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Impact of gender, age and experience of pilots on general aviation accidents

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ABSTRACT

General aviation (GA) accounts for more than 82% of all air transport-related accidents and air transport-related fatalities in the U.S. In this study, we conduct a series of statistical analyses to investigate the significance of a pilot's gender, age and experience in influencing the risk for pilot errors and fatalities in GA accidents. There is no evidence from the Chi-square tests and logistic regression models that support the likelihood of an accident caused by pilot error to be related to pilot gender. However, evidence is found that male pilots, those older than 60 years of age, and with more experience, are more likely to be involved in a fatal accident.

1. Introduction

According to the Bureau of Transportation Statistics of the U.S. Department of Transportation, aviation has a superior safety record in comparison to any other mode of transportation. Air transportation was accountable for about 0.03% of all accidents that happened in the air, on the highways and railroads in the U.S. between 1990 and 2003, while highways and railroads were responsible for 99.86% and 0.11% respectively. In the same period (1990–2003) only 1.98% of all fatalities occurred in the air transport-related accidents, whereas 95.56% of fatalities took place on the highways and 2.46% on the railways. While around 42,000 people in the U.S. die on the highways every year, air transportation accidents annually take fewer than 900 lives. However, if we categorize all aviation accidents in the U.S. into commercial air carrier and general aviation accidents, one can immediately recognize that the distribution of accidents and fatalities among the subgroups is very uneven. General aviation was accountable for 82% of total air transport related accidents and 83% of total fatalities that were associated with air transport between 1990 and 2003. General aviation (GA) is typically classified as the operations of civilian aircraft for purposes other than commercial passenger transport, including personal, business, and instructional flying.

Despite the fact that the majority of all aviation accidents are associated with GA, the research in this field has not received as much attention as it has for commercial aviation. The few published studies on the GA safety issues include the impacts on accidents from factors such as flight hours (e.g., O'Hare and Chalmers, 1999; Craig, 2001; Li et al., 2001), weather (McLean, 1986; Wiggins and O'Hare, 1995), pilot impairment and incapacitation (Taneja and Wiegmann, 2002; Booze, 1987), and flight phase (Dambier and Hinkelbein, 2006).

In the following analysis, we focus on investigating whether and how a pilot's gender, age and experience is related to the occurrence of pilot error and fatal accidents specifically in the GA setting. The implications from this research will be far reaching and particularly relevant to aviation management as there are many stereotypes and prejudices against pilots of specific gender and/or specific age groups (Vermeulen and Mitchell, 2007; Baker et al., 2001).

The remainder of this paper is organized as follows. Section 2 introduces the motivation and the main hypotheses. In Section 3, a brief description of the NTSB database is provided which is followed by an empirical analysis and the main results in Section 4. Finally, the conclusion is presented in Section 5.

2. Motivation and hypothesis development

In the study by Vail and Ekman (1986), the authors considered the impact of a pilot's gender in GA accident occurrences. The analysis used GA accident records data from the NTSB between 1972 and 1981 and the results suggested that male pilots had a higher rate of accidents than female pilots. The results also showed proof that the accidents involving male pilots were more likely to result in fatalities or serious injuries than were those involving female pilots.

The impact of pilot age on GA safety has been examined by Tsang (1992), Harkey (1996), McFadden (1996), Bazargan and Guzhva (2007) and others. By examining a large pool of psychological literature on cognitive-aging research, Tsang (1992) identified four

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cognitive functions that were essential to pilot performance and such functions were also found to be directly impacted by age. As suggested by the author, cognitive slowing and resource reduction were considered to be two general causes that led to age-related deficits. To better understand aging and pilot performance in a real setting, Harkey (1996) conducted an epidemiological analysis of GA pilots and their involvements in flight accidents. The results from Harkey's study implied that the pilots aged between 40 and 44 had a significantly higher accident rate than pilots between the age of 35 and 39. However, there is a lack of consistent empirical evidence supporting the view that younger pilots tend to have safer flight records. For example, Broach (2000) reported that older pilots in the age group between 50 and 59 did not appear to have statistically significant higher accident rates than pilots aged between 40 and 49.

The relationship between pilot's age and flight safety has always been a debated topic. The "Age 60 Rule" utilized by the FAA since 1959, prohibits any pilot aged beyond 60 from being engaged in flight operations of FAR[1] Part 121 carriers. On the other side, there have been reports and analyses showing that the differences in airplane accident rates between pilots of different age groups are not statistically significant (e.g., Broach, 2000). The inconclusive findings can be explained by the fact that while a pilot's performance is impacted by age, older pilots accumulate more experience and expertise in flying, both of which positively contribute to flight safety. This perspective is also supported by Li et al. (2001), who find that the chances of being in an accident are higher for inexperienced pilots than for experienced pilots.

The interactive impacts from the gender and age of pilots on flight safety were studied by McFadden (1996) in the commercial aviation context. McFadden found that the accident rates were significantly higher for female pilots as compared with male pilots employed in major airlines. However, it was also found that female pilots employed by major airlines were much younger and less experienced than their male counterparts. These results suggest that age might play a critical role in moderating the relationship between gender and pilot performance with respect to flight safety.

The other studies that investigate factors associated with risks of flight accidents in the GA setting include Li (1994), Li et al. (2001) and Taneja and Wiegmann (2002). Li et al. (2001) noted that more than 85% of all GA accidents have pilot error as a major causal factor. Taneja and Wiegmann (2002) found that there were significant associations between fatal GA accidents and pilot age-related impairment and incapacitation, which were further aggravated by pilots having alcohol, drug and cardiovascular problems. Li (1994) suggested that besides pilot-related factors causing accidents, aircraft and crash circumstances, instrument meteorological condition, and on-airport location were important to consider in predicting the risks of pilot errors and their consequences.

While the impact of pilot gender, age, and experience on the likelihood of pilot errors that cause aviation accidents and fatalities have received a considerable attention in sighted above studies, it seems that some of them have produced conflicted evidence. For instance, Tsang (1992) and Harkey (1996) suggest that older pilots are less safe, while Broach (2000) argues that older pilots have the same safety record as their younger counterparts. Vail and Ekman (1986) conclude that female pilots have fewer accidents, while McFadden (1996) finds that in commercial settings female pilots have higher accident rates.

To revisit the issue and examine how pilot error and fatal accidents are affected by pilot age, gender and experience using more recent data than in previous studies, we analyze a multi-year dataset of GA accidents reported by the NTSB from 1983 to 2002. The following section briefly discusses the data.

[1] Federal Aviation Regulations.

3. NTSB database

It has been required by the federal regulations that operators notify the NTSB immediately of airplane accidents and certain incidents. According to the definition given by FAR Part 830.2: An aircraft accident is defined as an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage. An aircraft incident is an occurrence other than an accident that affects or could affect the safety of operations. The information pertaining to these accidents and incidents are complied into a database. The NTSB aviation database contains the information for all civilian aircraft accidents and the follow-up investigation reports. Part of this database is public and can be accessed through the NTSB website.

In this study, we supplement the publicly available data with NTSB information on the age and gender of the pilots. The sample covers GA accidents between 1983 and 2002 and contains information about the accidents and pilot-related factors. Specifically, our dataset contains information on fatal and nonfatal accidents; pilot and non-pilot error caused accidents; gender; age; and flight experience of the pilots. In the following section we develop a series of statistical tests and models for data analysis.

4. Data description and empirical analysis

Naturally, the gender variable takes into considerations its two dimensions, male and female. As for the age variable, six different categories are assumed: younger than 20 years, 20–29, 30–39, 40–49, 50–59, and older than 60 years. This classification is consistent with the study by Li et al. (2001) on GA safety.

As a proxy for pilot experience, we use the total number of flight hours logged by the pilot involved in the accident. In distinguishing different categories, we use FAR Part 61 as guidance. Thus, we identify five categories of pilot's experience. Category I represents the least experienced pilots that have fewer than 100 h of total flight time (student-pilots and newly licensed private pilots). Category II consists of pilots with 100–300 h of total flight time (low-time private pilots and newly licensed commercial pilots). Category III covers pilots with 300–2000 h of total flight time (fairly experienced private pilots, low time commercial pilots, and newly licensed airline transport pilots). Category IV represents pilots with 2000–5000 h of total flight time (very experienced private and commercial pilots and moderately experienced airline transport pilots). Category V consists of the most experienced pilots with more than 5000 h of total flight time.

Furthermore, it is necessary to point out that in the following analysis, all the counts and numbers reported relate to the number of aircraft involved in the accidents. These counts do not represent the number of people who were injured or killed.

4.1. Age, gender and experience versus pilot error

As was found by Li et al. (2001), 85% of all general aviation accidents are caused by pilot error. A study by Baker et al. (2001) claims that there are large gender differences in the types of pilot error involved in general aviation crashes but the impact of the gender on the accident itself is not analyzed in their study. Baker et al. (2001) also find that older pilots make fewer errors. In this section we examine the association of a pilot's age and gender to the

Table 1
Classification of GA accidents based on pilot gender.

	Gender	
	Male	Female
Panel A: 1983–1992		
Pilot error	18,036	789
Non-pilot error	4194	165
Ratio of pilot errors	0.81	0.83
Panel B: 1993–2002		
Pilot error	12,861	526
Non-pilot error	3113	116
Ratio of pilot errors	0.81	0.82

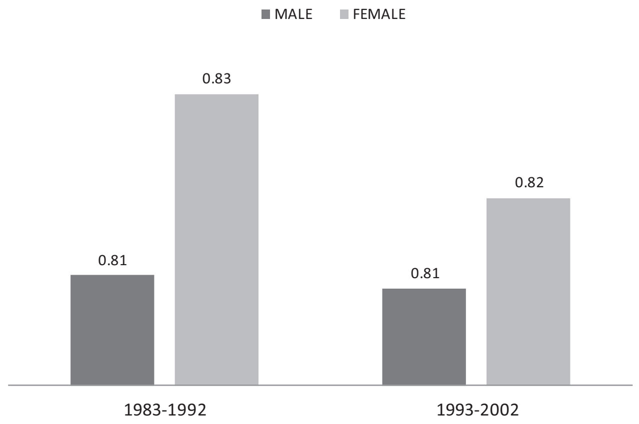

Fig. 1. Ratio of pilot error caused to total accidents versus pilot gender.

occurrence of pilot error for different categories of experience. To assess changes with time, we divide our sample into 2 panels that represent two decades: 1983–1992 and 1993–2002.

4.1.1. Impact of the pilot's gender on pilot error

In this section we conduct an exploratory analysis on whether the pilot's gender has any impact on pilot's error. Table 1 presents the total number of the GA accidents, which is measured by counting the number of aircraft involved in the accidents for each of the two decades considered. The results for each decade are categorized by pilot error and non-pilot error caused accidents, and by the gender of the pilot(s) involved in the accidents.

As presented in Table 1 and Fig. 1, the ratios of pilot errors to total accidents are higher for female pilots in both decades, suggesting that female pilots may have a slightly higher proportion of pilot errors than male pilots. However, the Chi-square test results in insignificant statistics which indicates that in both decades, both the male and female pilots were not different with respect to the proportion of accidents caused by pilot error. These results are different from McFadden (1996) findings for commercial airline pilots. Also, it seems that there is no trend with pilot errors for both male and female pilots. The ratios are consistent between both decades. A slight reduction in female pilot error ratio from 0.83 to 0.82 is not statistically significant.

Pilot experience is a major contributor to the increased risk of pilot errors (McFadden, 1997). Li et al. (2001) found that flight experience as measured in total flight time showed a significant protective effect on pilot error in general aviation crashes. Thus, we examine the pilot error caused accidents in each category of experience and then distinguish between male and female accidents for each category.

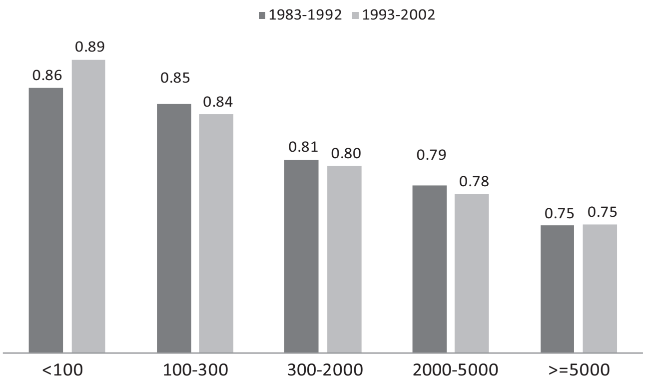

Fig. 2. Ratio of pilot error caused to total accidents versus pilot experience.

Tables 2 and 3 contain accident data by category of experience. As presented in Table 2 and Fig. 2, the ratio of pilot error caused to total accidents steadily declines with pilot experience. Moreover, the Chi-square test resulted in highly statistically significant differences among experience categories indicating that less experienced pilots are more likely to make an error that causes an accident. As expected, pilots with less than 300 h of total flight time of experience have the highest ratios of errors ranging from 84 to 89%. The results are consistent with the findings of Li et al. (2001). In addition, the effect of experience is persistent with time as shown by similar ratios for both sample periods.

Analyzing the gender of pilots within the experience categories enables us to avoid aggregation bias and compare male and female pilots with similar levels of experience. As presented in Table 3 and Fig. 3 there are slight differences in pilot error ratios between male and female pilots among almost all categories. However, almost none of the differences in ratios are statistically significant leading us to conclude that male and female pilots are not different with respect to their likelihood to be involved in a pilot error caused accident. One exception is the most experienced category (>5000 h) in the first sample period: 1983–1992. It seems that female pilots in this category were less likely to make an error than male pilot. However, the next sample period for the same category suggests that female pilots are similar to male pilots with respect to the ratio of errors that cause accidents.

Table 2
Classification of GA accidents based on pilot experience.

	Experience category				
	<100	100–300	300–2000	2000–5000	≥5000
Panel A: 1983–1992					
Pilot error	2827	3445	7772	2633	2148
Non-pilot error	449	608	1875	721	706
Ratio of pilot errors	0.86	0.85	0.81	0.79	0.75
Panel B: 1993–2002					
Pilot error	1560	2249	5650	2025	1903
Non-pilot error	201	422	1407	577	622
Ratio of pilot errors	0.89	0.84	0.80	0.78	0.75

Table 3
Classification of GA accidents based on pilot experience and gender.

	Experience category									
	<100		100–300		300–2000		2000–5000		≥5000	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Panel A: 1983–1992										
Pilot error	2545	282	3282	163	7504	268	2585	48	2120	28
Non-pilot error	391	58	587	21	1814	61	706	15	696	10
Ratio of pilot errors	0.87	0.83	0.85	0.89	0.81	0.81	0.79	0.76	0.75	0.74
Panel B: 1993–2002										
Pilot error	1430	130	2118	131	5432	218	1997	28	1884	19
Non-pilot error	187	14	399	23	1346	61	569	8	612	10
Ratio of pilot errors	0.88	0.90	0.84	0.85	0.80	0.78	0.78	0.78	0.75	0.66

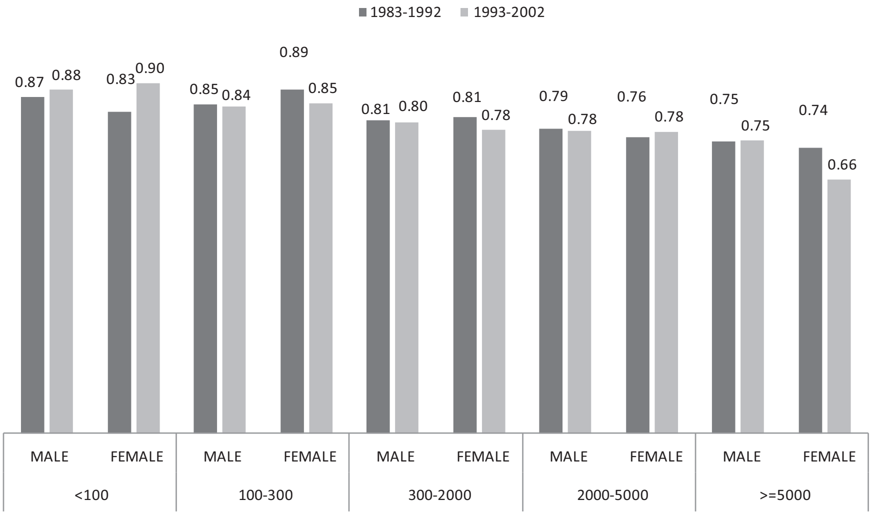

Fig. 3. Ratio of pilot error caused to total accidents versus pilot experience and gender.

4.1.2. *Impact of the pilot's age on pilot error*

To examine the impact of the age factor on pilot error, we consider six different age categories described in the beginning of Section 4. Table 4 presents the ratios of pilot error caused to total accidents for various age groups over the two decades from 1983 to 2002.

As shown in Table 4 and Fig. 4, the ratios of pilot error to total accidents are slightly different for different age groups. However, the Chi-square test indicates that the differences are not statistically significant meaning that with respect to the likelihood of making an error that could lead to an accident, pilots of different ages are not that different from each other. These results hold for both time periods and are in sync with Li et al. (2001) who note that neither pilot age nor gender is independently associated with the odds of pilot error.

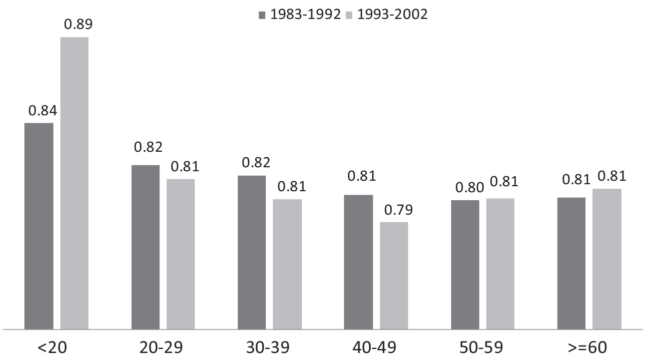

Fig. 4. Ratio of pilot error caused to total accidents versus pilot age.

Table 4
Classification of GA accidents based on pilot age.

	Age category					
	<20	20–29	30–39	40–49	50–59	≥60
Panel A: 1983–1992						
Pilot error	284	3251	4796	4757	3454	2283
Non-pilot error	53	704	1075	1138	839	550
Ratio of pilot errors	0.84	0.82	0.82	0.81	0.80	0.81
Panel B: 1993–2002						
Pilot error	209	1695	2230	3300	3104	2849
Non-pilot error	27	385	540	859	751	667
Ratio of pilot errors	0.89	0.81	0.81	0.79	0.81	0.81

Table 5
Classification of GA fatal accidents based on pilot gender over.

	Gender	
	Male	Female
Panel A: 1983–1992		
Fatal	4831	99
Non-fatal	17,399	855
Ratio of fatal accidents	0.22	0.10
Panel B: 1993–2002		
Fatal	3595	103
Non-fatal	12,379	539
Ratio of fatal accidents	0.23	0.16

4.2. *Age, gender and experience versus fatal accidents*

The result from previous studies has shown that about 20% of all GA accidents result in fatality (Bazargan and Guzhva (2007)). In this section, we examine the impacts of age, gender, and pilot experience on the proportion of fatal accidents relative to total GA accidents.

4.2.1. *Pilot gender and fatal accidents*

As shown in Table 5 and Fig. 5, male GA pilots were more likely to be involved in fatal accidents than female pilots in both decades. The Chi-square tests are statistically significant at the less than 1% level indicating that male and female pilots are really different with respect to fatal GA accidents. These results seem to support the findings of Vail and Ekman (1986) that male general aviation pilots are taking more risks than female pilots and those risks lead to more fatal accidents.

In addition, it seems that the trend for male pilots' ratio of fatal to total accidents was steady over time, while the trend for female pilots changed adversely. In 1983–1992 only 10% of accidents that female pilots were involved in resulted in fatalities. However, in 1993–2002 16% of all accidents with female pilots were fatal. This 60% increase is statistically significant at the 5% level and represents an adverse trend.

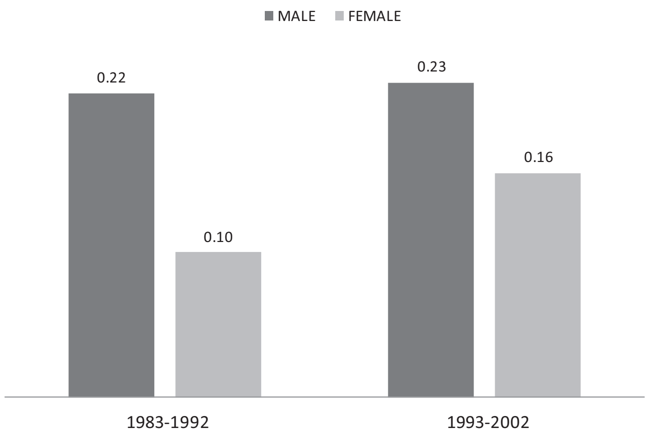

Fig. 5. Ratio of fatal to total accidents versus pilot gender.

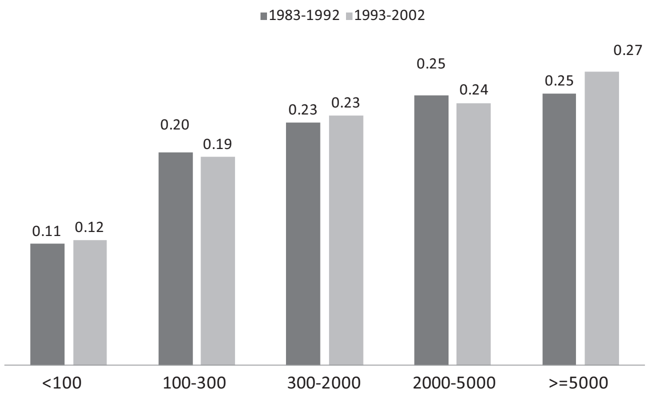

Fig. 6. Ratio of fatal to total accidents versus pilot experience.

Similar to the pilot error analysis, we examine the number of fatal accidents versus pilot experience and versus pilot gender within experience categories. Table 6 and Fig. 6 present the number of accidents and the ratios of fatal to total accidents for different levels of pilot experience.

It seems that the likelihood of pilots to be involved in a fatal accident is increasing with the pilots' experience. The results are consistent for both decades indicating that this surprising finding persists across time. The Chi-square tests resulted in the null hypotheses rejected at the 1% level suggesting that the differences are statistically significant.

Table 7 and Fig. 7 present fatal accident data and ratios of fatal to total accidents for male and female pilots within different categories of experience. Statistical significance of the Chi-square tests is indicated by small stars next to the category names, where "**" and "*" denote significance at the 5% and 1% levels respectively. It turns out that for almost all experience categories where the differences are significant, female pilots had much lower likelihood of being involved in a fatal accident than their male counterparts. The most striking difference is in the most experienced category (≥5000 h) during 1983–1992 where out of 38 accidents with female pilots only 2 were fatal. It is to be noted that since the number of fatal accidents with female pilots is low (less than 5), a valid Chi square test cannot be conducted for this category. The results persist across time with one outlier: The most experience category in 1993–2002 sample, where female pilots have unusually high ratio of fatal accidents.

4.2.2. *Pilot age and fatal accidents*

Table 8 and Fig. 8 present the ratios of fatal to total accidents for pilots in different age groups. It seems that older pilots are more likely to be involved in a fatal accident. The ratios of fatal to total accidents are especially high for pilots that are older than

Table 6
Classification of GA fatal accidents based on pilot experience.

	Experience category				
	<100	100–300	300–2000	2000–5000	≥5000
Panel A: 1983–1992					
Fatal	371	806	2186	844	723
Non-fatal	2905	3247	7461	2510	2131
Ratio of fatal accidents	0.11	0.20	0.23	0.25	0.25
Panel B: 1993–2002					
Fatal	206	519	1644	637	692
Non-fatal	1555	2152	5413	1965	1833
Ratio of fatal accidents	0.12	0.19	0.23	0.24	0.27

Table 7
Classification of GA fatal accidents based on pilot gender and experience.

	Experience category									
	<100*		100–300*		300–2000*		2000–5000		≥5000	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Panel A: 1983–1992										
Fatal	352	19	790	16	2141	45	827	17	721	2
Non-fatal	2584	321	3079	168	7177	284	2464	46	2095	36
Ratio of fatal accidents	0.12	0.06	0.20	0.09	0.23	0.14	0.25	0.27	0.26	0.05
	Experience category									
	<100**		100–300		300–2000**		2000–5000		≥5000**	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Panel B: 1993–2002										
Fatal	198	8	496	23	1596	48	627	10	678	14
Non-fatal	1419	136	2021	131	5182	231	1939	26	1818	15
Ratio of fatal accidents	0.12	0.06	0.20	0.15	0.24	0.17	0.24	0.28	0.27	0.48

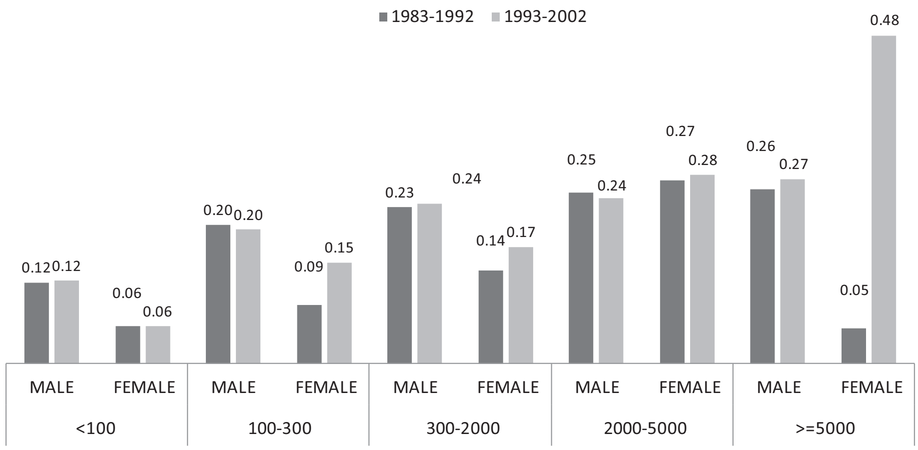

Fig. 7. Ratio of fatal to total accidents versus pilot gender and experience.

60. A study of crash risk on air taxi pilots by Li et al. (2003) states that flight experience, as measured by total flight time at baseline, showed a significant protective effect against the risk of crash involvement. But the protective effect of flight experience leveled off after total flight time reached 10,000 h. This might be true in the case of GA pilots as well. This is also suggested by the fact that the Chi-square tests for both decades are highly statistically significant at the 1% level supporting the observation that older pilots are different with respect to fatal accidents. One plausible explanation for such a result could be that older pilots typically are more experienced and fly more difficult flights, where a mistake or malfunction could have severe consequences. The ratios of fatal to total accidents are fairly consistent for different age categories for both decades suggesting that the results are persistent over time.

4.3. Effects of age and gender controlling for pilot experience

To further examine if gender, age and experience of pilots are associated with GA accidents being fatal or caused by pilot error, we employ the binary logistic regression model. Binary logistic regression is most commonly used when the dependent (response) variable is a dichotomous variable (i.e., it takes only two values coded as 0 and 1 to represent whether or not a specific event occurs). The independent (input) variables in the logistic regression could be continuous, categorical, or both. Unlike ordinary least square estimation, logistic regression does not assume that the dependent variable and independent variables have linear relationship. Nor does it assume that the dependent variable or the error terms are distributed normally. This estimation method is extensively

Table 8
Classification of GA fatal and non-fatal accidents based on pilot age.

	Age category					
	<20	20–29	30–39	40–49	50–59	≥60
Panel A: 1983–1992						
Fatal	38	712	1038	1348	1034	760
Non-fatal	299	3243	4833	4547	3259	2073
Ratio of fatal accidents	0.11	0.18	0.18	0.23	0.24	0.27
Panel B: 1993–2002						
Fatal	41	390	561	880	896	930
Non-fatal	195	1690	2209	3279	2959	2586
Ratio of fatal accidents	0.17	0.19	0.20	0.21	0.23	0.26

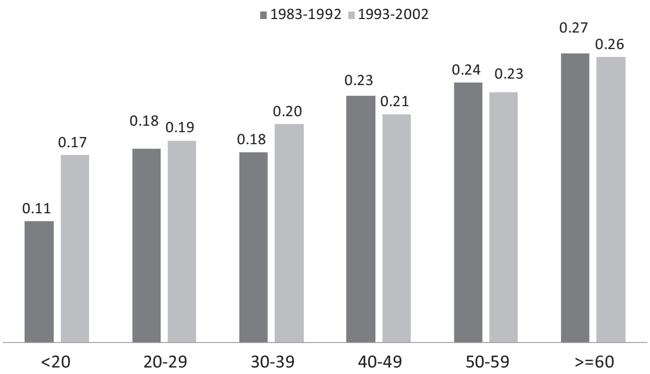

Fig. 8. Ratio of fatal to total accidents versus pilot age.

employed in medical and social science research (see Hair et al., 2005; Tabachnick and Fidell, 1996 for a comprehensive review). The studies by Li et al. (2001) and Baker et al. (2001) have also used logistic regression to conduct safety analysis in general aviation.

Prior to performing the analysis, we meticulously checked our dataset for the accuracy and missing variables in the sample. After the filtering process, we had a total of 39,800 GA accidents and incidents recorded between1983 and 2002. Of these records, 23,184 cases (58.2%) occurred between 1983 and 1992, and there were 16,616 accidents (41.8%) between 1993 and 2002.

4.3.1. *Pilot error versus age, gender and experience*

To insure the robustness of the results we use two slightly different logistic regression models. We run each model with two subsamples representing 1983–1992 and 1993–2002. Pilot error was used as the dependent variable in all models. If an accident was caused by pilot error the dependent variable is coded as one and zero otherwise.

The first model assumes that the marginal effect of pilot age and experience on the likelihood of pilot error is consistent across the whole range of age and flight experience. For instance, according to the first model assumptions one extra year of age and one extra hour of flight experience for a 20 year old pilot with 100 h of flight time will have the same effect as that of a 60 year old pilot with 6,000 h of flight time. The independent variables for the first model include pilot's gender, pilot's age, and pilot's total flight time.The model can be expressed as:

$$PilorError_i = a + b_1 Gender_i + b_2 \log(Age_i) + b_3 \log(Experience_i) + e_i (1)$$

where *PilotError* is 1 if an accident is caused by pilot error and 0 otherwise; *Gender* variable takes a value of 1 for female pilots and 0 for male pilots; *Age* is pilot's age in years and *Experience* is the total flight time of a pilot involved in an accident.

Table 9 presents the estimation results for Model (1) using the data for both decades. "*" indicates statistical significance at the 1% level. It turns out that all of the variables except *Gender* produced highly statistically significant coefficients. The results that are consistent between both decades suggest that female pilots are not significantly different from their male counterparts in terms of the likelihood of pilot error. However, the coefficient of *Age* indicates that older pilots are more likely to be involved in an accident caused by pilot error. As expected, the coefficient of *Experience* implies that more experienced pilots are less likely to make errors that would lead to accidents.

The second model is designed to differentiate the effect of pilot's age and experience on the likelihood of a pilot to be involved in an accident caused by pilot error among different age and experience categories. Thus, consistent with the Chi-square analysis the second logistic regression model includes six categories of pilot's age and five categories of pilot's experience. Six categories of pilot's age are: younger than 20 years old, 20–29, 30–39, 40–49, 50–59, and older than 60 years old. Five categories of pilot's experience include pilots with fewer than 100 h, 100–300, 300–2000, 2000–5000, and more than 5000 h of total flight time. Category III of pilot's age (30–39 years old) and Category IV of pilot's experience (2000–5000 h) are omitted from the logistic regression to be used as references. Those two categories represent the "average age" and the "average experience" pilots.

The model can be expressed as:

$$PilotError_i = a + b_1 Gender_i + b_2 Age1_i + b_3 Age2_i + b_4 Age4 + b_5 Age5_i + b_6 Age6_i + b_7 Exp1_i + b_8 Exp2_i + b_9 Exp3_i + b_{10} Exp5_i + e_i \quad (2)$$

where all of the variables are as explained above.

Table 10 presents the estimation results for Model (2) using the data for both decades. "*" indicates statistical significance at the 1% level. Model (2) provides additional insights on the likelihood of a pilot to be involved in an accident caused by pilot error with respect to pilot's gender, age and experience. Similar to Model (1), pilot's gender coefficients are not statistically significant in both decades indicating that male and female pilots have equal likelihood to make an error that would lead to an accident. However, with respect to pilot's age categories, Model (2) estimates are slightly different. It seems that during 1983–1992 pilots' age was not a significant factor in the likelihood of a pilot error. Conversely, as indicated by the statistically significant coefficient of *Age*6, in 1993–2002, 60 plus year old pilots were more likely to be involved in an accident caused by pilot error than the reference category of 30–39 year old pilots. Also, the experience category coefficients that are highly statistically significant, suggest that experience plays an important role in the likelihood of pilot error. Thus, pilots in the first three experience categories are more likely to have an accident caused by pilot error than the reference category of 2000–5000 h pilots. Likewise, more experienced pilots in Category V are less likely to make an error that would lead to an accident than pilots in the reference Category IV. Furthermore, as indicated by the coefficients and odds ratios the relative significance of the pilot experience is higher for low-time pilots. For instance, while pilots in experience Categories III and II are more likely to be involved in an accident caused by pilot error than pilots in the reference Category IV, the likelihood for pilots in Category I to be involved in such an accident is much higher.

Table 9
Pilot errors versus age and gender logistic regression estimates.

	Variables			
	Constant	Gender	Age	Experience
Panel A: 1983–1992				
Coefficient	1.85*	−0.07	0.37*	−0.15*
Odds ratio	6.34	0.94	1.44	0.86
Panel B: 1993–2002				
Coefficient	1.62*	−0.02	0.48*	−0.15*
Odds ratio	5.07	0.98	1.62	0.86

4.3.2. *Fatal accidents versus age, gender, and experience*

Similar to the previous section we apply two logistic regression models to investigate the effect of pilot age, gender and experience on the likelihood of a pilot to be involved in a fatal accident while controlling for pilot experience. The first model assumes that the marginal effect of pilot age and experience is consistent across the whole range of age and flight experiences, while the second model examines if the effects are different for different age and experience categories.

Table 10
Pilot errors versus pilot categories of age and gender logistic regression estimates.

	Variables										
	Const.	Female	Age1	Age2	Age4	Age5	Age6	Exp1	Exp2	Exp3	Exp5
Panel A: 1983–1992											
Coefficient	1.28*	−0.05	−0.07	−0.06	−0.02	0.03	0.07	0.56*	0.46*	0.13*	−0.18*
Odds ratio	3.59	0.95	0.93	0.94	0.98	1.03	1.07	1.75	1.58	1.14	0.84
Panel B: 1993–2002											
Coefficient	1.21*	−0.03	0.15	−0.05	−0.04	0.08	0.18*	0.74*	0.44*	0.14*	−0.18*
Odds ratio	3.35	0.97	1.17	0.95	0.96	1.09	1.19	2.10	1.56	1.15	0.83

Table 11
Fatal accidents versus age and gender logistic regression estimates.

	Variables			
	Constant	Gender	Age	Experience
Panel A: 1983–1992				
Coefficient	−2.65*	−0.70*	0.74*	0.13*
Odds ratio	0.07	0.50	2.09	1.14
Panel B: 1993–2002				
Coefficient	−2.11*	−0.27*	0.38*	0.14*
Odds ratio	0.12	0.77	1.46	1.15

The first model can be expressed as:

$$Fatal_i = a + b_1 Gender_i + b_2 \log(Age_i) + b_3 \log(Experience) + e_i \quad (3)$$

where *Fatal* is 1 if an accident caused fatal injuries and 0 otherwise; again *Gender* takes a value of 1 for female pilots and 0 for male pilots; *Age* is pilot's age in years and *Experience* is the total flight time of the pilot involved in the accident.

Table 11 presents the estimation results for Model (3) using the data for both decades. "*" indicates statistical significance at the 1% level. All of the coefficients in both decades are highly statistically significant. The results suggest that female pilots are less likely to be involved in fatal accidents than their male counterparts. On the other hand, positive and statistically significant coefficients of pilot age and experience indicate that older and more experienced pilots are more likely to be involved in fatal accidents than younger and less experienced pilots. A plausible explanation of these seemingly counterintuitive findings is that older and more experienced pilots can fly in more challenging flights (e.g., at night, in instrument meteorological conditions) where a wrong decision, mechanical malfunction, or pilot error is more likely to lead to a fatal accident than in case of flying in a less challenging flight (e.g., at day time in visual meteorological conditions).

As in the pilot error analysis the second logistic regression model is designed to differentiate the effect of pilot's age and experience on the likelihood of a pilot to be involved in a fatal accident among different age and experience categories. Similarly, we include six categories of pilot's age and five categories of pilot's experience in the model and utilize Category III of pilot's age (30–39 years old) and Category IV of pilot's experience (2000–5000 h) as reference categories.

The model can be expressed as:

$$Fatal_i = a + b_1 Gender_i + b_2 Age1_i + b_3 Age2_i + b_4 Age4_i + b_5 Age5_i + b_6 Age6_i + b_7 Exp1_i + b_8 Exp2_i + b_9 Exp3_i + b_{10} Exp5_i + e_i \quad (4)$$

Table 12 presents the estimation results for Model (4) using the data for both decades. "*" and "**" indicate statistical significance at the 1% and 5% levels respectively. Similar to Model (3), pilot's gender coefficients are highly statistically significant in both decades, indicating that female pilots are less likely to be involved in a fatal accident than male pilots. However, similar to the result of the Chi-square analysis in Section 4.2.1, the difference between male and female pilots diminishes over time. Both, *Female* coefficient and its odds ratio in 1993–2002 subsample suggest that the importance of this variable is not as high as in 1983–1993 period. It seems that female pilots are becoming just as likely as male aviators in terms of the likelihood of being involved in a fatal accident.

Also, with respect to pilot's age categories, Model (4) provides some additional insights. The results suggest that during 1983–1992 pilots in age Category I were not different from the pilots in the reference Category III with respect to the likelihood of being involved in a fatal accident, while pilots in all other categories were more likely to be involved in a fatal accident. On the other hand, 1993–2002 subsample analysis produces slightly different results. The coefficients of age Categories I through V are not statistically significant suggesting than only pilots that are older than 60 years old are more likely to be involved in a fatal accident than pilots in the reference category of 30–39 years old.

Also, the experience category coefficients that are highly statistically significant for Categories I through III in 1983–1992 subsample and for Categories I, II, and V in 1993–2002 subsample suggest that experience plays an important role in the likelihood of being involved in a fatal accident. Thus, pilots with less flight experience than the reference group of 2000–5000 h are less likely to have a fatal accident, while pilots with more experience are more likely to be involved in a fatal accident (based on 1993–2002 subsample). Also, as indicated by the coefficients and odds ratios, the relative significance of the pilot experience is increased for low-

Table 12
Fatal accidents versus pilot categories of age and gender logistic regression estimates.

	Variables										
	Const.	Female	Age1	Age2	Age4	Age5	Age6	Exp1	Exp2	Exp3	Exp5
Panel A: 1983–1992											
Coefficient	−0.60*	−0.68*	−0.10	0.09**	0.26*	0.28*	0.39*	−0.81*	−0.22*	−0.11*	−0.04
Odds ratio	0.55	0.51	0.90	1.09	1.29	1.33	1.48	0.44	0.80	0.90	0.96
Panel B: 1993–2002											
Coefficient	−0.51*	−0.28*	0.27	−0.02	0.01	0.07	0.19*	−0.84*	−0.24*	−0.03	0.14*
Odds ratio	0.60	0.76	1.31	0.98	1.01	1.08	1.21	0.43	0.79	0.97	1.15

experienced pilots meaning that low time pilots have less chances of being involved in a fatal accident than medium time pilots. Again, a potential explanation of these seemingly counterintuitive results is that more experienced pilots fly in more challenging conditions and perform more challenging flights.

5. Conclusion

In this paper we conduct multiple Chi-square tests and logistic regression analyses to examine the relationship between pilot-related characteristics, such as gender, age and experience and the likelihood of pilots being involved in a GA accidents caused by pilot errors that resulted in fatal injuries.

The findings suggest that male and female GA pilots are not different with respect to the likelihood of an accident being caused by pilot error. On the other hand, female GA pilots are less likely to be involved in fatal accidents than their male counterparts. This finding is in accordance with that of Vail and Ekman (1986). However, this apparent ability of female pilots to make fewer fatal mistakes diminishes with time. While the difference between male and female pilots is still significant in the second period sample (1993–2002), the magnitude is much smaller compared to the first period (1983–1992).

The Chi-square analysis and logistic regression performed with 1993–2002 data indicates that pilots that are older than 60 years of age are more likely to be involved in an accident caused by pilot error. In addition, 60 plus year old pilots are more likely to be involved in a fatal accident.

As expected, the analysis of the association between pilot experience and pilot error caused accidents, reveals that more experienced pilots are less likely to be involved in an accident caused by pilot error. This seems to hold true with the previous findings about airline pilots by Li et al. (2003). However, more experienced pilots are more likely to be involved in a fatal accident, probably, due to the higher risk environment they fly in and more challenging flights they perform.

The important managerial implication from this study is that there should be no discrimination between male and female pilots, or between young and senior pilots up to 60 years of age with respect to their safety performance, as measured by the likelihood of pilot error. Since the risks of pilot error might be more related to external environmental factors other than pilot-related characteristics, more attention should be given to training that would minimize safety implications of adverse external factors and to technological improvements that would increase flight safety.

References

Baker, S.P., Lamb, M.W., Grabowski, J.G., Rebok, G., Li, G., 2001. Characteristics of general aviation crashes involving mature male and female pilots. Aviation, Space, and Environmental Medicine 72, 447–452.

Bazargan, M., Guzhva, V., 2007. Factors contributing to fatalities in general aviation. World Review of Intermodal Transportation Research 2, 170–182.

Booze Jr., C.F., 1987. Sudden In-Flight Incapacitation in General Aviation. Federal Aviation Administration Washington DC Office of Aviation Medicine.

Broach, D., 2000. Pilot Age and Accident Rates: A Re-analysis of the 1999 Chicago Tribune Report and Discussion of Technical Considerations for Future Analysis.

Craig, P., 2001. Flying through the zone. A pilot's first 1,000 flight zone. In: Proceedings of 11th International Symposium on Aviation Psychology.

Dambier, M., Hinkelbein, J., 2006. Analysis of 2004 German general aviation aircraft accidents according to the HFACS model. Air Medical Journal 25 (6), 265–269.

Hair, J., Black, B., Babin, B., Anderson, R., Tatham, R., 2005. Multivariate Data Analyses, sixth edition. Prentice Hall.

Harkey, J.A., 1996. Age-related changes in selected status variables in general aviation pilots. Journal of the Transportation Research Board 1517, 37–43.

Li, G., 1994. Pilot-related factors in aircraft crashes: a review of epidemiologic studies. Aviation, Space, and Environmental Medicine 65 (October), 944–952.

Li, G., Baker, S., Grabowski, J., Rebok, G., 2001. Factors associated with pilot error in aviation crashes. Aviation, Space, and Environmental Medicine 72 (1), 52–58.

Li, G., Baker, S., Grabowski, J., Qiang, Y., McCarthy, M., Rebok, G., 2003. Age, flight experience, and risk of crash involvement in a cohort of professional pilots. American Journal of Epidemiology 157 (10), 874–880.

McFadden, K.L., 1996. Comparing pilot-error accident rates of male and female airline pilots. Omega 24 (August (4)), 443–450.

McFadden, K.L., 1997. Predicting pilot-error incidents of US airline pilots using logistic regression. Applied Ergonomics 28 (3), 209–212.

McLean, J., 1986. Determining the effects of weather in aircraft accident investigations. In: Proceedings of American Institute of Aeronautics and Astronautics (AIAA) 24th Aerospace Sciences Meeting.

O'Hare, D., Chalmers, D., 1999. The incidence of incidents: a nationwide study of flight experience and exposure to accidents and incidents. The International Journal of Aviation Psychology 9, 1–18.

Tabachnick, B.C., Fidell, L.S., 1996. Using Multivariate Statistics. HarperCollins, New York.

Taneja, N., Wiegmann, D., 2002. An analysis of in-flight impairment and incapacitation in fatal general aviation accidents (1990–1998). In: Proceedings of the Human Factors and Ergonomic Society 46th Annual Meeting , pp. 155–159.

Tsang, P., 1992. A reappraisal of aging and pilot performance. International Journal of Aviation Psychology 2 (3), 193–212.

Vail, G.J., Ekman, L.G., 1986. Pilot-error accidents: male vs. female. Applied Ergonomics 17, 297–303.

Vermeulen, L.P., Mitchell, J.I., 2007. Development and validation of a measure to assess perceptions regarding gender-related pilot behavior. International Journal of Aviation Psychology 17 (2), 197–218.

Wiggins, M., O'Hare, D., 1995. Expertise in aeronautical weather-related decision making: a cross-sectional analysis of general aviation pilots. Journal of Experimental Psychology: Applied 1 (4), 305–320.