International Journal of Comparative Psychology, 2002, **15**, 249-255.

SHORT COMMUNICATION

Comparative Approach to Pilot Error and Effective Landing Flare Instructions

Danny Benbassat, Charles I. Abramson
Oklahoma State University, U.S.A.
and
Kevin W. Williams
Civil Aeromedical Institute, Federal Aviation Administration, U.S.A.

One of the most difficult tasks confronting pilots is the brief transition between descent attitude and contact with the runway surface. This transition is known as the landing flare and requires pilots to level off the aircraft at a safe altitude above ground. General aviation landing flares are crucial to smooth and safe landings since flaring too high or too low may lead to a hard landing and possible structural damage. Nevertheless, the maneuver is poorly understood and landing flare accident rates are relatively high. This paper considers avian perceptual and stimulus discrimination abilities in order to better understand and improve the flare maneuver. It concludes by suggesting that the focus and methodology of modern psychology may have hindered the development of effective flare instruction.

Most pilots strive for perfect landings because landings are often used to evaluate pilot performance (Collins, 1981; King, 1998). The success or failure of a landing frequently depends on the brief transition between controlled descent and actual contact with the runway surface (Green et al., 1996). This transition is known as the landing flare and requires pilots to level off light general aviation (GA) aircraft about 3.0 to 6.1m (10-20 ft) from the ground (Federal Aviation Administration, Revised 1999). The purpose of this paper is to consider avian perceptual and stimulus discrimination abilities in order to better understand and improve the flare maneuver. The paper concludes by suggesting that the focus and methodology of modern psychology may have hindered the development of effective flare instruction.

Punctuating the crucial role of successful flares to smooth and safe landings, Benbassat and Abramson (2002a) found that 18.33% of all landing accidents in 1995, 1996, and 1997 were flare related accidents. Investigation by the first author into most recently available landing flare accident rates revealed that the trend had not changed in 1998. Nevertheless, the nature of flare accidents has been poorly understood, underreported, and under-investigated (Benbassat & Abramson, 2002b). Because the ability to determine altitude above ground level (AGL) is crucial to successful flares (Love, 1995), any attempt to ivestigate the nature of improper flares must first establish how pilots determine altitude AGL.

Correspondence concerning this article may be addressed to Danny Benbassat, Department of Psychology, Oklahoma State University, 215 North Murray, Stillwater, OK 74078, U.S.A. (dbenbassat@yahoo.com).

Depth Perception

Since general aviation aircraft altimeters are not accurate at low altitudes (see title 14 Code of Federal Regulations) and kinesthetic sensitivity is not fully developed in early phases of flight training (Jeppesen, 1985), pilots rely on vision and optic flow to determine altitude AGL during the landing phase of flight (Green et al., 1996; Grosz et al., 1995; Federal Aviation Administration, Revised 1999; Thom, 1992). In a survey study, pilots agreed that vision was more crucial to determining altitude AGL than instrument reading and kinesthetic information, yet were not able to explain how vision was used (Benbassat & Abramson, 2002a). The problem is also apparent in traditional certified flight instructor (CFI) instructions and flight manuals. Overall, a review of instructions found them to be inconsistent and no one method was found to be better than another (Benbassat & Abramson, 2002b).

The visually guided maneuver of the landing flare may be better understood by considering avian depth perception vision. Studies have suggested that some birds have specialized pathways for stereoscopic (binocular) and panoramic (monocular) vision (Güntürkün, Miceli, & Watanabe, 1993). Those birds can alternate between the two pathways as needed. For example, when pigeons peck they focus on close objects and use the binocular pathway. When they forage for food while in flight, pigeons attempt to detect distant objects and use the monocular pathway. Eagles and falcons also alternate between the two pathways. They use monocular vision to fixate on distant objects and switch to binocular vision when approaching their prey. An in-depth discussion of binocular and monocular cues is beyond the scope of this paper but examples of each are presented in Tables 1 and 2 respectively.

Table 1
Binocular Cues.

1. **Accommodation**. The lenses protrude for close and flatten for distant objects.
2. **Convergence**. The eyes move inward for close and outward for distant objects.
3. **Stereopsis**. The fusion of signals from slightly disparate retinal points that result in a visual appreciation of three dimensions.

Table 2
Monocular Cues.

1. **Horizon / end of runway** - appear to rise on the cockpit windshield as the aircraft approaches the ground.
2. **Shape of runway / runway markings** - appears to widen and shorten as the aircraft approaches the ground.
3. **Familiar objects** - shape and size appear less distorted as the aircraft approaches the ground.
4. **Motion parallax** - objects appear to move faster as the aircraft approaches the ground.
5. **Relative size** - objects appear larger as the aircraft approaches the ground.
6. **Texture gradient -** objects appear with more detail as the aircraft approaches the ground.

Thus, findings from birds that are able to alternate between binocular and monocular pathways suggest that binocular depth perception cues are only effective for short distances. Indeed, human studies have concluded that depth perception on approach and landing exceeds the critical ranges for binocular cues of approximately 6.1 m (20 ft) (Green, 1988; Reinhart, 1982; Reinhart, 1996; Reinhardt-Rutland, 1997). The realization that pilots rely on monocular cues to determine altitude AGL has far-reaching implications and will be discussed briefly.

First and foremost, whereas binocular sensitivity appears to develop naturally (Fox et al., 1980; Reading, 1983; Reinecke & Simons, 1974), monocular cues have to be learned through repeated experience (Arterberry, Yonas, & Bensen, 1989; Benson, 1999; Langewiesche, 1972; Marieb, 1995; Tredici, 1996) and sensitivity to monocular cues may even be affected by cultural factors (Hudson, 1960). Flight training manuals erroneously regard the ability to determine altitude AGL as natural when, in fact, it must be learned. As flight cadets attempt to interpret monocular cues from a novel perspective, experience is essential. Nevertheless, the one factor that student pilots lack is experience. In fact, a 5000 h total time pilot only has about 8 h of flare time (King, 1998).

Without experience how are student pilots expected to determine altitude AGL? Recall that CFIs cannot provide effective instruction because they cannot explain how vision is used on approach and landing. Just as automobile drivers cannot explain how they know it is time to apply brakes as they approach a stationary car at an intersection, pilots cannot explain how they know it is time to level off the aircraft at a safe altitude AGL. Thus, student pilots cannot be expected to effectively determine altitude AGL, and CFIs cannot be expected to explain what they know implicitly. In fact, many restrict their comments to: “just about now begin to flare,” which only increase student confusion and frustration.

Similarly, many flight manuals never address the issue of attempting to determine altitude AGL and instruct pilots to flare “within what appears to be about 10 to 20 feet above the ground” (Federal Aviation Administration, Revised 1999, p. 7-6). The inability to determine the importance of one monocular cue over another also contributes to the lack of standardized, objective, and safe flare instruction. Indeed, it appears that different pilots use different cues or combination of monocular cues, and that the importance of individual monocular cues can vary from airport to airport.

Flare Instruction

As described in Table 2, monocular cues provide depth perception because these cues appear different as the aircraft approaches the runway and perspective changes. For example, the runway image projected onto the retina changes as the aircraft approaches it. The position of the horizon on the aircraft windshield also changes as the aircraft approaches the ground. Expert pilots use that information and associate relevant monocular cues with safe flare altitude. Thus, the process of discriminating appropriate from inappropriate monocular cues is essentially a discrimination learning process. Unfortunately, pilots learn which cues are appropriate and which are not through trial-and-error. In other words, they learn by flaring high at times and low at other times (Benbassat & Abramson, 2002c).

Needless to say, learning to discriminate appropriate from inappropriate monocular cues through trial-and-error may increase the likelihood of flare accidents and structural damage to the aircraft. Optimal flare instruction should incorporate a discrimination learning process in which pilots never respond to inappropriate monocular cues. In the attempt to provide such optimal instruction, Benbassat and Abramson (2002c) considered work by Terrace with pigeons.

Terrace (1963a, 1963b) trained pigeons to peck an illuminated red key (S+). After conditioning to the red key the light was briefly turned off. The pigeons that were trained to peck the red key ignored it when it was turned off. After periods of red illumination in which the pigeons pecked and periods of darkness in which pigeons retreated, a dim green illumination was presented instead of total darkness (S-). Pigeons continued to ignore the key when it was green and to vigorously peck it when it was red.

Eventually, the green light was illuminated at the same intensity as the red key without eliciting any pecking behavior from the pigeons. Hence, Terrace conditioned the pigeons to discriminate the red from the green key without ever making an error. Errorless discrimination learning does not only establish a desired response without emitting undesired ones, but it also eliminates the experience of frustration (Terrace, 1964). Since organisms never respond to the negative stimulus, they never experience the frustration of unreinforced behavior common to trial-and-error learning.

Unlike the pigeon study by Terrace, Benbassat and Abramson (2002c) used two discriminative stimuli without fading. As noted earlier, monocular cues are the naturally occurring stimuli that pilots associate with safe flare altitude. Since inexperienced pilots cannot recognize these cues, Benbassat and Abramson used a second cue. Participants with no aviation training were trained to land a Cessna 182 simulator. Half were instructed to flare the simulated aircraft with the presentation of an auditory tone cued to the ideal flare altitude. The tone was triggered by a sensitive altitude encoding device that was independent from the aircraft altimeter. Thus, participants never flared the aircraft too low or too high, but more importantly they never responded to inappropriate monocular cues. In other words, participants associated appropriate monocular cues with safe flare altitude without ever making an error.

The other half of the participants was instructed to flare with traditional verbal instructions. Training was set to performance criteria and participants that met the criteria performed five solo landings. They were required to perform the solo landings without any assistance and were the sole occupants of the mock cockpit. Tone participants were informed that the tone would not be presented. Unlike the pigeon study by Terrace, the tone was not faded out but eliminated during the solo landings. The tone was not faded out because the sound produced by most training aircraft engines renders such an attempt impractical.

Flight simulator data gathered while participants performed the five solo landings revealed significant differences between control and tone participants. Those trained to flare with traditional flare instructions flared the aircraft significantly higher (M = 2838 ft mean sea level [MSL]) than those trained with the tone (M = 2825 ft MSL). As a result, control participants registered significantly higher impacts at touchdown (M = -448 ft/min) than did tone participants (M = -286 ft/min). Mean landing flare altitude by group for each solo landing and a depiction of the optimal flare altitude are presented in Figure 1. The optimal flare altitude was deducted from simulated flight performance data prior to the beginning of the study.

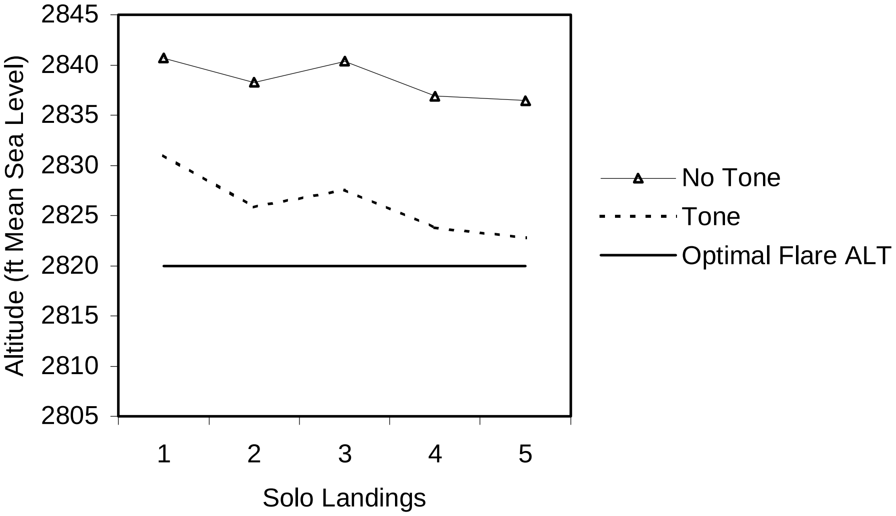

Figure 1. Control and tone mean flare altitude across five solo landings. There was no significant difference in mean flare altitude across solo landings within groups.

It is important to note that in addition to superior performance, tone participants never experienced the frustration of improper flares during training. In the case of landing an aircraft, the frustration that results from improper flares may foster anxiety and discourage student pilots from completing their flight training.

Afterthought

This paper discussed an aviation maneuver considered by many to be especially difficult (Benbassat & Abramson, 2002a; Bramson, 1982; Love, 1995). Yet, as mentioned earlier, improper flares were poorly understood and flare instructions were less than optimal. It is possible that the tendency to center on humans and ignore animal studies in aviation research contributed to the lack of an effective method for teaching proper landing flares.

The investigation of improper flares may have also been hindered by the increasing reliance on survey and questionnaire designs. Survey and questionnaire designs are often plagued with validity issues and may lead to inaccurate or misleading conclusions when exclusively used to study a phenomenon. For example, novice, intermediate, and expert pilots indirectly attested to the difficulty of the flare maneuver by rating flare accidents to be more than twice as frequent as they really were. Nevertheless, despite the fact that novice, intermediate, and expert ratings were not significantly different, expert pilots were more confident in the accuracy of their flare accident rates (Benbassat & Abramson, 2002a).

A second example illustrates inconsistencies between perceptions and behavior. In the simulated landing flare study mentioned previously control participants rated their landings as better than tone participants (Benbassat & Abramson, 2002c). Recall that while tone participants flared 5 ft above the optimal flare altitude, control participants flared 18 ft above and registered significantly higher impacts at touchdown. There are many reasons why control participants rated their landings as better than tone participants even though their landing performance was significantly worse. Similarly, there are many reasons why expert pilots were more confident but not more accurate than intermediate or novice pilots. Be that as it may, exclusive reliance on questionnaire and survey data may be misleading.

Taken as a whole, the consideration of animal studies should be encouraged and similar behaviors in different species compared. The comparative approach may provide parsimonious solutions and complement other, more cognitive, models of learning and behavior. The success of such an approach in a traditionally cognitive arena such as human factors in aviation holds promise for other mainstream psychology subfields.

References

Arterberry, M., Yonas, A., & Bensen, A. S. (1989). Self-produced locomotion and the development of responsiveness to linear perspective and texture gradients. *Developmental Psychology,* **25**, 976-982.

Benbassat, D., & Abramson, C. I. (2002a). Landing flare accident reports and pilot perception analysis. *International Journal of Aviation Psychology,* **12**, 137-152.

Benbassat, D., & Abramson. C. I. (2002b). General aviation landing flare instructions. *Journal of Aviation / Aerospace Education and Research,* **11**, 31-38.

Benbassat, D., & Abramson. C. I. (2002c). Errorless Discrimination Learning in Simulated Landing Flares. *Human factors and Aerospace Safety: An International Journal,* **2**, 319-338.

Benson, A. J. (1999). Spatial disorientation-general aspects. In J. Ernsting, A. N. Nicholson, & D. J. Rainford (Eds.), *Aviation medicine,* Third Edition (pp. 419 - 454). Oxford, Great Britain: Butterworth Heinemann.

Bramson, A. (1982). *Make better landings*. New York: Van Nostrand Reinhold.

Collins, L. (1981). *Takeoffs and landings.* New York: Delacorte Press / Eleanor.

Federal Aviation Administration (Revised 1999). *Airplane flying handbook (FAA -H - 8083 - 3).* Washington, DC: U.S Department of Transportation.

Fox, R., Aslin, R. N., Shea, S. L., & Dumais, S. T. (1980). Stereopsis in human infants. *Science,* **207**, 323-324.

Green, R. G. (1988). Perception. In J. Ernsting, & P. King (Eds.). *Aviation medicine, Second Edition* (pp. 391-401). Cambridge, UK: Butterworth Heinemann.

Green, R. G., Muir, H., James, M., Gradwell, D., & Green, R. L. (1996). *Human factors for pilots, Second Edition.* Hampshire, UK: Avebury Aviation.

Grosz J., Rysdyk, R., Bootsma, R. J., Mulder, J. A., Van der Vaart, J. C., & Van Wieringen, P. W. (1995). Perceptual support for timing of the flare in the landing of an aircraft. In P. Hancock, J. Flach, J. Caird, & K. Vicente (Eds.), *Local applications of the ecological approach to human-machine systems* (pp. 104-121). Hillsdale, NJ: Lawrence Erlbaum Associates.

Güntürkün, O., Miceli, D., & Watanabe, M. (1993). Anatomy of the avian thalamofugal pathway. In P. H. Zeigler & H. Bischof (Eds.). *Vision, brain, and behavior in birds* (pp.115-135). Cambridge, MA: MIT Press.

Hudson, W. (1960). Pictorial depth perception in sub-cultural groups in Africa. *Journal of Social Psychology,* **52**, 183-208.

Jeppesen (1985). *Private pilot maneuvers manual.* Englewood, CO: Jeppesen Sanderson.

King (Producer). (1998). *Takeoffs and landings made easy* [Film]. (Available from King Schools: 3840 Calle Fortunada, San Diego, CA 92123).

Langewiesche, W. (1972). *Stick and rudder.* New York: McGraw Hill.

Love, M. C. (1995). *Better takeoffs and landings.* Columbus, OH: Tab Books / McGraw-Hill.

Marieb, E. N. (1995). *Human anatomy and physiology, Third Edition*. Redwood City, CA: Benjamin / Cumming Publishing Company.

Reading, R. W. (1983). *Binocular vision: Foundations and applications.* Woburn, MA: Butterworth Publishers.

Reinecke, R. D., & Simons, K. (1974). A new stereoscopic test for amblyopia screening. *American Journal of Ophthalmology,* **78**, 714-721.

Reinhart, R. O. (1982). *The pilot's manual of medical certification and health maintenance.* Osceola, WI: Specialty Press.

Reinhart, R. O. (1996). *Basic flight physiology, Second Edition.* New York: McGraw-Hill.

Reinhardt - Rutland, A. H. (1997). Depth perception: A possible role for pictorial information in aviation. In R. S. Jensen, & L. A. Rakovan (Eds.). *Ninth international symposium on aviation psycholog, Vol. 2*. (pp. 1525-1529). Columbus, OH: Ohio State University.

Thom, T. (1992). *The pilot's manual flight training.* Frederick, MD: Center for Aviation Theory.

Terrace, H. S. (1963a). Discrimination learning with and without “error.” *Journal of the Experimental Analysis of Behavior*, **6**, 1-27.

Terrace, H. S. (1963b). Errorless transfer of a discrimination across two continua. *Journal of the Experimental Analysis of Behavior*, **6**, 223-232.

Terrace, H. S. (1964). Wavelength generalization after discrimination learning with and without errors. *Science*, **144**, 78-80.

Tredici, T. J. (1996). Ophthalmology in aerospace medicine. In R. L. DeHart (Ed.). *Fundamentals of aerospace medicine, Second Edition* (pp. 519-566). Baltimore, MD: Williams & Wilkins.

Received July 28, 2002.
First revision received September 25, 2002.
Second revision received December 11, 2002.
Accepted December 11, 2002.