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Geographic Region, Weather, Pilot Age and Air Carrier Crashes: a Case-Control Study

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Abstract

Background—Information about risk factors of aviation crashes is crucial for developing effective intervention programs. Previous studies assessing factors associated with crash risk were conducted primarily in general aviation, air taxis and commuter air carriers.

Methods—A matched case-control design was used to examine the associations of geographic region, basic weather condition, and pilot age with the risk of air carrier (14 CFR Part 121) crash involvement. Cases (n=373) were air carrier crashes involving aircraft made by Boeing, McDonnell Douglas, and Airbus, recorded in the National Transportation Safety Board's aviation crash database during 1983 through 2002, and controls (n=746) were air carrier incidents involving aircraft of the same three makes selected at random from the Federal Aviation Administration's aviation incident database. Each case was matched with two controls on the calendar year when the index crash occurred. Conditional logistic regression was used for statistical analysis.

Results—With adjustment for basic weather condition, pilot age, and total flight time, the risk of air carrier crashes in Alaska was more than three times the risk for other regions [adjusted odds ratio (OR) 3.18, 95% confidence interval (CI) 1.35 – 7.49]. Instrument meteorological conditions were associated with an increased risk for air carrier crashes involving pilot error (adjusted OR 2.26, 95% CI 1.15 – 4.44) and a decreased risk for air carrier crashes without pilot error (adjusted OR 0.57, 95% CI 0.40 – 0.87). Neither pilot age nor total flight time was significantly associated with the risk of air carrier crashes.

Conclusions—The excess risk of air carrier crashes in Alaska and the effect of adverse weather on pilot-error crashes underscore the importance of environmental hazards in flight safety.

Keywords

accident; aviation safety; pilot error; risk factors

INTRODUCTION

Several studies of crashes in general aviation, air taxis, and air carriers have identified a host of risk factors. Previously reported factors include pilot age, total flight time (as a proxy measure for pilot experience), flight time in the last 90 days (both as a measure of flight currency and a measure of fatigue), previous crash and incident involvement, driving-while-intoxicated history, instrument rating, fatigue, geography (particularly mountainous terrain), and others (2,5,9–20). Geographic variations in crash risk for general aviation and air taxis have been reported, but there is less information available in the scientific literature regarding geographic variations and environmental factors (or weather conditions) in the risk of air carrier crashes.

Examining crash risk in general aviation and air taxis, Kearney and Li (13) reported the incidence rate to be highest in Alaska (22.8 crashes per 100,000 flight h), followed by the rate in the Northwest Mountain region (12.3 crashes per 100,000 flight h). The effect of pilot age on crash risk has been examined in a number of studies with inconsistent findings (1). Pilot error is reported to be a contributing factor in 35% of air carrier crashes (19). Another factor that has received much attention as a marker for pilot experience is cumulative flight time (total flight time or flight time in a given make/model of aircraft). Li and Baker (15) examined the relationship between future mishap involvement and crash and violation history in commuter and air taxi flights and found a complex, nonlinear relation between total flight time, flight time in the last six months, and the risk of future crash involvement. In their study, total flight time as a measure of experience had a protective effect on the risk of crash involvement, but the protective effect diminished as total flight time increased. Research examining these factors in air carrier (Part 121) crashes is scant. This study aims to assess the association between these factors and the risk of air carrier crashes occurring in the U.S. between 1983 and 2002.

METHODS

The protocol for this matched case-control study was approved by the Institutional Review Boards of Columbia University and Johns Hopkins University. The cases consisted of air carrier crashes (i.e., “accidents”) investigated by the National Transportation Safety Board (NTSB). The NTSB is an independent federal agency charged by Congress with investigating every civil aviation crash in the United States. Controls were obtained from the incident data system of the Federal Aviation Administration (FAA). All aviation crashes are reported to the NTSB, and all incidents are recorded by the FAA. The NTSB records aviation crash investigation data using the core Factual Report (NTSB Form 6120.4) and a set of supplemental forms. The core Factual Report includes detailed information on crash circumstances, aircraft, the pilot involved in the crash and a written narrative outlining all factors contributing to the crash. Incident investigation and reporting follow the same procedures as crash investigation. Procedures for investigating and reporting aviation crashes and incidents are described in detail by the federal government (8).

The federal government defines an aviation crash as “an occurrence associated with the operation of an aircraft in which any person experiences serious injury or death within 30 days of the aviation event or in which the aircraft receives substantial damage.” (8) Serious injury refers to any injury resulting in a “fracture of any bone (excluding simple fracture of fingers, toes, or nose), causing severe hemorrhage, nerve, muscle, or tendon damage, involving any internal organ, second- or third-degree burns, burns affecting more than 5% of the body surface,

and requiring hospitalization for more than 48 hours.” (8) Substantial damage to an aircraft is defined as “damage or failure that requires major repair or replacement of the affected component.” (8) An aviation incident is defined as an occurrence other than a crash associated with the operation of an aircraft which affects or could affect the safety of operations. (8) Incidents encompass selected criminal acts reported to or by law enforcement agencies, emergency evacuations of aircraft, in-flight major component failures, and any reportable event that threatened or caused damage to aircraft or injury to persons (e.g., near mid-air collisions, pilot deviations, and maneuvers resulting in the loss of separation).

Cases and controls are limited to crashes and incidents occurring in the U.S. and involving scheduled or unscheduled flights governed by Title 14 Code of Federal Regulations Part 121 (14 CFR Part 121), and to aircraft made by three major manufacturers: Boeing, McDonnell-Douglas, and Airbus. Commuter air carriers and air taxis (14 CFR Part 135) and general aviation (14 CFR Part 91) were excluded from this study. Beginning in 1997, the definition of passenger-carrying aircraft covered under Part 121 was lowered from a capacity of 31 or more to 10 or more passengers. This change was effective at the same time in both cases and controls.

A total of 373 cases were selected from the 668 air carrier crashes identified from the NTSB aviation crash data system for the years 1983 through 2002. Of the excluded crashes, 57 occurred outside the geographic study area, 89 had missing information on pilot age or basic weather conditions, five were caused by criminal acts, and 144 involved aircraft made by companies other than Boeing, McDonnell-Douglas, and Airbus. We excluded crashes involving aircraft that were not made by the three major manufacturers to minimize the confounding effect of factors related to aircraft and flight characteristics and to focus on the major airlines. The 144 crashes that were excluded based on aircraft make involved planes manufactured by a variety of companies. These aircraft tended to be smaller than aircraft of the three major makes. The diversity of manufacturers of these aircraft also made it unfeasible to match cases and controls on the variable of aircraft make. Controls were matched with cases on calendar year of the index crash. A 1:2 case-control sampling ratio was used to increase the study power.

Age of the pilot-in-command was measured as a continuous variable in years and analyzed as a categorical variable: 29–39, 40–49, and 50–59 years. Pilot error was determined only for cases according to the probable causes of the crash as identified in the NTSB investigation reports. Total flight hours were categorized into four groups based on the approximate quartiles: ≤ 9000 , 9000–11999, 12000–15999, and ≥ 16000 h. Total flight time in the last 90 days was categorized as: < 120 , 120–169, 170–199, and ≥ 200 h. Basic weather conditions were coded in the NTSB investigation reports as visual meteorological conditions (VMC) or instrument meteorological conditions (IMC).

The geographic entities examined in this study include nine FAA regions defined as follows: Eastern Region (District of Columbia, Delaware, Maryland, New Jersey, New York, Pennsylvania, Virginia and West Virginia); Central Region (Iowa, Kansas, Missouri, and Nebraska); Alaska; Great Lakes (Illinois, Indiana, Michigan, Minnesota, North Dakota, Ohio, South Dakota, Wisconsin); New England (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont); Northwest Mountain (Colorado, Idaho, Montana, Oregon, Utah, Washington, Wyoming); Southern (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee); Southwest (Arkansas, Louisiana, New Mexico, Oklahoma, Texas); and Western-Pacific (Arizona, California, Hawaii, and Nevada).

In the exploratory data analysis, the characteristics of cases and controls were compared using Miettinen’s method (21) to account for the matched design. Conditional logistic regression

models were used to estimate odds ratios (ORs) of crash involvement according to the individual variables. Total flight time in the last 90 days was not included in the multivariate analysis because of missing data for 39% of the case pilots and 16% of the control pilots. Both crude and adjusted ORs are presented with 95% confidence intervals (CI). Data analysis was conducted using the Statistical Analysis System (SAS) software (SAS Institute, Cary, NC).

RESULTS

A total of 373 cases were matched to 746 controls. Case and control pilots were similar in age and total flight time (Table I). On average, case pilots were aged 48.2 ± 6.8 years and had $13,034 \pm 5,403$ h of total flight time, compared with 47.5 ± 6.7 years and $12,456 \pm 5,351$ h for control pilots. Case pilots on average had significantly greater total flight time in the last 90 days (163 ± 53 h) than control pilots (120 ± 92 h) ($p < 0.0001$).

The geographic distributions of cases and controls differed significantly, with disproportionately more cases occurring in the Alaska region (Table I). The distributions of season and basic weather conditions were similar between cases and controls (Table I). Overall, 80% of the cases and 78% of the controls occurred under VMC.

Multivariate analysis revealed that the risk of air carrier crashes in Alaska was significantly higher than in other regions (Table II). When the data were stratified according to the presence of pilot error, the excess risk associated with Alaska appeared to be more pronounced for crashes that involved pilot error, although the difference between the odds ratios was not significant (Table II). The stratification analysis also revealed an interaction between basic weather condition and pilot error on the risk of air carrier crashes. Specifically, IMC was associated with a significantly increased risk for pilot-error crashes and a significantly decreased risk of crashes without pilot error (Table II).

DISCUSSION

This case-control analysis indicates that environmental factors, particularly geographic region and adverse weather, are important contributors to air carrier crashes. While our finding of excess risk in Alaska is consistent with previous reports on general aviation, commuter air carriers, and air taxis (10,11,13), our study suggests that the heightened risk in Alaska appears to be more pronounced for pilot-error crashes than crashes without pilot error.

The excess crash risk in Alaska for general aviation, commuter air carriers, and air taxis was explained by a variety of factors such as inadequate flight experience, cultural and communication differences, mountainous terrain, rapidly changing weather conditions, poor landing surfaces, and economic pressures to meet schedules (2,4,6,7,23,24). The heightened risk in Alaska for air carriers, however, is likely to be mainly caused by environmental hazards, such as clear air turbulence and icy runways. Flight conditions in Alaska present several unique features. Proximity to the Arctic Circle produces long nights where day landings may actually be dark, and days where the horizons may be associated with increased glare (22). It is worth noting that, despite the excess risk, Alaska accounts for only 5% of all air carrier crashes.

Pilot age, flight experience and weather are among the most widely reported factors in general aviation and air taxi crashes. This study revealed that neither pilot age nor total flight time was significantly associated with the risk of air carrier crashes. This negative finding is not surprising given that air carrier pilots are generally much better trained and healthier than other pilots.

Longitudinal trends in air carrier crashes indicate that the proportion of crashes involving pilot error declined by 40% during the study period (3). Advances in aviation science and

technology, particularly enhanced avionics, may have helped reduce the risk of pilot error. In this study, we matched cases and controls on year of flight to control for temporal bias. We relied on the randomly selected controls matched on type of operation and year of flight. Our findings, however, are susceptible to unmeasured confounding variables. For example, our finding of excess risk of air carrier crashes in Alaska is based on the assumption that aviation incidents were reported uniformly across geographic regions. Since we have no data to verify this assumption, the validity of this finding could be threatened if aviation incidents in Alaska were less likely to be reported to the FAA than in other regions. Due to the large proportion of the cases with missing data on total flight time in the last 90 days, we were unable to include recent exposure to flight in the multivariate analysis. This data limitation along with unmeasured confounding variables may introduce biases to our results.

While using aviation incidents as controls offers several notable advantages (e.g., availability of data and compatibility of flight operations), pilots involved in aviation incidents are not the ideal comparison group for a case-control study. Given that incident record is known to be positively associated with subsequent crash risk (12,15), comparing pilots involved in aviation incidents with those involved in crashes is likely to attenuate the associations of pilot characteristics with crash risk. Selecting a random sample from the general population of air carrier pilots to serve as the controls may produce more valid estimates on personal factors, such as age and total flight time, but would not allow the assessment of environmental factors, such as geographic region and basic weather conditions.

Despite the above limitations, our study adds valuable data to the research literature on aviation safety. Using the matched case-control design and two well-established surveillance data systems, we are able to quantify the relative risks of air carrier crashes in different geographic regions and basic weather conditions. The NTSB and FAA data systems are marked by high quality and technical depth, which reduces misclassification of variables of interest. The excess risk associated with certain geographic regions, particularly Alaska, warrants further investigation. A better understanding of the causes underlying the heightened risk in Alaska may spur development of effective countermeasures from innovative technology and training programs.

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Table 1
 Characteristics of air carrier crashes (cases) and incidents (controls) in the study sample, United States, 1983–2002.

Characteristics	Cases		Controls		p-value
	n*	%	n*	%	
Age					
29–39	48	12.9	102	13.7	0.61
40–49	156	41.8	329	44.1	
50–59	169	45.3	315	42.2	
Total flight hours					
<9,000	80	22.3	139	26.2	0.71
9,000–11,999	81	22.6	124	23.4	
12,000–15,999	98	27.4	142	26.8	
≥16,000	99	27.7	125	23.6	
Total flight hours in the last 90 days					
<120	48	21.1	272	43.4	<0.0001
120–169	67	29.5	134	21.4	
170–199	47	20.7	84	13.4	
≥200	65	28.6	137	21.8	
Season					
Jan–Mar	98	26.3	206	27.6	0.48
Apr–Jun	95	25.5	159	21.3	
Jul–Sep	92	24.7	191	25.6	
Oct–Dec	88	23.6	190	25.5	
Basic weather condition					
Visual meteorological	296	80.0	581	77.9	0.42
Instrument meteorological					
Region	74	20.0	165	22.1	
Alaska	18	4.8	16	2.1	0.009
Central	12	3.2	42	5.6	
Eastern	61	16.4	125	16.8	
Great Lakes	60	16.1	160	21.5	
New England	12	3.2	28	3.8	

Characteristics	Cases		Controls		p-value
	n*	%	n*	%	
Northwest Mountain	36	9.7	76	10.2	
Southern	89	23.9	124	16.6	
Southwest	32	8.6	76	10.2	
Western-Pacific	53	14.2	98	13.2	

* Totals vary across variables due to missing data.

Table II

Crude and adjusted odds ratios (OR) with 95% confidence intervals (CIs) for air carrier crashes with and without pilot error, United States, 1983–2002.

Variable	Cases with Pilot Error [*]		Cases without Pilot Error [†]		Total	
	Crude OR (95% CI)	Adjusted OR (95% CI)	Crude OR (95% CI)	Adjusted OR (95% CI)	Crude OR (95% CI)	Adjusted OR (95% CI)
Age (yrs)						
23–39	1.65 (0.85, 3.22)	2.26 (0.87, 5.89)	0.75 (0.46, 1.24)	0.98 (0.55, 1.74)	0.99 (0.67, 1.47)	1.25 (0.78, 2.01)
40–49	1.00	1.00	1.00	1.00	1.00	1.00
50–59	1.30 (0.80, 2.05)	1.80 (0.90, 3.60)	1.06 (0.77, 1.47)	1.01 (0.68, 1.49)	1.13 (0.87, 1.48)	1.26 (0.91, 1.76)
FAA region						
Alaska	4.50 (1.39, 14.61)	6.76 (1.32, 34.72)	1.53 (0.63, 3.73)	2.29 (0.79, 6.63)	2.32 (1.16, 4.61)	3.18 (1.35, 7.49)
Other regions	1.00	1.00	1.00	1.00	1.00	1.00
Total flight time (hrs)						
<9,000	0.86 (0.44, 1.70)	0.75 (0.33, 1.72)	0.85 (0.52, 1.38)	0.96 (0.57, 1.62)	0.85 (0.57, 1.26)	0.89 (0.58, 1.37)
9,000–11,999	0.53 (0.25, 1.13)	0.63 (0.27, 1.44)	1.15 (0.72, 1.85)	1.22 (0.75, 1.98)	0.93 (0.63, 1.37)	0.95 (0.63, 1.42)
12,000–15,999	1.00	1.00	1.00	1.00	1.00	1.00
≥16, 000	1.12 (0.55, 2.27)	0.95 (0.43, 2.12)	1.05 (0.65, 1.71)	1.12 (0.67, 1.88)	1.08 (0.72, 1.61)	1.01 (0.66, 1.53)
Basic weather condition						
Visual meteorological	1.00	1.00	1.00	1.00	1.00	1.00
Instrument meteorological	1.87 (1.11, 3.17)	2.26 (1.15, 4.44)	0.57 (0.40, 0.87)	0.60 (0.37, 0.96)	0.88 (0.64, 1.21)	0.97 (0.67, 1.39)

^{*}There were 119 cases and 238 controls.

[†]There were 254 cases and 508 controls.