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Landing Flare Accident Reports and Pilot Perception Analysis

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This study examined flare accident rates and probable causes for improper flares. Measures included the analysis of 6,676 aircraft accident reports published by the National Transportation Safety Board and a 21-item perception questionnaire administered to 134 pilots with varying experience levels. The results revealed relatively high flare accident rates and showed that pilots believed the flare to be more difficult than 9 other standard flight maneuvers. The results also showed that pilots reported experience and instruction as the most important factors for proper flares. This study indicates that those factors are also probable causes for improper flares and discusses how they relate to depth perception.

One of the first obstacles that student pilots have to face is landing an aircraft. Perfect landings are the ambition of every pilot and landings are frequently used to evaluate pilot performance (Collins, 1981; King, 1998). Failure to properly land the aircraft increases the time to solo and may discourage students from pursuing the private pilot certificate. Yet, it is specifically the landing phase that most pilots struggle with (Balfour, 1988; Matson, 1973; Nagel, 1988). Figure 1 shows the breakdown of mean total and fatal accident-involved aircraft by first phase of operation for the years 1995, 1996, and 1997 (National Transportation Safety Board [NTSB], 1998, 1999, 2000) and establishes the landing phase as the leading cause of all nonfatal aircraft accidents.

A special maneuver within the landing phase of operation is the flare. The *flare* is the transition from a controlled descent to actual contact with the landing sur-

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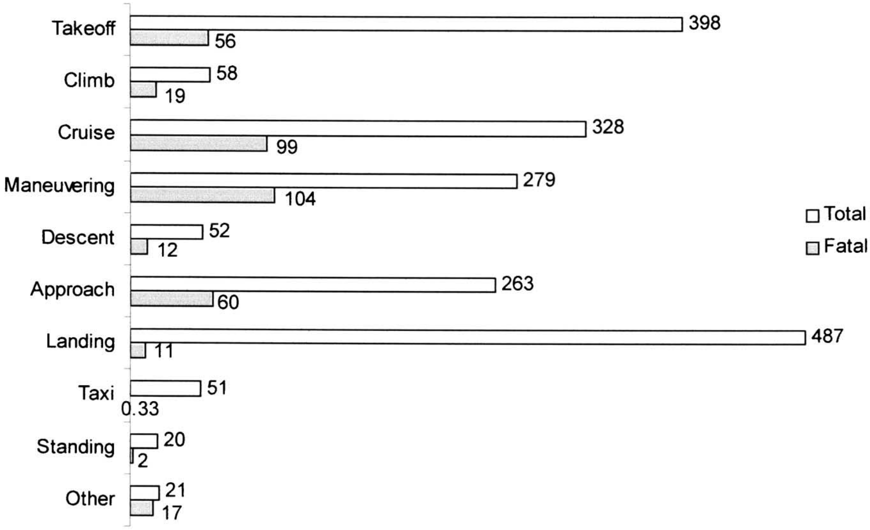

FIGURE 1 A breakdown of mean total and fatal accident-involved aircraft by first phase of operation, 1995, 1996, and 1997 (adapted from National Transportation Safety Board, 1998, 1999, 2000).

face (Federal Aviation Administration [FAA], 1999; Grosz et al., 1995) and is also known as the flareout, roundout, or leveloff (Jeppesen, 1985). The task of determining the aircraft altitude above ground is crucial to a successful flare (Green, Muir, James, Gradwell, & Green, 1996) and is accomplished by the use of vision more than any other sense (FAA, 1999; Jeppesen, 1985; Menon, 1996; Nagel, 1988; Thom, 1992). Specifically, pilots rely on monocular depth perception cues rather than binocular depth perception cues (Benson, 1999; Bond, Bryan, Rigney, & Warren, 1962; Langewiesche, 1972; Nagel, 1988).

Because binocular depth perception is innate or acquired very early in life (Fox, Aslin, Shea, & Dumais, 1980; Kalat, 1998; Reading, 1983; Reinecke & Simons, 1974) and monocular depth perception is learned or dependent on experience (Benson, 1999; Bramson, 1982; Langewiesche, 1972; Love, 1995; Marieb, 1995; Tredici, 1996), the difference between binocular and monocular cues is similar to the difference between nature versus nurture and is fundamental to flare-training methods (for functional differences between binocular and monocular cues see Güntürkün, Miceli, & Watanabe, 1993; Green, 1988; Reinhart, 1982, 1996; Reinhart & Rutland, 1997).

Failure to accurately determine aircraft altitude may result in flaring the aircraft too high (Gleim, 1998; King, 1999; Quinlan, 1999) or too low above the runway (Christy, 1991; Kershner, 1981; Love, 1995). Such flares may lead to a stall and a hard landing (FAA, 1999), bouncing (FAA, 1999; Kershner, 1998), or wheelbarrow landings (Butcher, 1996; Love, 1995) that contribute to increased payloads on the main landing gear tires and struts at impact. Improper flares also increase brake, nosewheel tire, and nosewheel shimmy dampener wear (on Cessnas; Christy, 1991; Jorgensen & Schley, 1990).

The psychological consequences of improper flares are subtler. Because pilots strive for perfect landings, improper flares may affect pilot self-esteem and self-efficacy. For student pilots, improper flares may directly contribute to an increase in time to solo, training costs, and dropout rates. In reference to the landing phase of operations, the *Flight Training Handbook* (as cited in Matson, 1973) determined that "if the student shows no progress at first, he may become discouraged and a severe mental handicap may develop" (p. 5).

The purpose of this study was to determine general aviation flare accident rates and to study probable causes for improper flares. For this purpose the *flare maneuver* was defined as the ability to determine 10 to 20 ft from the ground and initiate the leveloff.

STUDY 1: NTSB ACCIDENT REPORTS

Accident reports produced by the NTSB were analyzed to determine flare accident rates. The NTSB is an independent federal agency that investigates every civil aviation accident in the United States. The accident database compiled by the NTSB is open to the public and contains information about civil aviation accidents within the United States, its territories and possessions, and in international waters. In this study, only final descriptions of accident reports and probable causes were used. Because the lag time between preliminary and final reports is approximately 3 years, this study analyzed accident reports from 1995 (NTSB, 1998), 1996 (NTSB, 1999), and 1997 (NTSB, 2000). Each narrative was read and analyzed. An accident report was labeled as a flare accident if the NTSB determined the probable cause to be a flare accident or if there were definitive clues within the narrative that implicated a flare accident. Overall, 6,676 accident reports were analyzed.

STUDY 2: PILOT PERCEPTION QUESTIONNAIRE

Method

In addition to the analysis of NTSB reports, this study assessed pilot perceptions of the flare as a function of experience. Three groups of pilots (novice, intermediate, and expert) were surveyed with purposive sampling.

Participants

Participants were 134 pilots (novice = 55, intermediate = 45, expert = 34) from three Part 141-approved flight schools in the state of Oklahoma. The novice group included student pilots ($n = 55$; M age = 20.45, $SD = 3.31$; M total flight time = 27.68 hr, $SD = 16.26$) who were training for the private pilot certificate. Student pilot total time exceeded 10 hr but did not exceed 60 hr at the time of the study. The intermediate experience group included instrument student pilots ($n = 45$; M age = 22.27, $SD = 4.46$; M total flight time = 183.02 hr, $SD = 39.49$) who were training for the instrument-rating certificate. Instrument pilot total time exceeded 150 hr but was not more than 200 hr at the time of the study. Finally, the expert group consisted of certified flight instructors (CFIs) who were actively involved in student training ($n = 34$; M age = 25.85, $SD = 5.21$; M total flight time = 785.53 hr, $SD = 750.59$). The total pilot time for CFIs exceeded 300 hr at the time of the study.

The three flight schools were the Department of Aviation and Space at Oklahoma State University located in Stillwater, Oklahoma, the Spartan School of Aeronautics located in Tulsa, Oklahoma, and the Department of Aviation at the University of Oklahoma located in Norman.

Oklahoma State University is a large (approximately 19,553 students; *Summary of Enrollment Spring 2000,* 2000) comprehensive research university. Students participating in the bachelor degree in aviation sciences with specialization in the professional pilot program were recruited. The Department of Aviation and Space program operates from Stillwater Municipal Airport. Spartan is a private aeronautical college that offers diploma and associate degree programs. Students participating in the professional pilot diploma program and the professional pilot degree program were recruited. The Spartan School of Aeronautics operates from Richard Lloyd Jones Airport in Tulsa. Finally, the University of Oklahoma is a large (approximately 23,153 students; *Norman Campus Enrollment Summary,* 2000) comprehensive research university. Students specializing in the professional pilot or aviation management program that leads to an undergraduate degree in aviation were recruited. The Department of Aviation operates from Max Westheimer Airpark in Norman.

Materials

Pilot perceptions were assessed with a 21-item questionnaire. The questionnaire was developed with the assistance of novice, intermediate, and expert pilots. Experts in the field of aviation and psychology were asked to rate the items for content validity on a scale ranging from 1 (*low content validity*) to 10 (*high content validity*), and only items with a mean rating of 8 or higher were included in the questionnaire.

To conceal the true nature of the study, pilots were asked to rate the flare maneuver and nine other randomly selected standard flight maneuvers for the level of difficulty on a scale ranging from 1 (*extremely easy*) to 7 (*extremely difficult*) under optimal conditions (i.e., no wind, 10 miles visibility). After rating the 10 items, pilots turned the page and learned that the study was specific to the landing flare.

In Item 11, pilots were provided with the number of total annual U.S. landing accidents and were asked to estimate the number of annual flare accident frequencies. The total number of annual landing accidents was 487 and was composed from the mean number of landing accidents for 1995, 1996, and 1997. Pilot estimates of landing flare accident frequencies were compared with accident statistics derived from this study and provided an index to the perceived significance of the flare maneuver. Pilots were asked to indicate how confident they were in their estimates of annual flare accident frequencies on a scale ranging from 1 (*low confident*) to 7 (*high confidence*) in Item 12.

After rating their level of confidence, pilots turned the page and learned that the next items were not only specific to the landing flare but also to their ability to determine when to initiate the flare, that is, estimate 10 to 20 ft from the ground. Pilots imagined that they were transitioning from descent attitude to flare attitude in Item 13 and indicated how confident they were that their aircraft was 10 to 20 ft from the ground on a scale ranging from 1 (*low confidence*) to 7 (*high confidence*). In Item 14, pilots recalled their first solo flare attempts and rated factors that assisted them in determining the aircraft altitude before initiating the flare (CFI instruction, instrument readings, practice, pilot manual, ground-school training, other) on a 7-point-scale ranging from 1 (*not at all*) to 7 (*to great extent*). After a reminder that pilots flare the aircraft 10 to 20 ft from the ground, Item 15 ascertained how pilots rated the task of judging altitude when initiating the flare on a scale ranging from 1 (*very easy*) to 7 (*very difficult*). In Item 16, pilots imagined that they were on approach for landing and were asked to choose how they determine when to initiate the flare, that is, how did they know they were 10 to 20 ft from the ground (instrument readings, gut reaction, I don't, sense of sight, sense of balance, other). Pilots were asked to indicate if there was a need for improved flare-training methods in Item 17, on a scale ranging from 1 (*definitely yes*) to 7 (*definitely no*) and to what factors (pattern practice, natural ability, sheer luck, aviation books, my instructor, other) did they attribute their current successful landing flares in Item 18, on a scale ranging from 1 (*not at all*) to 7 (*to great extent*).

Whereas the preceding items were forced choice (Likert scale or multiple choice), the remaining three were open-ended. To gather comprehensive data, Items 19 and 20 reiterated Items 16 and 18, respectively, and required pilots to elaborate and explain their responses. Pilots were instructed to think carefully before they answered and be as specific as possible. Finally, in Item 21 pilots were asked to indicate what type of visual information assisted them in determining when to initiate the flare.

Design and Procedure

Pilots were approached in their respective flight centers or ground schools and asked to complete the questionnaires at their own pace.

Statistical Analysis

To control for training location, three separate sets of exploratory tests were conducted for each item. One set examined the effects of training location on novice pilot perceptions, another set examined the effects of training location on intermediate pilot perceptions, and the last set examined the effects of training location on expert pilot perceptions. Effects of training location were not anticipated because all training locations followed standardized Part 141 Federal Aviation Regulations, thus controlling for quality of training.

Next, depending on the results of the exploratory test, each item was analyzed for effects of experience (novice, intermediate, and expert) on pilot perceptions. One-factor analysis of variance (ANOVA) was used to test the effects of experience on perceptions for items that did not show a significant main effect of training location. Conversely, treatment by block design was used to test effects of experience on perceptions for items that did show a significant main effect of training location. All assumptions underlying the use of a one-factor linear ANOVA model (independence, normality, and homogeneity of variance) were verified. Tukey honestly significant difference tests were used to explore significant main effects. All comparisons were conducted at the .05 level of significance.

RESULTS

Study 1: NTSB Accident Reports

Overall, 6,676 accident reports produced by the NTSB were analyzed for flare accident rates. Because flare accident rates are subsumed within the landing category, results presented in this section are unique to this study. It was discovered that the NTSB investigated an average of 7.44 ($SD = 3.91$) flare accidents per month across the years 1995 ($M = 6.50$, $SD = 3.32$), 1996 ($M = 9.08$, $SD = 4.48$), and 1997 ($M = 6.75$, $SD = 3.62$). Given outliers, it would be prudent to consider that the mode and median of flare accidents across the 3 years was eight. There was no significant difference in mean flare accidents among the 3 years, $F(2, 33) = 1.654$, $p > .05$.

Figure 2 shows that the rates of flare accidents increased during the warmer months, but this trend can be found across phases of operation. The reason may be simply because more aircraft are flown during the warmer months the probability of accidents increase.

Flare accident rates by aircraft type are presented next. Overall, during the years 1995, 1996, and 1997, 83.96% of all aircraft involved in flare accidents were single-engine aircraft. Helicopter flare accident rates constituted 7.09% of all flare accidents, multiengine 5.97%, jet engine 1.49%, glider 1.12%, and

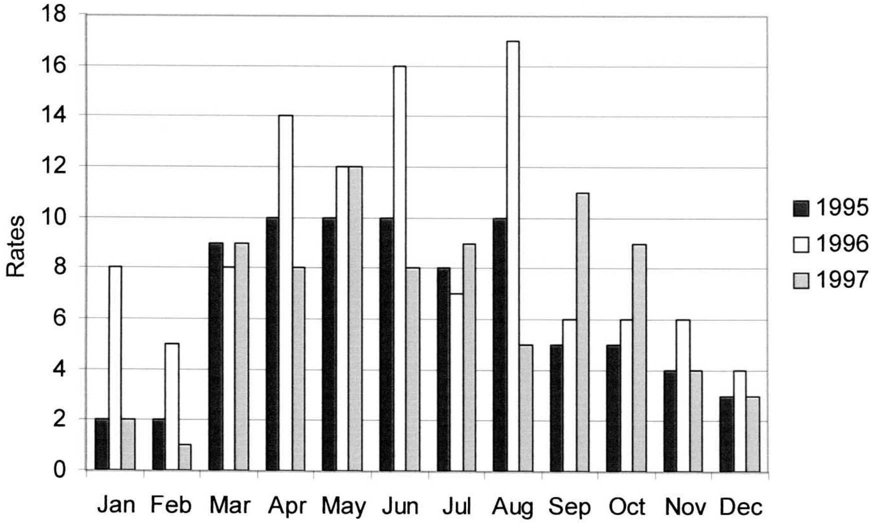

FIGURE 2 Flare accident rates by month and year.

gyroplane 0.37%. Similar proportions are also reflected in total accident by aircraft type data published by the NTSB.

Study 2: Pilot Perception Questionnaire

The effects of experience on pilot perceptions for each item, as well as omnibus findings, are presented next.

Perceived difficulty. As shown in Figure 3, significant effects of standard flight maneuvers on pilot perceptions were found, $F(9, 1330) = 32.469$, $p = .001$ ($\xi^2 = .180$, power = 1.00). Post hoc analysis revealed that pilots believed the flare maneuver ($M = 3.07$, $SD = 1.42$) to be more difficult than steep turns ($M = 2.61$, $SD = 1.18$), takeoff roll ($M = 1.42$, $SD = .778$), holding altitude ($M = 2.18$, $SD = 1.13$), climbing ($M = 1.57$, $SD = .862$), descending ($M = 1.62$, $SD = .940$), taxiing ($M = 1.42$, $SD = .843$), coordinated turns ($M = 2.04$, $SD = 1.07$), forward slip ($M = 2.31$, $SD = 1.26$), and landing roll ($M = 2.06$, $SD = 1.35$). Furthermore, results indicated significant effects of experience on pilot perceptions, $F(2, 131) = 6.875$, $p = .001$ ($\xi^2 = .095$, power = .917). Post hoc analysis indicated that novice pilots ($M = 3.58$, $SD = 1.41$) believed the flare maneuver to be more difficult than intermediate ($M = 2.84$, $SD = 1.15$) or expert ($M = 2.56$, $SD = 1.54$) pilots. Intermediate and expert pilot perceptions did not differ.

When pilots were asked to rate the task of judging altitude when initiating the flare, there was no effect of experience on pilot perceptions, $F(2, 131) = .911$,

$p > .05$. Mean perceived difficulty was 3.32 ($SD = 1.41$). Similarly, when pilots were asked to indicate how confident they were that their aircraft was 10 to 20 ft from the ground, pilot perceptions were not affected by experience, $F(2, 131) = 1.960$, $p > .05$. Mean pilot confidence rating ($M = 5.57$, $SD = 1.13$) was compared with a theoretical population mean ($M = 4$) to determine confidence magnitude. Findings indicated that pilots were confident in their ability to estimate the aircraft altitude during the flare, $t(133) = 16.004$, $p = .0001$.

Perceived significance. Experience did not influence pilot estimation of flare accident rates, $F(2, 125) = 2.773$, $p > .05$. Overall, regardless of experience, pilots estimated that there were 199.39 ($SD = 135.81$) flare accidents per year. Pilot estimates were compared with flare accident rates for 1995, 1996, and 1997. The mean number of flare accidents during the 3 years was 89.33 ($SD = 17.09$). Thus, pilots estimated flare accident rates to be more than twice as frequent as they really were. Pilots were not equally likely to be confident in their answers, $F(2, 131) = 6.487$, $p = .002$ ($\xi^2 = .090$, power = .901). Post hoc analysis indicated that expert pilots ($M = 3.94$, $SD = 1.23$) were more confident than intermediate ($M = 3.18$, $SD = 1.21$) or novice pilots ($M = 2.96$, $SD = 1.23$). Note that expert pilots tended to be more confident in their estimates of flare accident rates despite not being more accurate than novice or intermediate pilots.

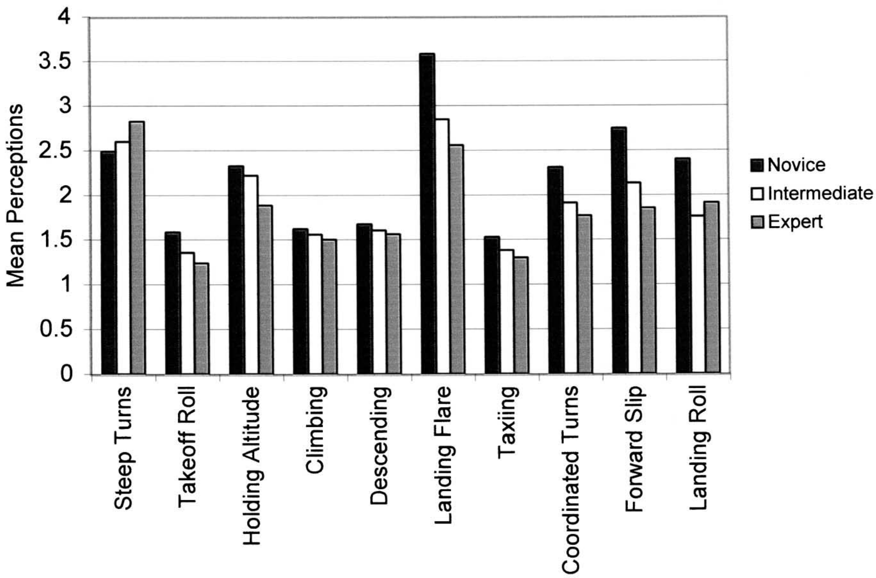

FIGURE 3 Perceptions of difficulty by maneuver and pilot experience.

Components of successful flares. As shown in Figure 4, factors that may have assisted pilots in estimating their altitude during their first solo flare attempts had a significant effect on pilot perceptions, $F(4, 665) = 159.818$, $p = .001$ ($\xi^2 = .490$, power = 1.000). Post hoc analysis revealed that practice ($M = 6.43$, $SD = .984$) assisted pilots more than CFI instructions ($M = 5.33$, $SD = 1.54$), instrument readings ($M = 3.20$, $SD = 1.75$), the pilot manual ($M = 2.43$, $SD = 1.47$), and ground school ($M = 3.34$, $SD = 1.75$). Pilots believed that, with the exception of practice, CFI instructions help them more than instrument readings, the pilot manual, and ground school during their first solo attempts. The success of past solo flare attempts were not affected by experience, $F(2, 131) = .858$, $p > .05$.

As depicted in Figure 5, similar effects were noted for factors that contributed to current successful landing flares, $F(4, 665) = 301.606$, $p = .001$ ($\xi^2 = .645$, power = 1.000). Post hoc analysis revealed that pilots attributed their current successful flares to pattern practice ($M = 6.32$, $SD = 1.10$) rather than their instructor ($M = 5.70$, $SD = 1.33$), natural ability ($M = 4.63$, $SD = 1.43$), aviation books ($M = 2.75$, $SD = 1.35$), or sheer luck ($M = 1.78$, $SD = 1.18$). Pilots believed that their instructor helped them more than natural ability, aviation books, or sheer luck and attributed their successful landing flares to natural ability rather than aviation books or sheer luck.

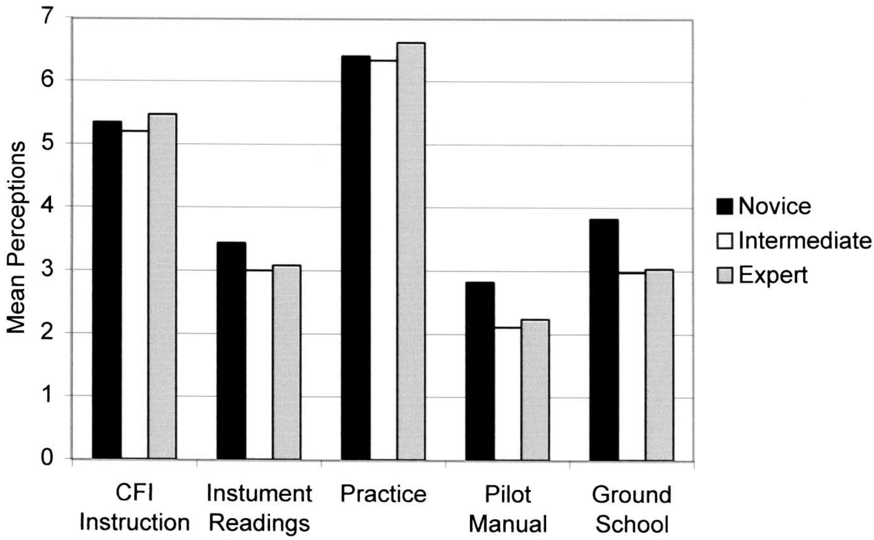

FIGURE 4 Contributing factors to successful flares during initial solo attempts.

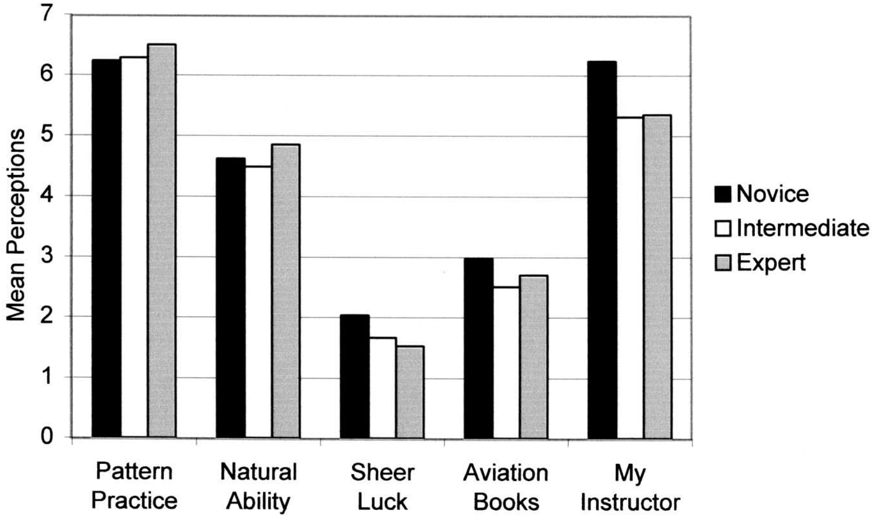

FIGURE 5 Contributing factors to current successful landing flares.

The contribution of pattern practice, $F(2, 131) = .628$, $p > .05$, and natural ability, $F(2, 131) = .627$, $p > .05$, to the success of current landing flares were not affected by pilot experience. Nevertheless, experience did have an effect on pilot perceptions regarding the contribution of CFI instruction, $F(2, 131) = 8.442$, $p = .001$ ($\xi^2 = .114$, power = .962). Post hoc analysis indicated that novice pilots ($M = 6.24$, $SD = 1.30$) contributed their successful landing flares to their CFI more than intermediate ($M = 5.31$, $SD = 1.38$) or expert ($M = 5.35$, $SD = 1.38$) pilots. Intermediate and expert pilots did not differ. Finally, experience did not have an effect on pilot perceptions regarding the need for improved training methods, $F(2, 125) = .510$, $p > .05$. Mean pilot perception was 3.63 ($SD = 1.54$).

Monocular cues. Overall, 86.93% of all pilots (novice = 76.4%, intermediate = 84.4%, expert = 100%) used vision to determine when to initiate the flare, 9.16% used gut reaction (novice = 16.4%, intermediate = 11.1%), 2.66% used instrument readings (novice = 3.6%, intermediate = 4.4%), 0.70% used a sense of balance (novice = 1.8%), and 0.70% did not know when to initiate the flare (novice = 1.8%). The type of visual information pilots used to determine when to initiate the flare is depicted in Figure 6. According to the results, 26.04% of the pilots (novice = 10.65%, intermediate = 7.69%, expert = 7.69%) indicated the horizon and end of runway, 18.93% (novice = 9.47%, intermediate = 5.92%, expert = 3.55%) indicated the shape of the runway and runway markings, 9.47% (novice = 4.14%, intermediate = 2.37%, expert = 2.96%) indicated familiar

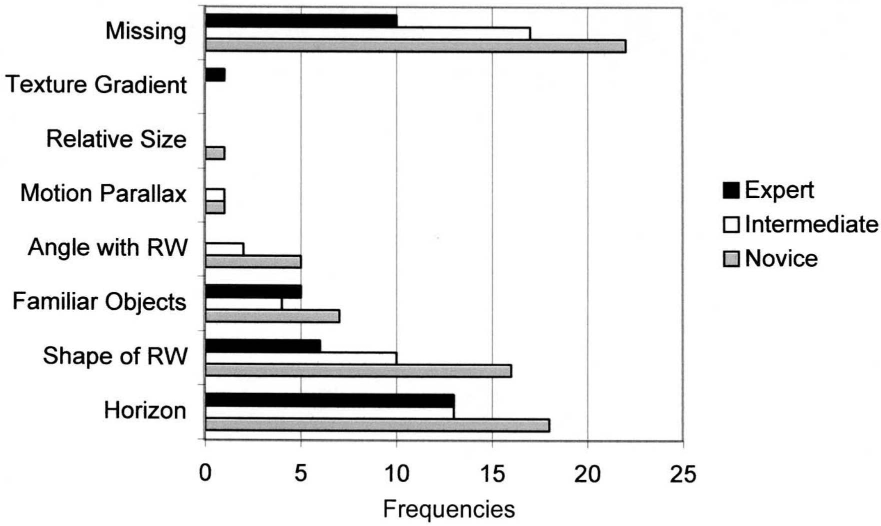

FIGURE 6 Monocular cues employed during the landing flare.

objects, 4.14% (novice = 2.96%, intermediate = 1.18%) indicated angle with runway, 1.18% (novice = 0.59%, intermediate = 0.59%) indicated motion parallax, 0.59% of the expert pilots indicated relative size, and 0.59% of experts indicated texture gradient. Figure 6 also shows that 28.99% (novice = 13.02%, intermediate = 10.06%, expert = 5.92%) were not able to indicate how vision assisted them to determine altitude above the ground. It is interesting to note that 10.06% (novice = 5.92%, intermediate = 1.18%, expert = 2.96%) indicated the use of kinesthetic information such as ground effect or "sinking rate" as a contributing factor to successful landing flares.

DISCUSSION

Pilots and authors provide anecdotal evidence concerning the difficulty of the flare maneuver, but the scientific literature has generally failed to address the issues of flare accident rates and probable causes for improper flares. By addressing these issues, we wished to stimulate further study of the flare maneuver and training methods associated with it.

This study first separated flare accident rates from landing accident rates. The task was unique to this study because the NTSB and leading insurance companies, such as the Aircraft Owners and Pilots Association Insurance Agency (B. Jennings, personal communication, October 4, 2000), do not distinguish between flare accidents and landing accidents. Findings revealed relatively high flare accident rates.

In fact, 18.33% of all landing accidents in 1995, 1996, and 1997 were flare-related accidents and even that assessment is conservative. Actual rates may be higher because private aircraft owners may underestimate flare incidents or simply avoid the embarrassment of reporting a flare incident to the NTSB. It was further found that not all accident reports that included the symptoms of improper flares were diagnosed as flare accidents. This fact indicates that actual flare accident rates may be higher simply because they are difficult to diagnose. As a consequence, it is sensible to suggest that organizations such as the NTSB and insurance companies consider the flare in a special category by separating flare accident rates from total landing accident rates.

The relatively high flare accident rates may serve as indirect evidence concerning the difficulty of the flare maneuver. Analysis of pilot perceptions provided more direct evidence. Participating pilots believed the flare maneuver to be more difficult than steep turns, takeoff roll, holding altitude, climbing, descending, taxiing, coordinated turns, forward slips, or landing roll and tended to overestimate the number of flare accidents per year. Taken as a whole, evidence from accident reports and pilot perceptions indicates that the flare maneuver is a significant hurdle in the quest for perfect landings and supports the need for further flare-related studies.

In reference to flare accidents, it is possible that the factors that contribute to proper flares are also probable causes for improper flares. As noted earlier, proper flares depend on monocular cues, and monocular cues depend on experience (Hawkins, 1993; Rinalducci, Patterson, Forren, & Andes, 1985). Despite commitment, ambition, and enthusiasm, what many student and general aviation pilots lack is experience. On average, the flare only lasts approximately 6 sec and a pilot with a total time of 5,000 hr only has approximately 8 hr of flare time (King, 1998). Without experience, how are student pilots expected to perform proper flares? Indeed, all pilots attested to the importance of experience, and novice pilots found the flare maneuver to be more difficult than intermediate or expert pilots. Perhaps instruction on appropriate monocular cues would eliminate the experience precondition for proper flares.

Despite the appeal of teaching monocular cues, it is not clear which depth perception cues are most important during the flare. In fact, pilots use different cues or combinations of monocular cues. For example, overall, the horizon and end of runway, shape of runway or runway markings, and familiar objects were the most frequent visual cues that pilots used to estimate their altitude during the flare. However, University of Oklahoma pilots most frequently used the horizon or end of runway, whereas Oklahoma State University pilots used the shape of runway or runway markings.

Furthermore, despite all pilots recognizing instruction as the second most important factor for proper flares, it may prove especially difficult to teach appropriate monocular cues. It appears that awareness is not critical to the learning of monocular cues; whereas all pilots recognized vision as the most important tool for depth perception during the leveloff, most pilots could not explain how vision is used during the flare. If that is the case, how are flight instructors expected to teach what they themselves do not know? Indeed, a review of the literature revealed that there was no agreement among training methods on how to use vision during the landing flare, and no one training method was found to be more effective than another (see Matson, 1973). Anecdotal evidence also indicated that instruction provided by flight-training manuals (Bramson, 1982) and CFIs (Kershner, 1998; Penglis, 1994) was inconsistent and ambiguous. It is possible that "the reason no student knows where the ground begins is because the method we use to teach landings to students is wrong and does not work" (Penglis, 1994, p. 91).

Despite findings of implicit support concerning the difficulty of the flare maneuver, this study failed to find omnibus effects of experience on pilot perceptions. Similarities among novice, intermediate, and expert perceptions were perplexing. The explanation may be embedded within the design. In this study, *novices* were defined as student pilots, *intermediates* were defined as instrument pilots, and *experts* were defined as flight instructors (CFIs). Naturally, CFI and student interaction in Part 141 flight schools is frequent and intensive. It is possible that flight instructors may have answered the various items from the perspective of their students, not their own. Alternatively, student pilots may have emphasized CFIs' concerns rather than their own.

Pilot perception data were also plagued with possible validity concerns characteristic to survey designs. For example, participants may have interpreted questions in different ways and may have been influenced by demand characteristics or role demands (McBurney, 1994). For example, the tendency of pilots to be confident in their ability to estimate altitude during the flare, and to provide lukewarm support for improved flare-training methods, may have stemmed from the answers pilots believed were expected from them. Such expectations may have developed from the pilot role as a "top gun" that should not admit to difficulties or lack of confidence (recall that expert pilots were more confident, but not accurate, in their estimate of flare accident rates). Perhaps special caution and methodologies, such as implicit data gathering, should be used when studying the unique population of aviators.

Finally, recommendations for future studies may be suggested. Past studies have attempted to identify and analyze the various monocular cues that enhance depth perception during the flare (e.g., Mulder, Pleijsant, van der Vaart, & van Wieringen, 2000; Riordan, 1974). However, it has already been established that monocular cues enhance depth perception during the approach, landing, and flare, and it appears that any attempt to determine how pilots use these cues is futile (Tiffin & Bromer, 1943; Warren & Owen, 1982). Pilots use different monocular cues or a combination of cues. Suffice it to say that with experience, visual cues are learned and proper flares executed (Green, 1988).

Future studies should address the issues of experience and proper instruction instead of providing further evidence on the usefulness of monocular cues and mental representations of depth perception such as time-to-contact (see Grosz et al., 1995; Mulder et al., 2000). Behavioral methods that optimize learning and provide standardized flare instruction are recommended.

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REFERENCES

Balfour, A. J. C. (1988). Accident investigation and its management. In J. Ernsting & P. King (Eds.), *Aviation medicine* (2nd ed., pp. 697–702). Oxford, England: Butterworth Heinemann.

Benson, A. J. (1999). Spatial disorientation—General aspects. In J. Ernsting, A. N. Nicholson, & D. J. Rainford (Eds.), *Aviation medicine* (3rd ed., pp. 419–454). Oxford, England: Butterworth Heinemann.

Bond, N. A., Bryan, L. G., Rigney, J. W., & Warren, N. D. (1962). *Aviation psychology (aero-space science series).* Los Angeles: Aviation and Missile Safety Division, University of Southern California.

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

Butcher, R. (1996). *Private pilot flight training manual.* Orange, CA: Skyroamers.

Christy, J. (1991). *Good takeoffs and good landings* (2nd ed.). Blue Ridge Summit, PA: Tab.

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

Federal Aviation Administration. (1999). *Airplane flying handbook (FAA-H-8083-3, Rev. ed.).* 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.

Gleim, I. N. (1998). *Flight/ground instructor* (6th ed.). Gainesville, FL: Gleim.

Green, R. G. (1988). Perception. In J. Ernsting & P. King (Eds.), *Aviation medicine* (2nd ed., pp. 391–401). Cambridge, England: Butterworth Heinemann.

Green, R. G., Muir, H., James, M., Gradwell, D., & Green, R. L. (1996). *Human factors for pilots* (2nd ed.). Hampshire, England: 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, Inc.

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.

Hawkins, F. H. (1993). *Human factors in flight* (2nd ed.). Brookfield, VT: Ashgate.

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

Jorgensen, C. C., & Schley, C. (1990). A neural network baseline problem for control of aircraft flare and touchdown. In M. W. Miller & R. S. Sutton (Eds.), *Neural networks for control* (pp. 403–425). Cambridge, MA: MIT Press.

Kalat, J. W. (1998). *Biological psychology.* Pacific Grove, CA: Brooks/Cole.

Kershner, W. K. (1981). *The flight instructor's manual* (2nd ed.). Ames: Iowa State University Press.

Kershner, W. K. (1998). *The student pilot's flight manual* (8th ed.). Ames: Iowa State University Press.

King. (Producer). (1998). *Takeoffs and landings made easy* [Motion Picture]. San Diego, CA: King Schools.

King. (Producer). (1999). *Cleared for takeoff—Cessna private pilot* [CD-ROM]. San Diego, CA: King Schools.

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

Love, M. C. (1995). *Better takeoffs & landings.* Columbus, OH: Tab.

Menon, P. K. (1996). *Machine-vision aids for improved flight operations.* Moffett Field, CA: NASA Ames Research Center.

Marieb, E. N. (1995). *Human anatomy and physiology* (3rd ed.). Redwood City, CA: Benjamin/Cumming.

Matson, W. R. (1973). *The comparative effectiveness of a prolonged flare and normal flare on student pilot achievement in the landing maneuver and on time to solo.* Unpublished doctoral dissertation, Oklahoma State University, Stillwater.

McBurney, D. H. (1994). *Research methods* (3rd ed.). Pacific Grove, CA: Brooks/Cole.

Mulder, M., Pleijsant, J., van der Vaart, H., & van Wieringen, P. (2000). The effects of pictorial detail on the timing of the landing flare: Results of a visual simulation experiment. *International Journal of Aviation Psychology, 10,* 291–315.

Nagel, D. C. (1988). Human error in aviation operations. In E. L. Wiener & D. C. Nagel (Eds.), *Human factors in aviation* (pp. 263–303). San Diego, CA: Academic.

National Transportation Safety Board. (1998, September). *U.S. general aviation, calendar year 1995: Annual review of aircraft accident data.* Washington, DC: Author.

National Transportation Safety Board. (1999, May). *U.S. general aviation, calendar year 1996: Annual review of aircraft accident data.* Washington, DC: Author.

National Transportation Safety Board. (2000, September). *U.S. general aviation, calendar year 1997: Annual review of aircraft accident data.* Washington, DC: Author.

Norman campus enrollment summary. (2000). [Brochure]. Norman: University of Oklahoma, Institutional Research and Reporting.

Penglis, G. M. (1994). *The complete guide to flight instruction.* Highland City, FL: Rainbows.

Quinlan, E. (1999). *Recreational airplane pilot.* Oak Brook, IL: Aviator.

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

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.

Reinhart, R. O. (1996). *Basic flight physiology* (2nd ed.). New York: McGraw-Hill.

Reinhart, R. O., & 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 psychology* (Vol. 2, pp. 1525–1529). Columbus: Aviation Department, The Ohio State University.

Rinalducci, E. J., Patterson, M. J., Forren, M., & Andes, R. (1985). Altitude estimation of pilot and non-pilot observers using real-world scenes. In R. S. Jensen & J. Adrion (Eds.), *Proceedings of the third symposium on aviation psychology* (pp. 491–498). Columbus: Department of Aviation, The Ohio State University.

Riordan, R. H. (1974). Monocular visual cues and space perception during the approach and landing. *Aerospace Medicine, 45,* 766–771.

Summary of enrollment spring 2000. (2000, February). [Brochure]. Stillwater: Oklahoma State University, Office of the Registrar.

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

Tiffin, J., & Bromer, J. (1943, April). *Analysis of eye fixations and patterns of eye movement in landing a piper cub J-3 airplane* (Rep. No. 14). Washington, DC: CAA Division of Research.

Tredici, T. J. (1996). Ophthalmology in aerospace medicine. In R. L. DeHart (Ed.), *Fundamentals of aerospace medicine* (2nd ed., pp. 519–566). Baltimore: Williams & Wilkins.

Warren, R., & Owen, D. H. (1982). Functional optical invariants: A new methodology for aviation research. *Aviation, Space, and Environmental Medicine, 53,* 977–983.

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