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Perceived Importance of the Visual Cues to the Timing of the Landing Flare

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ABSTRACT

One of the first obstacles that confront student pilots is the landing flare. Of special concern is the initial decrease in rate of descent, also known as the leveloff. The ability to time this maneuver is crucial to a smooth and safe landing, but poorly understood. Ninety-two aviators in two Part 141 flight schools completed a perception questionnaire in the attempt to further explore the role of visual cues in timing the landing flare. Findings suggest that pilots find it difficult to articulate or identify these visual cues. These findings highlight the shortcomings of current landing instruction and emphasize the need to transition from verbal to nonverbal instruction.

The importance of timing general aviation landing flares is well documented. Initiating the flare too high or too low may cause structural damage (Christy, 1991; Jorgensen & Schely, 1990) and even discourage some students from pursuing the private pilot certificate (Collins, 1981; King, 1998; Matson, 1973). Nevertheless, the mechanisms by which pilots time the landing flare are equivocal. The purpose of this paper is to investigate the visual cues pilots use to time the landing flare.

Scientific publications have attempted to explore the procedural process of timing the landing flare, and although an in-depth discussion is beyond the scope of this paper, the use of optic flow and monocular cues will be considered. Gibson (1950) and Calvert (1950) first considered the notion of optic flow. As the aircraft approaches the runway, everything expands in an apparent outward motion with the exception of the touchdown focal point that has an optic flow expansion of zero (Grosz et al., 1995; Thom, 1992). Current *time-to-contact* theories (Grosz et al., 1995; Mulder, Pleijsant, van der Vaart, & van Wieringen, 2000) suggested that pilots use this rate of angular expansion to estimate time of impact.

Thus, time-to-contact theorists suggest that pilots time (i.e., initiate) the flare as a result of a perceived time-to-collision with the runway, not as a result of perceived altitude Above Ground Level (AGL) (Lee, 1976). Other theorists suggest that pilots initiate the flare as a result of perceived altitude AGL. They suggest that as the aircraft approaches the runway, pilots attend to two-dimensional cues laden with depth perception information (Benson, 1999). These cues are known as *monocular cues* and were studied at least as early as Leonardo Da Vinci to promote the effect of depth in a two-dimensional canvas. Table 1 summarizes monocular cues that pilots frequently use to infer altitude AGL.

Table 1.

Frequently Used Monocular Cues on Landing Flare

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.

Note. Based on findings from this study and findings from Benbassat and Abramson (2002b); monocular cues are not placed in order of importance.

Time-to-contact and monocular theories are traditionally presented as separate and independent (Beall & Loomis, 1997). Nevertheless, it is possible that the two are interdependent. The ability to perceive angular expansion depends on the perception of runway outlines, texture gradient (Mulder, Pleijsant, & van der Vaart, 2000), and the horizon (Hasbrook, 1983). Lee (1976) considered time-to-contact in the visually guided procedure of braking an automobile. He suggested improving rear-end delineation and texture gradient in order to reduce rear-end collisions. Thus, the detection of outward angular expansion may depend on monocular cues.

Three concerns arise when considering the practical application of time-to-contact and monocular cues to pilot training. First, after being acquired, both skills represent procedural knowledge. That knowledge tends to be automatic, effortless, and especially difficult to articulate (Berbaum, Kennedy, & Hettinger, 1991). Perhaps that is why instruction manuals are incongruent as to the use of vision in timing the landing flare, and certified flight instructor attempts at explaining the issue sometimes lead to more confusion and frustration (Benbassat & Abramson, 2002c).

Second, the practicality of time-to-contact and monocular cues as flight training aids is questionable. The mathematical construct of time-to-contact is not readily transformable into explicit instructions and the use of monocular cues is inconsistent. It appears that pilots use different cues, or a combination of cues, and that no one cue appears to be more important than another (Bond, Bryan, Rigney, & Warren, 1962; Green, 1988; Riordan, 1974; Tiffin & Bromer, 1943; Warren & Owen, 1982).

Third, it appears that the learning of time-to-contact (Hasbrook, 1983) and monocular cues (Rinalducci, Patterson, Forren, & Andes, 1985) depend on experience. Thus, student pilots must resort to trial-and-error learning that increases the likelihood of improper flares and aircraft structural damage. Non-aviators who were taught to land a Cessna 182 simulator provided evidence to this trial-and-error hypothesis (Benbassat & Abramson, 2002a). Results showed that control participants flared high at times and low at other times compared to experimental participants that learned to flare using an altitude discrimination tone.

Some researchers have used the protocol method (Berbaum, Kenndedy, & Hettinger, 1991) or relied on memory to identify the cues that pilots use in timing the landing flare (Benbassat & Abramson, 2002b). Because these methods require verbal skills and conscious retrieval of information, they may be insensitive measures. This study attempted to further explore the role of visual cues by

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minimizing the dependency on verbal skills and conscious retrieval of information.

METHOD

Pilot Perception Questionnaire

Participants

A convenience sample of 92 aviators (male = 83, female = 9, M_{age} = 22.83) in flight training programs was used. Three experience blocks were created to determine the effect of flight time on perception. Aviators with 10-60 hr of total flight time were labeled novice experience pilots (N = 38; total flight time, M = 24.06, SD = 22.57, Mdn = 13.50; M_{age} = 21.26, SD = 3.78). Those with 150-250 hr were labeled intermediate experience pilots (N = 29; M total flight time = 178.58, SD = 38.06; M_{age} = 22.27, SD = 5.08). Finally, aviators with more than 300 hr were labeled expert experience pilots (N = 25; total flight time, M = 919.00, SD = 733.54, Mdn = 645.000; M_{age} = 25.88, SD = 6.78).

Flight training centers were the Oklahoma State University (OSU) Stillwater and Tulsa campuses. The OSU-Tulsa campus also provided ground and flight instruction to Tulsa Community College students through the Aviation Education Alliance. Both flight centers were approved for Federal Aviation Regulation Part 141 (FAA, 2004) flight training and both used Cessna 152 and Cessna 172 as primary trainers.

Materials and Procedure

The questionnaire used in this study was the same one used by Benbassat, Williams, & Abramson (2005). The questionnaire was developed with the assistance of aviators and aviation experts. This paper discusses one item that relates to the visual cues pilots use to time the landing flare.

Participants were presented with a screenshot from a Microsoft Flight Simulator 2000 Professional Edition. The screenshot depicted a cockpit view from a Cessna 182 Skylane on approach for landing at Mojave Airport (KMHV) in California. As shown in Figure 1, the screenshot included an instrument panel view and outside anterior view of final approach to runway 12. Interior and exterior views depicted a normal approach and aircraft configuration. Finally, the screenshot depicted the aircraft at 2918 ft MSL, which is 127 ft AGL.

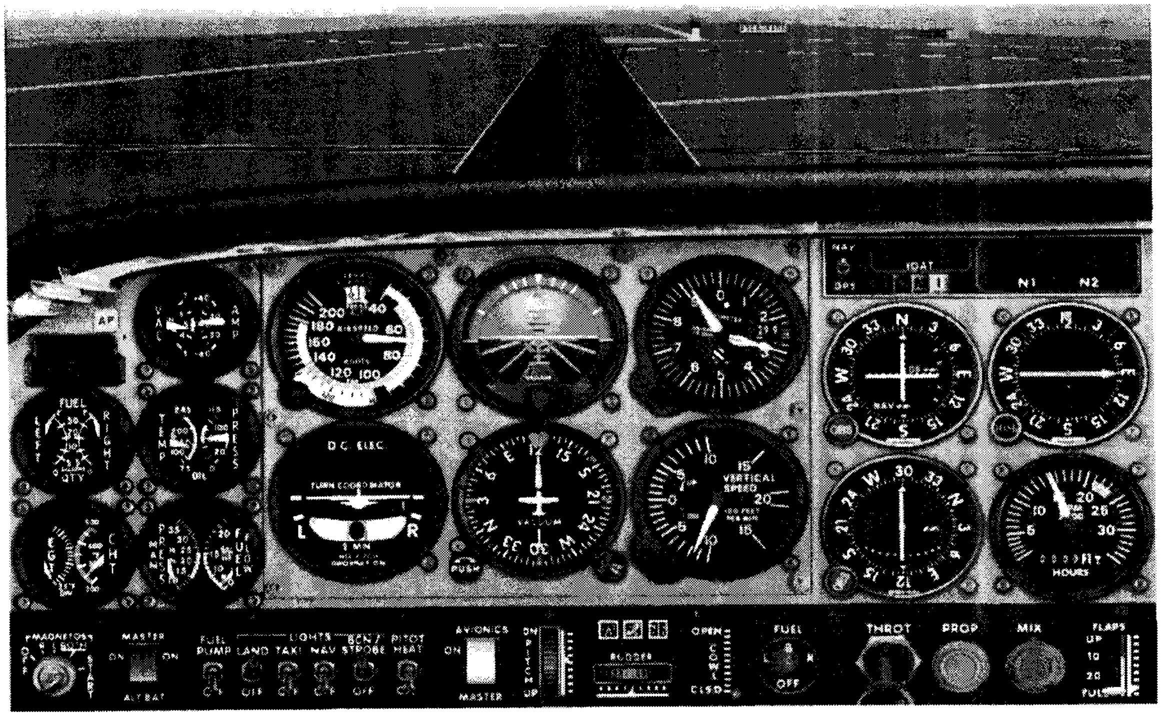

Figure 1. Microsoft Flight Simulator screenshot of a Cessna 182 on final.

Note. Screen shot reprinted by permission from Microsoft Corporation; Figure was reformatted to journal specifications.

Instructed to assume "optimal conditions (i.e., no cross-wind, unlimited visibility) and normal landing procedures (i.e., no obstructions, adequate runway length, hard surface)", participants imagined that they are "on a standard approach for landing in a Cessna 182...cleared to land and have completed the landing checklist. There is no conflicting traffic, and [their] airspeed, pitch, and runway centerline alignment are fine." Participants then used the diagram to circle the objects or areas they used to time the landing flare, both inside and outside the cockpit. They also labeled the circles and ranked them from most important to least important.

The questionnaires were completed in ground and aviation theory classes in the Fall of 2002. Certified flight instructors who did not attend or teach classes were provided with questionnaires individually.

RESULTS

Altitude AGL perception aids

Figure 2 summarizes the aids that pilots used to determine altitude AGL. Overall, 25.88% indicated the shape of the runway or runway markings, 25.88% the altimeter, 17.76% horizon or runway end, 9.64% peripheral vision, 4.56% vertical speed indicator (VSI), 4.06% attitude indicator (AI), 3.55% familiar objects, and 2.57% indicated the turn coordinator. The three most frequent visual aids were the shape of the runway or runway markings, horizon or runway end, and peripheral vision.

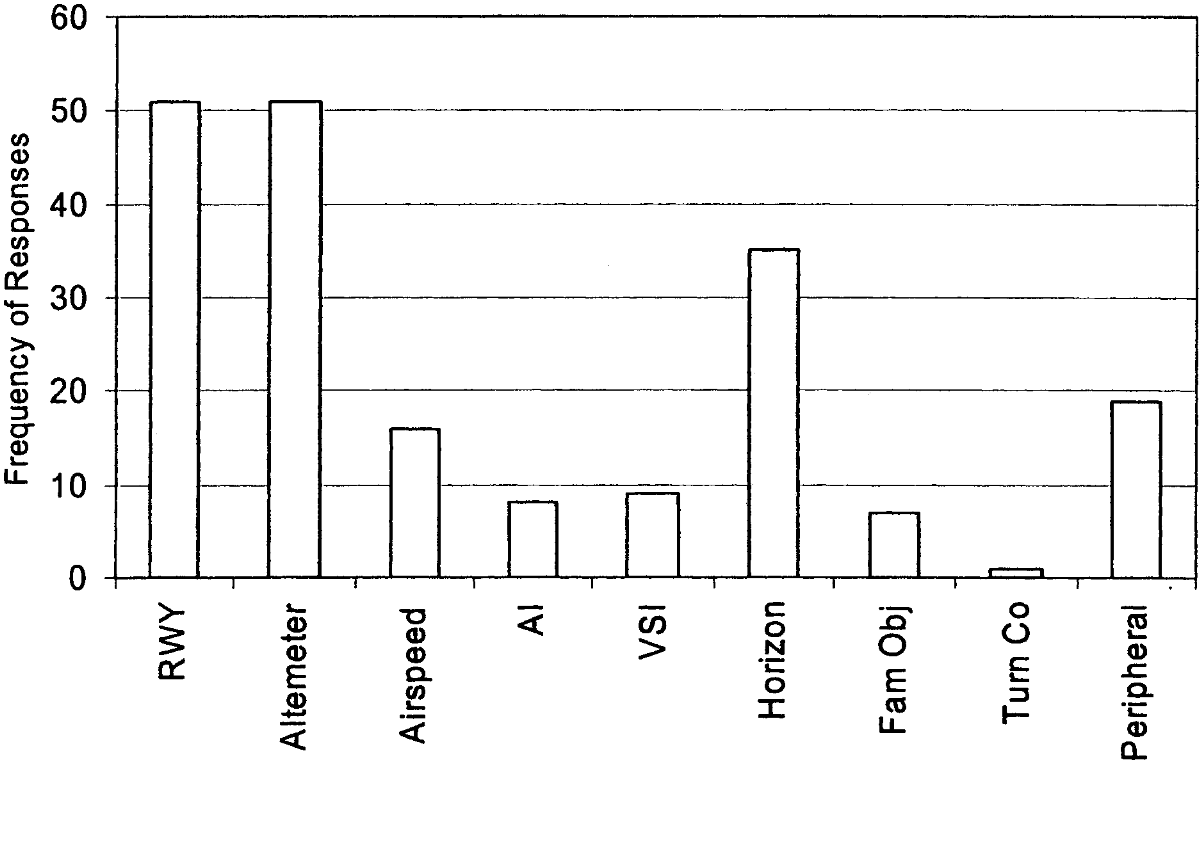

Figure 2. Altitude AGL perception aids prior to landing flare.

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The proportion of altitude AGL perception aids by experience is presented in Figure 3. Whereas expert (34.61%) and intermediate (27.86%) pilots believed the runway or runway marking to be the most important aid, novice pilots chose the altimeter (34.52%). The second most important aid was determined to be the horizon or runway end by expert pilots (25.0%), altimeter by intermediate pilots (24.59%), and runway or runway markings by novice pilots (19.04%). Finally, intermediate (16.39%) and novice pilots (14.28%) chose the horizon or runway end while expert pilots chose peripheral vision (17.30%) as the third most important aid.

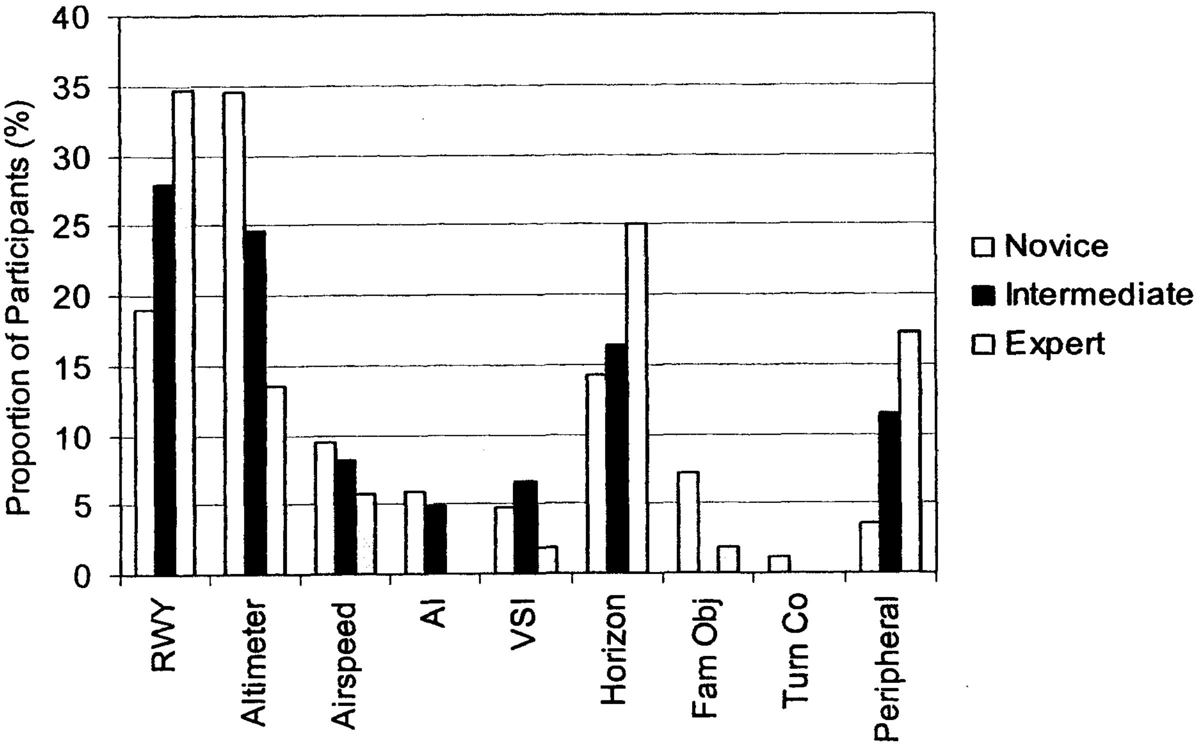

Figure 3. Altitude AGL perception aids by experience.

DISCUSSION

This study supported the equivocal process of determining altitude AGL. Altimeter reading and the runway or runway markings emerged as the most important aids in determining the aircraft altitude AGL. Whereas the runway or runway markings are prominent visual aids when leveling off (Benbassat & Abramson, 2002b; Riordan, 1974), altimeter readings are not reliable. According to the Federal Aviation Administration (2004), indicated altitude may be within 75 ft of true altitude (p. 762). The problem becomes evident when considering that general aviation aircraft flare 10-20 ft AGL. As shown in Figure 3, the altimeter was the first and second preferred altitude AGL aid for novice and intermediate pilots respectively.

Whereas the altimeter is an intuitive altitude AGL perception aid, it is not clear what altitude information is provided by the airspeed indicator, attitude indicator (AI), and vertical speed indicator (VSI). Yet, Figure 2 shows that these instruments were mentioned as altitude AGL perception aids. These findings may be attributed to incoherent questionnaire instructions or participant lack of attention. Nevertheless, as cited in the materials section, participants were explicitly instructed to circle altitude perception aids. It is impossible to eliminate the possibility of lack of attention or carelessness, but such behavior is not expected or characteristic of professional aviators.

A parsimonious alternate to incoherent instructions or lack of attention may be procedural knowledge that is not mediated by conscious awareness. Albeit vision is the most important altitude perception aid on approach and landing, pilots find it difficult to articulate how vision is used to determine altitude AGL (Benbassat & Abramson, 2002b). This study presented pilots with a Microsoft screenshot in the hope that they could identify what they find difficult to articulate. Nevertheless, it is possible that in the desire to satisfy role demand, pilots simply circled all familiar cues, altitude or otherwise. For example, the airspeed indicator is used to control the rate of descent on approach and the VSI may be used to reference the rate of descent. Thus, the inappropriate responses may indicate that pilots were unable to provide appropriate responses.

In reality, aviators learn to associate visual cues with altitude AGL. It is recommended that future studies utilize behavioral techniques to facilitate and haste this association. Such techniques may reduce flight training costs, pilot attrition from flight training programs, improper flares, and maintenance expenditure associated with improper flares.

Danny Benbassat, Ph.D. is the director of the Human Factors Laboratory at Ohio Northern University. His students study broad range of topics such as automotive human factors, aviation human factors, and human-computer interaction. As an aviator, Dr. Benbassat has taken a special interest in the landing flare and has been studying the maneuver since 2002.

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