of the observer, the angle between the runway sidelines is constant and the aim point markers move downward in the image.



(b) With pure downward movement of the observer, the angle between the runway sidelines increases and the aim point markers move upward in the image.



(c) When the observer maintains a constant glide-slope towards the aim point, the angle between the runway sidelines increases and the aim point markers stay at a constant height in the image.

Fig. 3 Change of the visual scene for (a) forward motion, (b) downward motion and (c) glide slope tracking. The sequences show a constant speed motion, at constant time intervals (within a sequence). θ is the angle between the runway sidelines. The rightmost pictures combine all sequence geometries.

It can be shown that

$$\theta = 2\tan^{-1}\left(\frac{\omega}{y}\right) \tag{1}$$

with ω half the real runway width and y the height of the observer above the runway [1]. This means that θ can be used as an altitude cue, although care must be taken when the runway width is different from what the pilot is used to.

Previous research indicated that the time derivative of θ is used as a cue for flare timing [2]. It can easily be shown that

$$\begin{aligned}\dot{\theta} &= \frac{-2\omega}{y^2+\omega^2}\cdot\frac{dy}{dt}\\ &= \frac{\text{Runway width}}{\text{Altitude}^2+\left(\frac{1}{2}\text{Runway width}\right)^2}\cdot\text{Sink rate.}\end{aligned} \tag{2}$$

Since approaches with higher sink rates require flare initiation at a higher altitudes, commencing the flare at a specific value of $\dot{\theta}$ could make sense.

2.3 Related Research

As mentioned before, in some previous papers we discussed visual cues in general [9], visual cue analysis of aircraft landing through pilot modeling [2], and visual cues for flare timing (in particular the motion of the runway sidelines, $\dot{\theta}$) [1]. These works, obviously, form the basis and general background of the research presented here.

Pilots and training literature generally mention that the flare should be initiated at a certain altitude [6 p.6.9, 7 p.6.10, 10]. However, several researchers have found that sink rate also plays an important role for the timing of the flare initiation [10–14, 15 Vol.1, §2.4.5]. Some also mention the distance to the desired touchdown point could be a factor, with initiation at higher altitudes in case of feared undershoot [12, 13].

An interesting combination of altitude and sink rate is contained in the variable τ, specifying 'time to contact' and first defined by Lee [16, 17]. The altitude-based τ_z (altitude divided by sink rate) has been suggested as a guide for the flare phase [12, 18]. Others have suggested a *visual* time to contact cue, the runway width-based τ_W, which is defined as the apparent runway width (W in fig. 2(b)) divided by its time derivative [19–21].

Several visual cues (such as θ, $\dot{\theta}$, W and τ_W) depend on the physical runway width. This is undesirable, since not all runways have the same width, and thus basing decisions on such a cue could be disastrous for approaches to runways with different dimensions than the pilot is used to. It appears however that pilots actually *do* experience such 'runway width illusions' [22–24][1], which makes it more likely that visual cues like these are actually used. (Pilots may however "calibrate" their perception using some other cues and still use the width-dependent cues.)

3. HYPOTHESIS

The hypothesis in this paper is that pilots use the speed of rotation of the runway sidelines ($\dot{\theta}$; eq. 2) as a cue for flare timing. As explained in the "background" section (sect. 2), this visual cue integrates information about altitude and sink rate, which are the two main aircraft states involved in the flare maneuver. We formulated the $\dot{\theta}$ hypothesis after analysis of data from simulated landings of both a Do228-202 turboprop and a B767-300 jet aircraft [1, 2]. The experiments we present here are a first effort to further test this hypothesis. We are especially looking for answers on the following 2 questions:

1. Does the hypothesis hold over a wide range of approach conditions?
2. Does every (good) pilot use this cue, or are there other (main) strategies?

4. MATERIALS & METHODS

4.1 Apparatus & Subjects

For the experiments we used a Boeing 767-300 full flight training simulator owned by All Nippon Airways (ANA) operated by certified pilots. The simulator includes simulation of motion and sounds, most notably engine noise and radio altitude (RA) call-outs when the landing gear is at 100, 50, 30, 20 and 10 feet above the ground. All approaches started 2 NM (3.7 km) out of runway 35 of Shimojishima airport, Okinawa, Japan, in a trimmed condition and on the glide slope. Simulated gross weight was ±125.000 kg and the simulated weather was clear.

The subjects in this study were two certified pilots, whom we will here refer to as KOB and OTA, having 8370 and 2700 hours flight experience respectively. They were asked to land the aircraft under several conditions like they would do normally. The pilots were instructed that they could use the flight director display in the beginning of each approach, but that they should switch to visual approach as soon as possible. Previous data —which lead to the hypothesis currently under investigation— were obtained with the same settings by pilot SUZ who had 8340 hours flight experience at the time.

4.2 Experiment Conditions

Training literature and pilots generally state that the flare should be commenced "at a certain altitude" while several researchers found the sink rate influenced flare timing. We therefore want to setup an experiment where the pilots have to land under different sink rate conditions.There are several ways to change the (nominal) sink rate at approach.

Changing the commanded glide slope is probably the most applied method [12, 19–21]. However, especially commercial airliner pilots are not used to glide slopes significantly different from 3 degrees, so we cannot expect to measure the pilot's normal behavior and data will be unreliable. Additionally, it is not clear in which ratio airspeed and sink rate should be adapted to reach such a different glide path.

Approaches with head or tail winds are more natural to the pilot than glide slope changes. Only in case of head wind the pilot corrects the airspeed with half of the wind speed. This means the wind always changes the aircraft's ground speed, and the pilot has to adjust the sink rate to keep a 3° glide path.

Changes in weight influence the aircraft dynamics. Although partly corrected for by higher airspeeds, higher gross weights still result in higher sink rates throughout the approach. Large weight changes may have the drawback that the aircraft inertia and thus response time increases. As the pilot will know the gross weight, he may give the flare command earlier just because he knows the aircraft requires more time to settle, rather than because an earlier flare would be needed. (We currently do not know how big this effect is though.)

---

[1] Reynolds [24] actually found that pilots did not suffer the illusion in dynamic experiments, although they did when they had to make altitude estimates based on a static scene. Non-pilot participants suffered the illusion in both the static and dynamic experiments.

There are some other ways to test the $\dot{\theta}$-hypothesis. This would involve changing the appearance of the perceived cue rather than the aircraft state.

Changing runway widths would result in different values for $\dot{\theta}$ even for similar approach paths (eq. 2). However, pilots may be used to different runway widths because different widths are encountered in real life, and compensate for this. On the other hand, it is know that differences in runway width may lead to illusions and wrong altitude judgments [22–24]. As it is hard to tell how the illusions and altitude perception influence particular results, this method is not preferred.

Tapering runways , that is, runways which get narrower or wider towards the far end, would influence the perceived $\dot{\theta}$ in a complex way. One problem with this method is its practical implementation, since the simulator scene would have to be adapted. Another problem is that the tapered runway may provoke illusions similar to the 'sloping terrain illusion' [25–28].

We chose to use head and tail winds to adjust the nominal sink rates in these experiments. We used the maximum allowed wind conditions of 40kt head wind and 20 kt tail wind (21 and 10 m/s respectively), resulting in nominal sink rates of about 3.2 m/s (head wind), 3.9 m/s (calm) and 4.4 m/s (tail wind). For a different study some crosswind approaches were flown in the same experiment session. Winds were 20kt from a 60° angle, which results in airspeeds and sink rates equivalent to the calm wind case. Some light turbulence was added in these crosswind approaches.

4.3 Data Processing

From the simulator we obtained state data such as position, orientation, airspeed and sink rate, as well as control inputs at a rate of 30 Hz. We applied a moving average filter of 20 samples to all state data to reduce noise. We chose the touchdown point as the point with maximum vertical acceleration and selected all data below 300 ft (91 m) altitude up to touchdown for analysis. From the aircraft state values and the known runway geometry we calculate the visual cues as the pilot would see them. We assume the pilot's control is driven by these visual cues and we don't explicitly analyze the motion and aural cues.

The moment of flare initiation is determined manually based on the column (elevator) control, with reference to the time histories of pitch, sink rate, height of the horizon in the visual field, etc. Even though literature generally assumes flare control to be smooth[2] [12, 19, 29], we found in previous experiments that the pilot often performs the flare in 2 steps [1]. First he pulls the column a bit and regards the aircraft's response, then he pulls more to achieve a proper flare. Later we found confirmation of this notion in some literature [14 p104] and also in a discussion with ANA pilots [priv. comm.]. In this analysis we consider the second step (which may coincide with the first) to be the 'true' flare and consider the first step a 'pre-flare'.

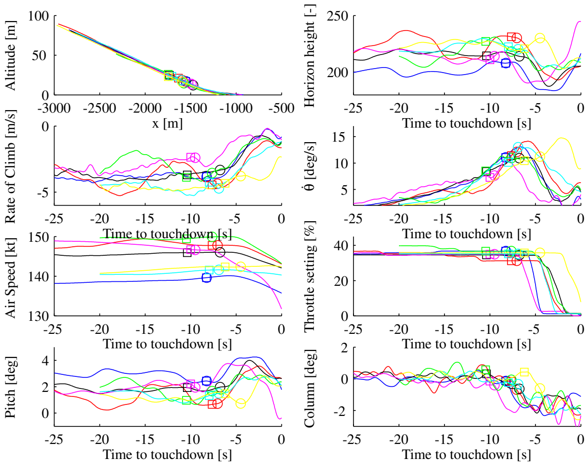
5. RESULTS

Unfortunately, the limited availability of the simulator allowed only two or three repetitions under each condition. The pilots also seemed to see the strong winds as a challenge, especially the tail wind. It is, however, something they train for. For one landing of pilot KOB it was impossible to define the moment of flare initiation.

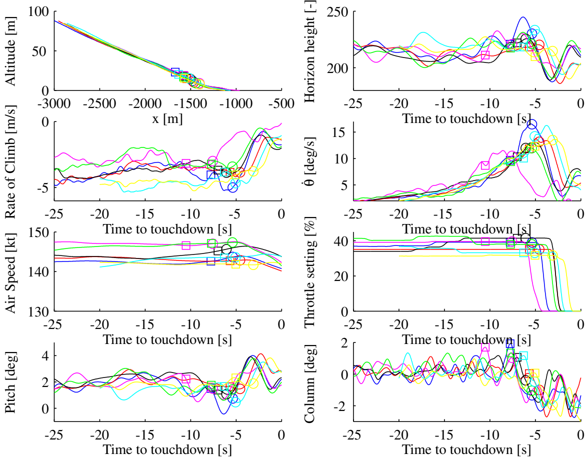
A one-way analysis of variance (ANOVA) showed there was a significant effect of each of the three wind cases on the sink rate during the glide phase (1‰, $F(2,9)=86.74$, $p<10^{-6}$) and also at the moment of flare initiation (5%, $F(2,9)=5.34$, $p=0.014$). This means the experiment setup was successful in achieving a variation in approach conditions.

It appeared that the pilots often initiated the flare well above 30 ft and up to 60 ft altitude, even when we disregard the pre-flare. This is much higher than the values prescribed in training literature (see §2.1). Heffley et al. [13 p104] found similar discrepancies between training literature and simulator practice for jet aircraft. A Japan Airlines Boeing 747 pilot commented that flares in the simulator should be initiated earlier (around 50 ft) than in the real aircraft (around 30 ft). Because of these notes we feel that the obtained experiment data are not exceptional.

Figure 4 shows the profiles of the landing approaches flown in this experiment. A few more data sets were obtained, but these lacked a corresponding set flown by the other pilot under the same conditions. The omitted sets are in agreement with the results and conclusions presented here.



(a) Data for pilot KOB



(b) Data for pilot OTA

Fig. 4 Selection of state, control and visual cue time histories for pilots KOB and OTA. Data sets were selected such that the experiment conditions match between the pilots. The square indicates the start of the 'pre-flare', while the circle indicates the true flare.

---

[2] This may still be true for small aircraft

Figure 5 presents a close-up of the $\dot{\theta}$ data around the moment of flare initiation. In the data for captain pilot KOB we see that 4 of the 7 flares are commenced at a $\dot{\theta}$ of about 11 °/s. The remaining 3 data sets are the *first* landing trials under head wind (magenta), cross wind (red) and tail wind (cyan) conditions. Since the second head, cross- and tail wind landings were in the cluster around $\dot{\theta}$=11 °/s, we argue that the pilot was somehow surprised by the strong wind effects and therefore performed worse in the initial trials. The Hampel-test ([30]) confirmed that these 3 points should indeed be regarded as outliers. Other parameters, especially glide slope and sink rate, also seem to be different for these 3 landing approaches, although according to the Hampel-test they were not significantly outliers.

For junior pilot OTA there seems to be no consistent value of the $\dot{\theta}$ cue at the moment of flare initiation. Second landings for each case seem to be a bit more consistent than the first trials. Differences may be caused by the wind, although the extreme value in the calm (no-wind) is very peculiar. Wind effects did not reach significance in an ANOVA analysis.

A statistical analysis (Tab. 1) shows that the main aircraft state parameters during the glide phase and at touch down were not significantly different between both pilots. Note that the glide path is very close to the desired glide slope of 3 °. The sink rates during the glide and at the moment of flare initiation are also within the expected ranges. However, the sink rate at touch down is quite high (0.5 – 1 m/s is ideal), meaning that landings were a bit rough.

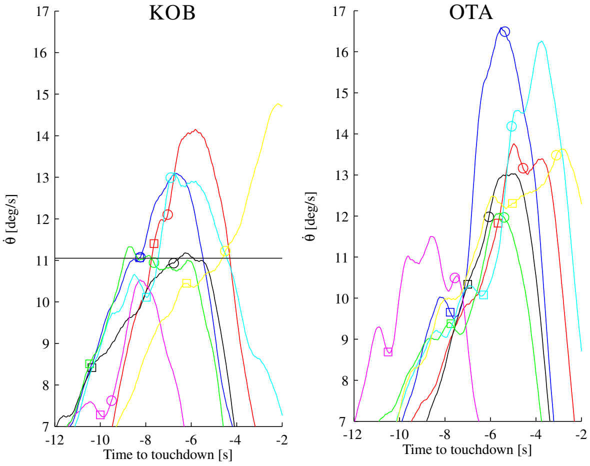


Fig. 5 Comparison of the $\dot{\theta}$ cue around the moment of flare initiation for both pilots. **Colors:** blue: calm, cyan & yellow: tail wind, red & black: crosswind, magenta & green: head wind.

Table 1 Statistical analysis including mean values, standard deviations and one-way ANOVA analyses. The rightmost column indicates whether values of pilots KOB and OTA are significantly different (- means 5% significance was not reached).

	KOB Mean	KOB St.dev.	OTA Mean	OTA St.dev.	F(1,12)	p $(\times 10^{-3})$	Significance
During glide phase (average over the timespan 15 – 10 s before touchdown)							
altitude	36.61	10.21	38.89	8.94	0.20	.	-
sink rate	3.70	0.85	3.58	0.78	0.08	.	-
pitch	1.79	0.73	1.97	0.37	0.35	.	-
glide path	2.92	0.29	2.83	0.20	0.46	.	-
At the true flare initiation (average over 1 s prior to flare; this reflects cue integration)							
altitude	17.68	2.77	13.06	3.03	8.86	3.6	5%
sink rate	3.75	0.69	3.91	0.64	0.21	.	-
τ_z	4.78	0.64	3.36	0.70	15.66	0.4	1%
θ	119.30	7.89	133.30	9.60	8.89	3.6	5%
$\dot{\theta}$	10.52	1.40	12.47	1.79	5.16	16.9	5%
τ_θ	11.64	2.60	10.89	1.63	0.43	.	-
W	34.73	5.38	45.87	7.22	10.73	1.9	1%
τ_W	6.57	1.68	11.51	3.61	10.78	1.8	1%
At touch down							
sink rate	1.36	0.50	1.36	0.64	0.00	.	-
x (-1000)	-28.24	100.27	-71.60	60.06	0.96	.	-

Table 1 further indicates that pilot KOB initiates the flare significantly earlier (higher altitude, higher real time-to-contact τ_z) than pilot OTA. From this analysis it can not be concluded whether this difference is due to their different use of visual cues, since all proposed flare timing cues (even the altitude cue θ) have significantly different values for each pilot.

A quick analysis of the coefficients of variation[3] shows that the variation of $\dot{\theta}$ at flare initiation is lower than that of W (0.12 vs. 0.15) and much lower than the variation of τ_W (ca. 0.25) for both pilots. If we would discard the 3 sets with outlier $\dot{\theta}$ values for pilot KOB, the variation of $\dot{\theta}$ is even a factor 10 lower than that of τ_W.

6. DISCUSSION

We can obviously state that the $\dot{\theta}$ values at flare for the three trials where pilot KOB first encountered each wind type, are outliers. Can we then also state that our hypothesis holds for pilot KOB? Although these 3 approaches did seem a bit different, they were not significantly so. Therefore we should keep the possibility open that pilot KOB has several methods to decide the timing of his flare initiation, of which the $\dot{\theta}$ cue is one.

Pilot OTA's data seem to reject the $\dot{\theta}$-hypothesis. However, no other visual cue or aircraft state was found indicative for his flare timing. It seems that his flares are timed sloppily and late, and that he makes up for that by exerting relatively aggressive, high amplitude control actions during the flare phase (fig. 6). After all, there was no significant performance difference between the two pilots at touch down. High amplitude control is undesired at low altitudes, and captain pilots like KOB (and SUZ in the previous experiments) may have learned through experience how to avoid this by appropriately timing the flare initiation.

7. CONCLUSION

Due to the small sample size and therefore limited possibilities of statistical analysis, it is difficult to draw hard conclusions. It seems very likely that pilot KOB used the speed of apparent rotation of the runway sidelines, $\dot{\theta}$, as a cue for flare initiation at least in some of his landings. Although the results are still open to discussion, the data presented here seems to support our hypothesis. The first question we raised regarding our hypothesis can thus be answered: the $\dot{\theta}$-cue can be used over a wide range of conditions.

As for junior pilot OTA, there is no clear indication that he is using $\dot{\theta}$. The results, however, made clear that junior pilot OTA's control *during* the flare phase is very different from veteran pilot KOB's. Whether this is really related to the amount of flight experience or just an interpersonal difference can not be established from this data. It seems likely that experience plays a major role since it is well known that proper landing technique is one of the most difficult things to learn in pilot training [21, 31, 32].

The second question we raised would thus be answered by the statement that, at least as far as the current experiments go,

---

[3] the coefficients of variation —standard deviation divided by the mean— is a dimensionless inequality measure which can be used to compare variables which are measured on ratio scales. θ itself for example can not be analyzed this way, as we could just as well define this cue as $180 - \theta$, and θ must thus be considered an interval scale.

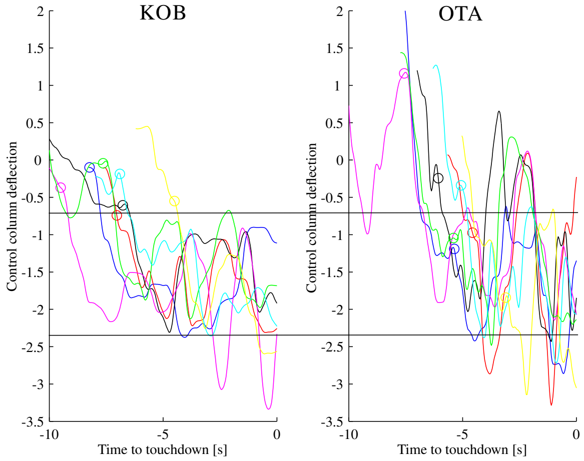


Fig. 6 Difference between the two pilots in column control during the flare phase. Standard deviations of pilot OTA's column control were higher than pilot KOB's at a 1% significance level (F(1,12)=20.04, p= 0.00015).

all experienced pilots have been shown to use the $\dot{\theta}$-cue and show calm and conservative control throughout the flare, while the junior pilot who does not seem to rely on the $\dot{\theta}$-cue as much, needs stronger control actions in the final phase of landing. In other words, it seems that the use of the $\dot{\theta}$-cue for flare initiation comes with more sophisticated control.

The experiments additionally revealed that the pilots flare much earlier (at much higher altitudes) than training literature advises. This could be a general trend, or a specific artifact of jet aircraft simulators. In the latter case, this would indicate some imperfection of the simulation, possibly omission of ground effects or variations in wind speed over altitude.

ACKNOWLEDGMENTS

The authors wish to thank the pilots and staff of All Nippon Airways (ANA) for their cooperation in obtaining the landing data and for the enlightening discussions. It is further acknowledged that Jorg Entzinger receives a Japanese government (Monbukagakusho) scholarship and partial support from the 21st Century COE Program Mechanical Systems Innovation.

REFERENCES

[1] Jorg Onno Entzinger and Shinji Suzuki. Visual cues in manual landing of airplanes. In *Proceedings of KSAS–JSASS Joint International Symposium on Aerospace Engineering*, pages 388–395. The Korean Society for Aeronautical & Space Sciences, November 2008. URL `http://jorg.entzinger.nl/`. Paper #C3-3.

[2] Jorg Onno Entzinger. Modeling of the visual approach to landing using neural networks and fuzzy supervisory control. In Ian Grant, editor, *CD Proceedings of the 26th International Congress of the Aeronautical Sciences (ICAS2008), Anchorage, Alaska, USA*, Edinburgh, UK, September 2008. Optimage Ltd. URL `http://jorg.entzinger.nl/`. Paper #440.

[3] Ryota Mori, Shinji Suzuki, Kazuya Masui, and Hiroshi Tomita. Neural network analysis of pilot landing control in real flight. *Journal of Mechanical Systems for Transportation and Logistics*, 1(1):14–21, 2008. ISSN 1882-1782.

[4] Ryota Mori and Shinji Suzuki. Modeling of human pilot landing approach control using stochastic switched arx. In *Proceedings of the AIAA Modeling and Simulation Technologies Conference, Chicago, Illinois*, aug 2009. #AIAA-2009-6031 [in press].

[5] Ryota Mori, Shinji Suzuki, Yuki Sakamoto, and Hiroshi Takahara. Analysis of visual cues during landing phase by using neural network modeling. *Journal of Aircraft*, 2007.

[6] Boeing. *767 Flight Crew Training Manual*. The Boeing Company, 7th (oct 31, 2007) edition, 1999. #FCT 747-400 (TM).

[7] Boeing. *747-400 Flight Crew Training Manual*. The Boeing Company, 6th (oct 31, 2007) edition, October 2001. #FCT 767 (TM).

[8] Airbus. *Airbus Flight Crew Training Manual – ANA A318/A319/A320/A321 fleet FCTM*. Airbus Customer Services, Technical Data Support & Services, rev date 09/07 edition, September 2007.

[9] Jorg Onno Entzinger and Shinji Suzuki. Modeling of the human pilot in aircraft landing control. In *Proceedings of the 10th APRU Doctoral Students Conference*. Association of Pacific Rim Universities, July 2009. URL `http://jorg.entzinger.nl/`. Paper #460.

[10] Robert K. Heffley and Ted M. Schulman. Derivation of human pilot control laws based on literal interpretation of pilot training literature. In *AIAA Guidance and Control Conference Albuquerque, NM*, pages 513–519., New York, 1981. American Institute of Aeronautics & Astronautics. #AIAA-1981-1822.

[11] Munir Orgun, Venkata R. Pappu, and Alfredo A. Toledo, Jr. Method and apparatus for controlling flare engagement height in automatic landing systems. US Patent 5020747, June 1991. URL `http://www.patentstorm.us/patents/5020747.html`. The Boeing Company.

[12] Jacqueline Grosz, Rolf Th. Rysdyk, Reinoud J. Bootsma, J.(Bob) A. Mulder, J.(Hans) C. van der Vaart, and Piet C. W. van Wieringen. Perceptual support for timing of the flare in the landing of an aircraft. In Peter A. Hancock, John M. Flach, Jeff Caird, and Kim J. Vicente, editors, *Local applications of the ecological approach to human-machine systems*, volume 2 of *Resources for Ecological Psychology*, chapter 4, pages 104–121. Lawrence Erlbaum Associates, Hillsdale, NJ, 1995. ISBN 0-8058-1380-2.

[13] Robert K. Heffley, Ted M. Schulman, Robert J. Randle, Jr, and Warren F. Clement. An analysis of airline landing flare data based on flight and training simulator measurements. Technical Report TR 1172-1R, Systems Technology Inc. / NASA Ames Research Center, 1982. URL `http://www.robertheffley.com/pages/bib.htm`.

[14] Robert K. Heffley, Ted M. Schulman, and Warren F. Clement. An analysis of airline landing flare data based on flight and training simulator measurements. Technical Report #83N10047 / NASA-CR-166404, Systems Technology Inc. / NASA Ames Research Center, August 1982. URL `http://ntrs.nasa.gov/`.

[15] USAF. *Air Force Manual 11-217 (Flying Operations – Instrument Flight Procedures)*. USA Department of the Air Force, January 2005. URL `http://www.e-publishing.`

`af.mil/`. [Formerly AFM 51-37 and AFM 11-212].

[16] David N. Lee. Visual information during locomotion. In Robert B. MacLeod and Herbert L. Pick, Jr, editors, *Perception: Essays in Honor of James J. Gibson*, chapter 14, pages 250–267. Cornell University Press, Ithaca and London, 1974. ISBN 0801408350.

[17] David N. Lee. A theory of visual control of braking based on information about time-to-collision. *Perception*, 5: 437–459, 1976.

[18] Michael Jump and Gareth D. Padfield. Tau flare or not tau flare: that is the question: Developing guidelines for an approach and landing sky guide. In *AIAA Guidance, Control and Navigation Conference*, San Fransisco, 2005. #AIAA-2005-6404.

[19] Max Mulder, Jan-Mark Pleijsant, J.(Hans) C. van der Vaart, and Piet C. W. van Wieringen. The effects of pictorial detail on the timing of the landing flare: Results of a visual simulation experiment. *The International Journal of Aviation Psychology*, 10(3):291–315, 2000.

[20] Sunjoo K. Advani, J.(Hans) C. van der Vaart, Rolf Th. Rysdyk, and Jacqueline Grosz. What optical cues do pilots use to initiate the landing flare? results of a piloted simulator experiment. In *AIAA Guidance, Navigation, and Control Conference and Exhibit*, 1993. #AIAA-93-3561-CP.

[21] Stephen Palmisano, Simone Favelle, Gavin Prowse, Richard Wadwell, and Ben Sachtler. Investigation of visual flight cues for timing the initiation of the landing flare. Technical Report #B2005/02121, Australian Transport Safety Bureau, June 2006.

[22] Gavan Lintern and Michael B. Walker. Scene content and runway breadth effects on simulated landing approaches. *The International Journal of Aviation Psychology*, 1(2): 117–132, April 1991.

[23] Henry W. Mertens and Mark F. Lewis. Effect of different runway size on pilot performance during simulated night landing approaches. Technical Report FAA-AM-81-6 / AD-A103190, FAA Civil Aeromedical Institute, February 1981. URL `http://handle.dtic.mil/100.2/ADA103190`.

[24] Natalie Beth Reynolds. An investigation into landing approach visual illusions. Master's thesis, University of Waikato, New Zealand, 2007. URL `http://adt.waikato.ac.nz/public/adt-uow20070223.112316`.

[25] FAA. *Instrument Flying Handbook*. U.S. Department of Transportation, Federal Aviation Administration, 2007. URL `http://www.faa.gov/library/manuals/aviation/instrument_flying_handbook/`. #FAA-H-8083-15A [Ch. 1 on visual & optical illusions].

[26] National Transportation Safety Board. Aviation accident database & synopses. Online. URL `http://www.ntsb.gov/NTSB/Query.asp`. [Accident Numbers NYC00LA202,NYC03LA144, ATL00FA075, LAX86LA318, ATL88FA230 on sloping runway illusion].

[27] Conrad L. Kraft. Measurement of height and distance information provided pilots by the extra-cockpit visual scene. In *Visual Factors in Transportation Systems: Proceedings of Spring Meeting, 1969*, pages 84–101, Washington, D.C., 1969. Committee on Vision, National Academy of Sciences–National Research Council.

[28] Conrad L. Kraft. A psychophysical contribution to air safety: Simulator studies of visual illusions in night visual approaches. In H. L. Pick, Jr, H. W. Leibowitz, J. E. Singer, A. Steinschneider, and H. W. Stevensons, editors, *Psychology: From research to practice*, pages 363–385. Plenum, New York, 1978. ISBN 0306311321.

[29] FAA. *Airplane Flying Handbook*. U.S. Department of Transportation, Federal Aviation Administration – Flight Standards Service, 2004. #FAA-H-8083-3A [Ch. 8 on landing].

[30] Laurie Davies and Ursula Gather. The identification of multiple outliers. *Journal of the American Statistical Association*, 88(423):782–792, September 1993.

[31] Paul A. Craig, John E. Bertrand, Wayne Dornan, Steve Gossett, and Kimberly K. Thorsby. Ab initio training in the glass cockpit era: New technology meets new pilolts. a preliminary descriptive analysis. In *13th International Symposium on Aviation Psychology*, 2005.

[32] Danny Benbassat and Charles I. Abramson. Landing flare accident reports and pilot perception analysis. *The International Journal of Aviation Psychology*, 12(2):137–152, 2002.