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Errorless discrimination learning in simulated landing flares

Danny Benbassat and Charles I. Abramson
Department of Psychology
Oklahoma State University, USA

Abstract

Proper landing flares are crucial to smooth and safe landings. Nevertheless, landing flare accident rates are relatively high and past studies have implicated flaws in flare instruction. This study tested the effectiveness, ergonomics, and safety of a novel landing flare discriminative cue. Twenty-six participants with no prior aviation background were trained to land a Cessna 182S simulator. Control participants were provided with traditional landing flare instructions and experimental participants with a discriminative auditory cue. Results indicated that control participants flared significantly higher, registered higher impacts at touchdown, and appeared to initiate the flare in a trial-and-error fashion.

Introduction

The landing flare can be defined as the transition from a controlled descent to actual contact with the runway surface (Federal Aviation Administration, Revised 1999). The approach to landing is analogous to a car racing towards a brick wall. Just as drivers apply brakes in order to avoid an unpleasant impact, pilots flare the aircraft in order to avoid a collision with the runway surface (see Grosz et al.,

Correspondence: Danny Benbassat, Department of Psychology, 215 North Murray, Oklahoma State University, Stillwater, OK 74078, USA or e-mail: dbenbassat@yahoo.com

1995). The purpose of this study was to test the effectiveness, ergonomics, and safety of a novel landing flare discriminative cue.

One of the first problems pilots face is determining when to initiate the flare, that is when to brake the descent rate (Langewiesche, 1972; Love, 1995). In fact, the ability to determine altitude above ground level (AGL) is crucial to a successful landing. The consequences of flaring the aircraft too high AGL may include an imminent stall and a hard landing (Gleim, 1998; Jeppesen, 1985). The consequences of flaring too low are more intuitive and resemble those of stopping a car too late as it races towards a wall. In addition to a hard landing, flaring too late may result in ballooning (Kershner, 1998; King, 1999) or bouncing (Kershner, 1998). Both low and high flares may lead to structural damage (Christy, 1991; Jorgensen and Schley, 1990) and adversely affect pilot confidence and self-efficacy (Flight Training Handbook, as cited in Matson, 1973, p. 5).

Pilots acknowledge that the landing phase of operation is the leading cause of all non-fatal aircraft accidents (Balfour, 1998, Nagel, 1988). In a recent groundbreaking study, Benassat and Abramson (2002a) reported that 18.33% of all landing accidents in 1995, 1996, and 1997 were flare related accidents. Preliminary investigation by the authors into most recently available National Transportation Safety Board (NTSB) accident reports suggest that the trend had not changed in 1998. The ability to determine altitude AGL (above ground level) and initiate the flare or level-off will be discussed next. That ability is crucial to proper flares (Grosz et al., 1995) and may provide clues to the relatively high flare accident rates.

When automobile drivers approach a stationary car at an intersection they apply brakes in order to stop at a reasonable and safe distance. Nevertheless, they may not be able to explain how they determine distance from the stationary car. Likewise, pilots and certified flight instructors (CFIs) are unable to explain how they determine altitude AGL as they approach the runway (Benbassat and Abramson, 2002a; Hasbrook, December, 1979). Experts agree that pilots use various cues such as monocular cues, sinking rate, and time-to-contact (Denker, 1995; Jeppesen, 1985). Whereas it appears that monocular cues are the predominant depth perception cues on approach and landing (Benson, 1999; Reinhardt-Rutland, 1997), experts cannot agree which cues are more important then others. In fact, it appears that pilots use different cues or combination of cues (Berbaum, Kennedy, and Hettinger, 1991; Mulder, Pleijsant, van der Vaart, and van Wieringen, 2000; Riordan, 1974).

Since comments such as: 'just about now begin to flare' increase the frustration of not knowing how to determine altitude AGL, student pilots must learn from experience (Benson, 1999; Thom, 1992). But, experience is the single ingredient that all student pilots lack. In fact, a 5000 hrs total time pilot only has about eight hrs of flare time (King, 1998), and novice, intermediate, and expert pilots all have attested to the difficulty of the flare manoeuvre (Benbassat and Abramson, 2002a). Penglis (1994) echoed pilot sentiments by saying: 'you have no idea where the air ends and the ground begins. The closer you get to the ground, the less you are aware where it begins' (p. 90).

As mentioned, the task of determining altitude AGL is critical to a successful flare, and requires pilots to engage in a process of altitude discrimination. Initially, pilots flare the aircraft at different altitudes AGL, but with time pilots restrict the flare to altitudes that will ensure smooth and safe landings. Behaviorists have successfully demonstrated that organisms respond to cues that signal the presentation of reinforcement and ignore cues not associated with reinforcement (see Houston, 1991). The visual cues that pilots use to determine altitude AGL appear different as the aircraft descends towards the runway and experienced pilots use that information in order to initiate the flare at a safe altitude. With time, the cues that represent appropriate flare altitude AGL become a signal to initiate the flare because they are followed by reinforcement. In the case of landing an aircraft, reinforcements may consist of reduced tension as the flare is initiated, smooth and safe landings, and complimentary evaluation from passengers.

The difficulty aviators encounter during the landing flare is tantamount to that encountered by string players. Accurate intonation is crucial to a successful musical performance and is one of the first difficulty music students face (Salzberg, 1980; Smith, 1995). Like altitude AGL, intonation is arranged on a continuum and pitch discrimination improves with experience (Elliot, 1974). According to Welch (1985), musicians use different cues or combination of 'meaningful' (p.147) cues to determine their intonation. Those external cues provide objective feedback of pitch accuracy and allow the musician to detect intonation deviations. With time, musicians 'internalise' (Welch, 1985, p. 148) the external cues and perform accurately without them. An additional advantage of the external feedback is that it provides accurate intonation information regardless of the musical skills and knowledge of the instructor.

In reference to intonation, studies found that contingent feedback was found to be more effective than verbal feedback alone (Welch, Howard, and Rush, 1989; also see Smith, 1995) or model performance (Salzberg, 1980). It was further found that meaningful cues were more effective than continuous visual information in string players (Salzberg, 1980; Smith, 1985, 1987; for a related study see Liebermann and Goodman, 1991). Unlike musicians that use feedback to determine the discrepancy between the actual and intended pitch, aviation instructions must contend with safety issues. Specifically, aviation flare instructions should incorporate errorless discrimination learning (see Terrace, 1963a, 1963b) in which pilots never respond to inappropriate flare altitudes AGL.

Thus, it is believed that an external discriminative cue will facilitate the task of discriminating altitude AGL as the aircraft descends towards the runway. With such a cue, pilots will consistently initiate the flare at an ideal flare altitude and associate that altitude with appropriate depth perception cues. In addition, an external beacon will provide standardised discriminative information regardless of the knowledge or expertise of the flight instructor. Eventually, it is believed that pilots will be able to initiate the flare at an appropriate altitude without the external cue.

In light of flare accident rates and flaws in traditional flare instruction (Benbassat and Abramson, 2002b) the authors considered an alternative. The present study compared the quality of simulated landings between traditional landing flare instructions and instructions that included a novel discriminative cue.

Method

Participants

Participants were 26 undergraduate students from Oklahoma State University with normal vision (FAR – 67.103, Federal Aviation Administration, 2002) and no prior aviation experience. They were asked to commit to three 60 min block sessions on three consecutive days and were randomly assigned to a control (males = 6, females = 7; mean age = 19.62) or experimental (males = 8, females = 5; mean age = 21.31) condition. Thus, each condition included 13 participants.

According to Federal Aviation Regulations (FAR – 91.17, Federal Aviation Administration, 2002) participants were required to avoid consumption of alcohol at least 8-hrs prior to their simulated flights. Participation was voluntary and anonymous with the exception of demographic information that included gender and age.

Research instrument

Flight simulator Microsoft Flight Simulator 2000 (FS2000) professional edition was a technologically advanced and detailed personal flight simulator program with more than 20,000 airports and 14 aircraft. FS2000 also provided detailed 3D scenery with 16-bit colour based on true elevation data. FS2000 ran on a Pentium 500 (Dell computer OptiPlex GX1P) with a 1024 x 768 resolution for optimal graphics quality and instrument panel readability.

For the purpose of this study, the FS2000 simulated the controls, performance, and cockpit of a Cessna Skylane (Cessna 182S). The Cessna 182S is a high performance general aviation aircraft with a seating capacity of four. The aircraft scenery and instrument controls were projected (Sanyo ProEx multimedia projector, model PLC-8810N; Chatsworth, CA) onto a 2.04 x 1.524 m (6.85 x 5.00 ft) screen, 2.337 m (7.800 ft) away from the participant. A CH Products flight simulator yoke (CH71 USB LE Flight Sim Yoke, FSY208LE; Vista, CA) was used to control the elevators, ailerons, throttle, flaps, elevator trim, and landing gear brakes.

Flare Beacon The approach and touchdown phases overload the visual sensory modality as pilots attend to instrument approach gauges, monitor pattern traffic, check aircrafts or objects on active and incursion runways, and attempt to determine altitude above ground level (AGL). Furthermore, the need to transition from scanning instruments inside the cockpit to visual scanning of the airport environment is especially crucial during the approach and touchdown phases. Thus, an auditory discriminative cue that allows pilots to continually scan the airport environment without adding an additional visual task was used.

Proper landing flares depend on the ability to discriminate altitude AGL. The discriminative cue in this study alerted participants when the aircraft reached an ideal flare altitude. The auditory alert cue was referred to as the flare beacon and consisted of a four-dash tone (FS2000 outer marker sound file 'outermk.wav'). The WAV file was opened with a Microsoft Window Media Player and the playback option was set to loop twice.

In addition to reducing the visual overload and eliminating the need to gaze in a particular direction, auditory signals have faster reaction times associated with them. Indeed, current warning and advisory aircraft signals are auditory (Doll and Folds, 1986; Lyons, Gillingham, Teas, Ercoline and Oakley, 1990; Van Laer, Galanter and Klein, 1960).

Design and procedure

Volunteers with no prior ground or flight time were trained to land in a Microsoft Flight Simulator 2000 (FS2000) Professional Edition located at the Department of Psychology at Oklahoma State University. Participants were randomly assigned to a control or experimental condition. Both groups received identical landing training with the exception of flare instructions. Participants in the control group received traditional flare instructions. The instructions included CFI demonstrations and verbal descriptions of when to initiate the flare in order to ensure a smooth and safe landing. Those in the experimental condition learned to flare with an additional aid in the form of a four-dash beacon (FS2000 outer marker sound file 'outermk.wav'). The beacon was triggered when the aircraft was at a constant altitude of 9.14 m (30 ft) AGL, and participants were instructed to initiate the flare in response to the beacon.

The first session (time = 60 min) consisted of elementary aircraft instrument and performance familiarisation instructions from a certified pilot (the first author). Instructions included introduction to the FS2000 airspeed indicator, attitude indicator, altimeter, turn coordinator, heading indicator, and vertical speed indicator. Following cockpit familiarisation, the flight instructor departed from runway (RWY) 17 in Stillwater Municipal (KSWO) airport in a westerly heading (270°) and climbed to 3000 ft MSL. After levelling off at the assigned altitude, participants were introduced to and performed shallow banks, climbs, descends, and approach to landing stalls. Those manoeuvres were deemed important for the purpose of this study. Session one ended with landing instructions and two simulated landings to RWY 12 (dimension = 2926 x 61m [9600 x 200 ft], elevation = 2790 ft MSL) in Mojave airport (KMHV). The simulated scenario placed the aircraft on a long final approach at 4680 ft MSL and a heading of 122°. The automatic wing leveller was activated in order to keep the participants from over rolling the aircraft and reduce the workload on the participants. Thus, participants were only required to perform one shallow left bank and control the aircraft pitch, flaps, elevator trim, and brakes.

Before starting the FS2000 scenario (Tutorial 7, Situation 3) participants used the game controllers function to ensure the flight controls (CH Flight Sim Yoke LE) were free and correct. After pressing the Test tab, participants moved the yoke to all extremes and confirmed that the '+' followed the movements of the yoke handle. Participants also verified that the throttle lever, as well as, elevator trim, landing brakes, and flaps setting buttons were responsive. Participants then reset the altimeter to 29.92 inches of mercury to ensure standard altitude setting, lowered full flaps, idled the throttle, and set the elevator trim for landing.

Participants started the simulation after completing the 'before starting' simulation checklist. FS2000 Tutorial 7, Situation 3 placed the aircraft on a high (1659.96 ft AGL) 3.551 km (2.206 mi) final approach for RWY 12. The scenario was chosen because the aircraft could clear the runway threshold with full flap settings and idled throttle, thus eliminating the need to manipulate those controls. Landing procedure standardisation was further guaranteed as evident from figure 1.

CESSNA
MODEL 182S

SECTION 4
NORMAL PROCEDURES

LANDING PROCEDURES

BEFORE STARTING SIMULATION

(1) Flight Controls -- **FREE and CORRECT**
(2) Altimeter -- **SET**
(3) Wing Flaps -- **FULL**
(4) Mixture -- **RICH**
(5) Prop -- **HIGH RPM**
(6) Throttle -- **IDLE**
(7) Elevator Trim -- **LANDING**

START SIMULATION

(1) Pitch for **70 KIAS**
(2) Aim for **RWY 4-22**
(3) Bank left at **3500 ft** to align with centerline
(4) Pith **12°** for flare
(5) Apply breaks at touchdown

NOTE: This checklist was customized for use with FS2000 and the aircraft simulator study.

Figure 1 Landing checklist

Pilots were instructed to pitch for 70 KIAS after starting the simulation and maintain that airspeed until the landing flare. Figure 2 shows that participants were instructed to aim for the incursion of RWY 4-22 with RWY 17. Traditionally, the active RWY numbers are the preferred aiming point during a normal landing. However, the incursion of RWY 4-22 was perceived as a notable landmark and was preferred in order to ensure a standardised aiming point.

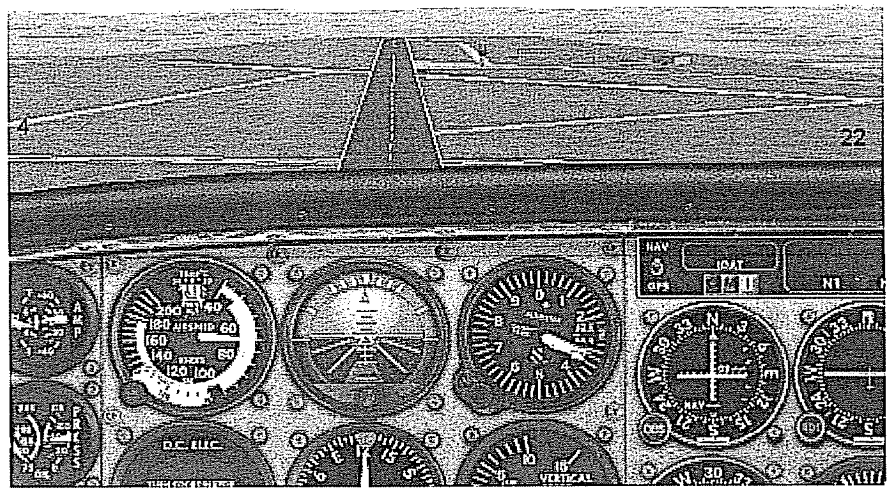

Figure 2 Landing aiming point (RWY 4-22). 4-22 RWY numbers added to figure only **(Screen shot reprinted by permission from Microsoft Corporation)**

As noted, the FS2000 landing scenario placed the aircraft on a high final approach to RWY 12 with an indicated heading of 122°. This configuration necessitated a shallow bank correction in order to maintain RWY centreline alignment. As a consequence, participants were instructed to execute one full left aileron deflection at 3500 ft MSL. The wing leveller prevented an excessive correction and ensured an appropriate shallow turn for RWY alignment.

The standardised approach and descent was maintained until the landing flare. Participants in the control instruction condition were instructed to determine the aircraft altitude and initiate the flare at a safe altitude AGL. The flight instructor advised the participants when flaring too high or too low and demonstrated when appropriate. In fact, each control and experimental session started with the flight instructor at the controls and a demonstration of three landings. The landing flare was also compared to braking an automobile before impacting a wall in order to help participants determine altitude AGL. Finally, the inability of the altimeter to accurately gauge low altitudes AGL was disclosed and participants were advised not to fixate their gaze during the approach and touchdown.

In addition to CFI demonstrations and verbal instructions, participants in the experimental condition were instructed to flare the aircraft with the presentation of the flare beacon at 2820 ft MSL. As shown in table 1, the ideal landing flare altitude (2820 ft MSL; 30 ft AGL) was determined from the analysis of 180 landings from 6 altitude categories AGL (10 ft, 20 ft, 30 ft, 40 ft, 50 ft, 60 ft) and the results are presented in figure 3.

Table 1 Landing Flare Measures

	Alt AGL (ft) (ELEV=2790 ft MSL)					
	10	**20**	**30**	**40**	**50**	**60**
VStd (ft/min)						
Mean	-680.27	-518.57	-275.47	-334.97	-351.87	-469.20
Median	-717.50	-568.00	-273.00	-344.50	-365.00	-478.00
STEV	200.17	146.54	46.68	70.36	79.81	58.15
Dist (km)						
Mean	.376	.369	.329	.307	.353	.331
Median	.372	.376	.333	.314	.345	.336
STEV	.056	.029	.039	.025	.046	.032
Actual Flare Alt (ft MSL)						
Mean	2795.73	2804.38	2813.21	2823.35	2833.53	2843.2
Median	2795.70	2804.34	2813.50	2823.31	2833.15	2843.1
STEV	1.968	3.083	2.174	3.232	2.828	2.775
Vtd (kts)						
Mean	49.17	51.97	53.03	50.80	52.80	51.233
Median	49.00	52	53	51.00	53.00	52.00
STEV	3.074	.808	1.033	1.989	1.030	1.633
Remarks	Bounce[1,2]	Bounce[3]				

Note:
n =30
VStd = Vertical speed at touch down
dist = Distance from aiming point
Alt = Altitude
Vtd = Velocity at touch down

1 Initial touchdown point M = 0.0836 km before aiming point (landings 1, 4, 5, 10, 19, 28, 29)
2 Crash (landings 22, 25)
3 Initial touchdown point M = 0.0317 km before aiming point (landings 18, 23, 24, 29)

Participants were instructed to maintain a flare attitude of 12° until touchdown in order to ensure standardised operations. Instructing participants to apply full brakes immediately after touchdown completed the touchdown phase. The standardised landing procedures were practiced in session two (landings, n=10; time = 50 min) until participants were able to land the aircraft without the assistance of the flight instructor. During the last session (time = 45 min), participants performed three dual landings and five solo landings without the aid of the instructor or the beacon (for the experimental group).

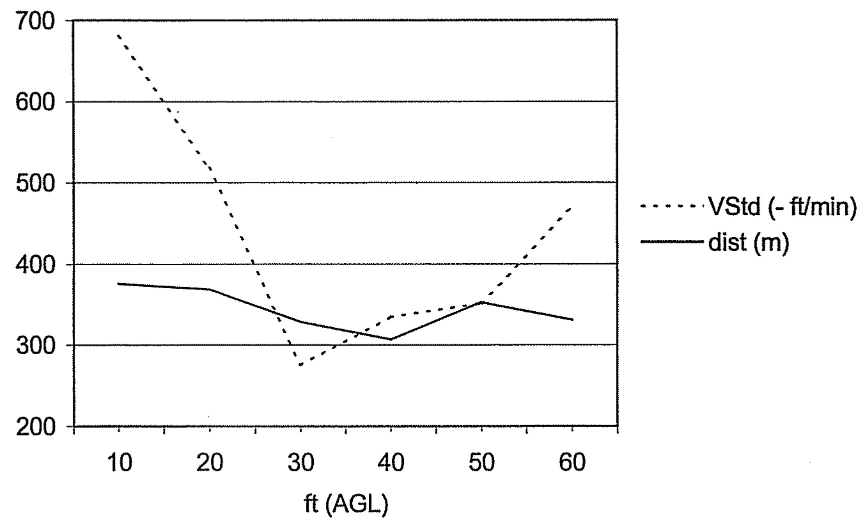

Figure 3 Vertical speed at touchdown (VStd) and distance (dist) from aiming point

Participants were cleared to solo after three consecutive landings that included proper pitch for aiming point, RWY centreline alignment, pitch configuration during the flare, and proper brake application. Landing analysis measures that consisted of flare altitude, vertical speed at touchdown (VStd), distance from aiming point (dist), and velocity at touchdown (Vtd) were collected during the five solo landings. Whereas the participants directly manipulated flare altitude, VStd, Vtd, and dist were byproduct measures of flare altitude.

Before each solo flight the flight instructor selected the MS2000 Landing Analysis and Flight Video features from his vantage point 2.438 m (8 ft) posterior to the participant. While vertical velocity at touchdown (VStd) data were obtained from the landing analysis feature, actual flare altitude, distance from aiming point (dist) and velocity at touchdown (Vtd) were obtained from the flight video analysis.

Design

As table 2 shows, most flight simulator measures were moderately correlated. Therefore, the four measures were regarded as related measures of the 'quality of landing' construct. Hence, multivariate analysis was used to determine effects of training method on quality of landing and univariate analyses of means were conducted to determine effects of training method on each flight measure.

Table 2 Correlation matrix for flight simulator measures

		VStd	Flare ALT	Vtd
Flare ALT	Pearson Correlation	-.727**		
	Sig. (2-tailed)	.000		
	N	26		
	r^2	.530		
Vtd	Pearson Correlation	-.622**	-.496**	
	Sig. (2-tailed)	.001	.010	
	N	26	26	
	r^2	.390	.250	
Dist	Pearson Correlation	-.395*	.224	-.301
	Sig. (2-tailed)	.046	.272	.135
	N	26	26	26
	r^2	.160	.050	.090

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The first set of hypotheses tested for significant differences in dispersion of flare altitudes between the control and experimental groups. The notion that pilots determine altitude AGL in a trial-and-error fashion supported the expectation for larger flare altitude variability in the control condition.

The second set of hypotheses related to differences in mean performance. Private-pilot students traditionally perform three consecutive solo landings and CFIs determine quality of landing based on the 'average' of the three. Furthermore, solo landings are not considered practice landings and pilots are only allowed to solo after performing consistently good landings. Hence, variability in quality of landing among individual solo flights was expected to be small and averaging the performance of solo flights was deemed sensible. An analysis of flare altitude standard deviation (STDEV) for solo flights per participant supported the notion that the performance of each participant was stable across solo flights.

Performance was compared for each measure and flare altitude was of primary importance. The notion that pilots traditionally tend to execute high flares supported the expectation for higher flares in the control condition. Results are presented next in International Civil Aviation Organisation (ICAO) standard units.

Results

Analysis of Variance

Levene's test for homogeneity of variance was performed and led to rejection of the null hypothesis regarding flare altitude variability between the control and experimental groups, $F(24) = 14.298$, $p = .001$. As figure 4 illustrates the flare altitude STDEV for the control condition (SD = 11.8460 ft) was significantly higher than that of the experimental condition (SD = 4.6702 ft). The tendency of control participants to determine altitude AGL in a trial-and-error fashion becomes apparent when considering figure 5.

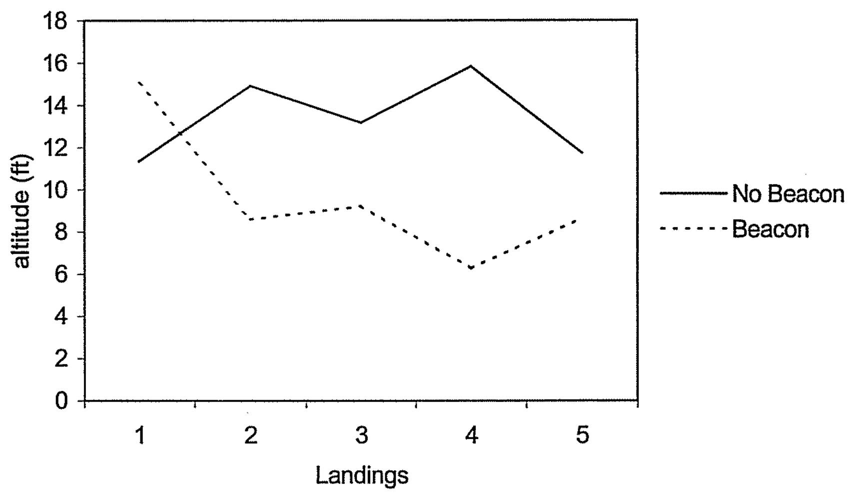

Figure 4 Control and experimental flare altitude STDEV across five solo landings

Further Levene's tests for homogeneity of variance revealed no significant differences between the control and experimental conditions for VStd, $F(24) = 2.002$, $p =.170$; Vtd, $F(24) = 1.112$, $p = .302$; and dist, $F(24) = 1.459$, $p = .239$.

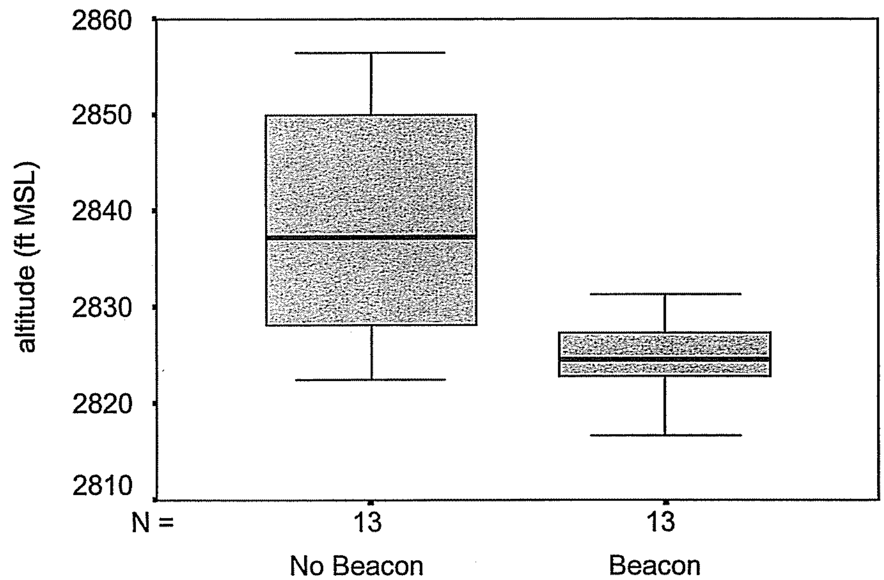

Figure 5 Control and experimental boxplot

Analysis of means

A multivariate analysis of variance was performed to determine the effect of training method (control, experimental) on quality of landing as measured by flare altitude, vertical velocity at touchdown (VStd), distance from aiming point (dist), and velocity at touchdown (Vtd). Results indicated that there was a significant effect of training method on quality of landing, F = 7.2446, p = .001 (eta^2=.580, power=.983).

Following the significant multivariate test, univariate analyses were conducted to determine the effect of training method on each landing measure. The Bonferroni procedure produced a modified alpha level of .0125 in order to safeguard against Type I error across the univariate tests.

Effect of training method on flare altitude (ft MSL) with significant variance estimates were significant, F(1,15.642) = 14.594, p = .001 (eta^2 = .378, power = .956). Figure 6 shows that participants in the control condition (M = 2838.5529 ft MSL) flared higher than participants in the experimental condition (M = 2825.0615 ft MSL) by 3.08 to 23.90 ft. Similarly, effects of training methods on VStd (ft/min) were significant, F(1,24) = 27.144, p = .0001 (eta^2 = .531, power = .999). Impact at touchdown was greater for the control condition (M = -448.3077 ft/min) than the experimental condition (M = -286.9846 ft/min) by –247.93 to –74.72 ft/min.

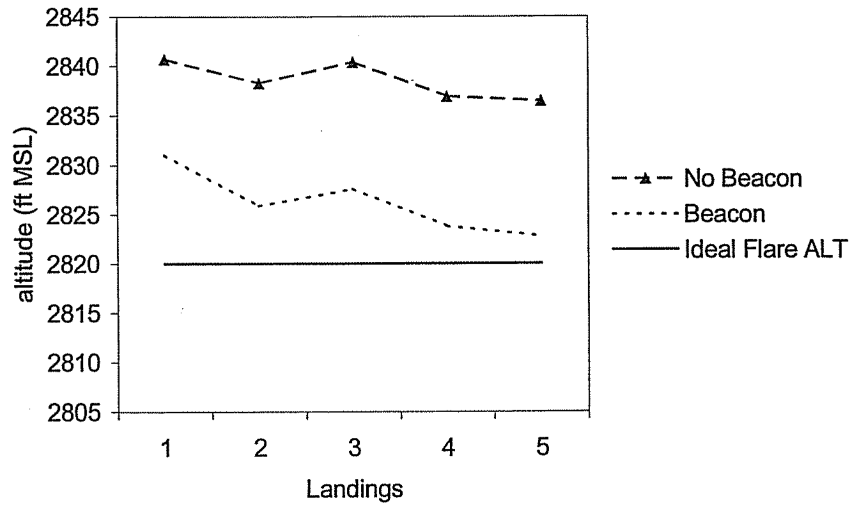

Figure 6 Control and experimental mean flare altitude across five solo landings

There was no effect of training method on Vtd (kts), F(1,24) = 4.429, p = .046 among the control (M = -48.8000 kts) and experimental (M = 50.4461 kts) conditions, or dist (km), F(1,24) = .360, p > .05 among control (M = .3052 km) and experimental (M = .2997 km) conditions. Finally, training method had no effect on time-to-solo (number of landings) among control (M = 10.2308) and experimental (M = 9.3077) participants, t (24) = 1.368, p > .05.

Discussion

Summary

By standardising all manoeuvres and procedures this study isolated the approach and touchdown phases from the flare manoeuvre. Moreover, this study isolated two phases within the landing flare manoeuvre itself. Specifically, the ability to determine altitude AGL and level off the aircraft was isolated from the round-out in which pilots increase the angle of attack in order to allow the aircraft to settle on its main landing gear. Thus, the ability to determine altitude AGL and level off the aircraft in order to initiate the flare was studied.

Flight simulator measures were gathered from control (no beacon) and experimental (beacon) solo flights and analysed for quality of landing. The first analysis regarded significant differences in mean flare altitude between the control and experimental groups. Findings suggested that experimental flares (M = 2825.06 ft MSL) were initiated in proximal distance to the ideal flare altitude (2820 ft MSL). On the other hand, control participants initiated their flare significantly higher then the ideal flare altitude (M = 2838.55 ft MSL). As a consequence, the impact that control aircraft sustained (M = -448.31 ft/min) during landings were significantly higher then those sustained (M = -286.98 ft/min) by experimental aircraft.

The second analysis regarded significant differences in the dispersion of flare altitude around group means between the control and experimental conditions. This analysis directly hinted at a flaw in current flare instructions. As mentioned, proper flares depend on experience and certified flight instructor (CFI) instructions. Nevertheless, despite commitment and ambition, student pilots lack experience and CFIs cannot explain how to determine altitude above ground level (AGL). Hence, it is likely that student pilots learn to flare in a trial-and-error fashion.

Learning by trial-and-error would imply that pilots flare high at times and low at other. Hence, subsequent landing flares are improved through a trial-and-error fashion. Needless to say, learning to flare through trial-and-error increases the likelihood of flare accidents or aircraft structural damage, require more flare practice time, which increases training costs, and may add to pilot frustration and feelings of low self-efficacy.

Findings from this study supported the notion that student pilots learn to determine altitude AGL in a trial-and-error fashion. Results indicated that the dispersion of flare altitudes around the mean for the control group was significantly higher (11.85 ft) than the dispersion of flare altitudes for the experimental group (4.67 ft). Hence, the ability of experimental participants to initiate flares at consistent altitudes may be a reflection of their ability and confidence in determining altitude AGL.

Conclusions and recommendations

This study addressed limitations in the ability to determine altitude AGL and flaws in traditional flare instructions by testing the effectiveness of a novel discriminative cue. The effectiveness and distinct advantages that resulted from the use of the discriminative cue are discussed next.

First and foremost, the discriminative cue was effective in teaching participants how to determine altitude AGL. Recall that experimental participants soloed the aircraft without the aid of the flare beacon, yet flared the aircraft at proper altitudes AGL. Like musical intonation studies, it was found that CFI verbal feedback and demonstrations alone were inadequate in teaching participants to determine altitude AGL. It was also noted that meaningful cues were more effective than continuous visual information in aiding musicians to produce proper intonation.

Thus, the ability to determine the distance on the fingerboard, place the fingers, and produce proper intonation depended on discriminative cues. Likewise, meaningful cues (i.e. monocular) were more effective than continuous visual information (i.e. binocular; see Benbassat and Abramson, 2002b) in aiding participants to flare at proper altitude AGL. Training participants to 'encode' relevant visual cues as signalling appropriate flare altitude AGL was found to aid participants in determining altitude AGL and initiate proper flares in a consistent manner.

The programmatic learning of appropriate discriminative cues resulted in the initiation of proper flares AGL and a significant impact reduction at touchdown. Potential in-vivo consequences extend far beyond the laboratory study. The discriminative cue proved to be a thrifty mode of instruction in terms of both time and money. Note that experimental participants learned to execute significantly better flares after only 15 simulated landings. Thus, such a device would reduce training costs.

Furthermore, the consequences of proper flares may directly alter landing flare accident statistics. Reducing flare accident rates will increase general aviation safety and decrease maintenance costs by reducing improper flare structural damage and wear-and-tear on the aircraft. Finally, moving one step closer to smooth and safe landing will increase pilot confidence and self-efficacy.

The inherent characteristics of an automated discriminative cue provide further benefits to general aviation flare instructions. Teaching to determine altitude AGL with an automated discriminative cue or flare beacon ensures consistent and objective instructions. Thus, the pilot is advised when to flare the aircraft on each and every landing at an exact altitude AGL. In addition to providing standardised instructions, the discriminative cue alleviates CFI burden during the landing. Certified flight instructors are not required to explain what they themselves do not know and granted the leisure to concentrate on safety during the landing.

Finally, recall that the discriminative cue signals the presence of appropriate altitude cues. Hence, the flare beacon represents an individualised training approach that permits pilots to incorporate various appropriate altitude cues or combination of cues. As discussed earlier, pilots determine altitude AGL through the use of cues such as monocular cues, sinking rate, and time-to-contact. Whereas experts agree that monocular cues are of utmost importance, it is unclear which monocular cues are most important and it appears that pilots use different cues or combination of cues.

Imagine a flight instructor that routinely advises her student pilot to flare at the height of the local hangar. Now imagine the student pilot on his first solo cross-country flight to an airport without hangars (Denker, 1995). The discriminative cue is a powerful conditioning tool because all relevant appropriate altitude cues (monocular and other) are associated with an ideal altitude above ground level (AGL). Thus, through individualised instruction, the ability to determine altitude AGL generalises to different airport environments and terrains.

The discussion now turns to possible limitations and criticisms. Participants in this study were trained to land a Cessna 182S Skylane and advised when to flare based on that particular aircraft weight and balance. The argument that flare altitude changes as a function of aircraft weight challenges the effectiveness of the flare beacon method. Nevertheless, student pilots that train for the private pilot certificate typically spend 40 - 60 hours in a light general aviation aircraft such as a Cessna 152 Aerobat or a Piper PA-28 Cherokee.

Thus, transitioning from a Cessna 152 to a Piper PA-28 would not significantly hinder the ability to determine altitude AGL (Jeppesen, 1985). However, transitioning from a Cessna 152 to a twin Beech 76 Dutchess would. Learning to flare higher as aircraft weight and subsequent speed increases requires experience. Nevertheless, pilots previously trained with a discriminative cue will have a flare altitude reference point that would allow them to appreciate what it means to flare higher. As a consequence, the ability to discriminate altitude and flare higher should be facilitated by previous training with the flare beacon. Finally, the flare beacon may also be used as an instruction modality on heavier aircraft.

As mentioned, Microsoft Flight Simulator professional edition (FS2000) was an advanced flight simulator with detailed 3-D scenery. Nevertheless, it was not an approved Personal Computer Training Device (PCATD) by the Federal Aviation Administration (FAA) Flight Standards Service (AFS – 800 as of April 6, 2001). In addition, the limited field of view, lack of kinaesthetic information such as sinking rate and ground effect, and reliance on the FS2000 landing analysis feature could limit potential findings.

In spite of suggested limitations, FS2000 feedback for improper landings was provided in the form of visual-audio effects that produced a 'sensation' of a hard landing, bouncing, or porpoising. Moreover, it has been suggested that that kinaesthetic sensation is of limited use to novice pilots (Jeppesen, 1985). Thus, findings support future studies with more advanced Flight Training Devices (FTDs) and in-vivo studies with training aircrafts.

In conclusion, this study tested the effectiveness, ergonomics, and safety of the flare beacon as an instruction modality. The benefits of the flare beacon in determining altitude AGL that were discussed earlier were supported by two case studies. Recall that simulator flight measures were collected while participants performed five solo landings. With the exception of two experimental participants, each participant flared at approximately the same altitude AGL on each landing.

Nevertheless, the behaviour of two experimental participants hinted at the compelling advantages of the flare beacon. The most dramatic case was that of T7 which flared too high on the first solo landing. Immediately following the high flare T7 uttered: 'felt like I flared high.' There are many reasons why T7 flared high on the first landing, but more importantly was the fact that T7 was able to recognise the high flare. In fact, T7 verbalised that recognition immediately after flaring even though T7 was the only occupant in the mock cockpit. Furthermore, T7 not only recognised the high flare, but dramatically improved the subsequent flare on the second landing from 2837.91 ft to 2823.14 ft MSL (ideal flare altitude: 2820 ft MSL).

In reference to ergonomics and safety, recall that participants were presented with an auditory tone so that it would not interfere with the demanding visual tasks present on approach and touchdown. An auditory modality was also chosen in order to differentiate it from the visual task of identifying monocular cues (for similar modality concurrent tasks see Logie, Gilhooly, and Wynn, 1994). Pilots were not only able to hear and react to the tone, but were not distracted or alarmed by the tone. Thus, taken as a whole, findings from this study support future studies with a discriminative cue in-vivo. Accurate and inexpensive vertical altitude measures are currently available and can easily be adapted to a training aircraft without a significant impact to the aircraft weight-and-balance.

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