FIA Score: A Simple Risk Index for Predicting Fatality in Aviation Crashes

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Background: Previous studies have identified a variety of risk factors for occupant fatality in aviation crashes. A simple composite index measuring the risk of fatality in a given crash, however, is lacking.

Methods: The FIA Score is a four-point (0–3) index based on the number of three risk factors for occupant fatality present in a given aviation crash: *f*ire, *i*nstrument meteorological condition, and being *a*way from airport. We assessed the validity of this risk index using aviation crash investigation data from the National Transportation Safety Board for the years 1983 to 2005. Sensitivity, specificity, and area under the receiver operating characteristic curve according to the type of flight operations were computed. The analysis was first limited to pilot-in-command fatality and then replicated to any fatality.

Results: The study sample consisted of 44, 828 aviation crashes, in which 7,889 (18%) pilots-in-command were fatally injured. The pilot crash fatality rate was 3%, 18%, 62%, and 89% for FIA Scores of 0 (none of the 3 risk factors present), 1, 2, and 3 (all 3 risk factors present), respectively. The FIA Score performed consistently well in predicting pilot fatality in crashes involving different types of flight operations. The area under receiver operating characteristic curve was 0.86 (95% confidence interval [CI]: 0.78–0.95) for major airline crashes, 0.83 (95% CI: 0.80–0.85) for commuter and air taxi crashes, and 0.81 (95% CI: 0.81–0.82) for general aviation crashes. The results were similar when the outcome was measured by whether or not the crash resulted in any fatality.

Conclusions: The FIA Score appears to be a valid tool for measuring fatality risk in aviation crashes. Given its simplicity, the FIA risk index should be readily applicable to trauma research and prevention.

Key Words: Accident, Aviation, Fire, Mortality, Risk assessment, Safety.

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Aviation is an important mode of transportation. In 2005, U.S. air carriers served a total of 657 million passengers with an additional 14 million tons of goods.[1] Civil aviation consists of two categories of flight operations: commercial and noncommercial. Commercial flights refer to those transporting people and goods for generating revenue, including air carriers, commuters, and air taxis. Noncommercial flights, usually called general aviation, are operated for pleasure or private business. Flight safety varies markedly with the type of operation. The fatal crash rate per 100,000 flight hours in 2006 was 0.011 for air carriers, 0.357 for commuter and air taxis, and 1.32 for general aviation.[2] Despite the low fatal crash rates, aviation safety remains a serious concern. Public concern about aviation safety results not only from the intense news media coverage of aircraft crashes, but also from the potential for a large number of casualties from a single crash because of any human error or mechanical malfunction. The crash fatality rate, defined as the proportion of crashes that are fatal, is indeed much higher in aviation than in motor vehicles. In 2001, for example, the crash fatality rate in aviation was approximately 19% compared with 0.6% in motor vehicles.[1,3]

In the past two decades, numerous studies have examined factors influencing occupant survival in aviation crashes.[4–12] Emerging from these studies are three major risk factors for occupant fatality: fire, instrument meteorological conditions (IMC), and off-airport location. Fire, primarily resulting from the crash impact and leakage of fuel, poses the most important hazard to occupant survival in aviation crashes. In a study involving 888 commuter and air taxi crashes, Li and Baker [7] found that postcrash fire was associated with an 8-fold increased risk of pilot fatality after adjustment for pilot characteristics (e.g., age and total flight time) and crash circumstances (e.g., type of aircraft, basic weather condition, location, and time). The excess risk of occupant fatality associated with fire has been confirmed in subsequent studies of general aviation crashes,[9,12,13] helicopter crashes,[4,6] rotary-wing aircraft crashes,[10] and air taxi crashes.[5]

The odds of fatality given a crash also vary significantly with basic weather conditions. Crashes occurring in IMC have 7- to 9-fold increased odds of fatality compared with crashes in visual meteorologic conditions.[4,5] The heightened risk of fatality in crashes in IMC may result from several mechanisms, including greater impact forces, delayed search

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and rescue efforts, and increased exposure of crash survivors to hazardous environmental factors such as subzero temperature.[14]

Crash location is another important determinant of survival outcome in aviation crashes. In a study of general aviation crashes, Li and Baker[9] reported that 36% of the pilots in crashes occurring away from airports were fatally injured, compared with 6% of the pilots in crashes at airports. The effect of off-airport location on crash fatality has been consistently documented in different flight operations and different countries.[5,10,11] Like IMC, off-airport location may increase the risk of crash fatality through multiple pathways. Crashes occurring away from airports are more likely to involve high-speed, uncontrolled impacts into terrain than on-airport crashes. Off-airport locations may also hamper search and rescue attempts.[14]

On the basis of our extensive research on aviation crashes and a thorough review of the pertinent literature, we developed a simple index for measuring fatality risk in aviation crashes. This risk index, called the FIA Score, is numerically equal to the total number of the three risk factors—***f***ire, ***I***MC, and being ***a***way from airport—present in a given crash. In this article, we assess the validity of the FIA Score using data for a sample of 44,828 aviation crashes investigated by the National Transportation Safety Board (NTSB).

MATERIALS AND METHODS

Data Source

Data for this study came from the NTSB aviation crash surveillance system. NTSB is an independent Federal agency charged by Congress with investigating every civil aviation crash in the United States and major mishaps in other modes of transportation (railway, marine, pipeline, and highway). Crash investigations are conducted for determining the probable cause of the crash and for making recommendations for preventing future crashes.

The NTSB defines an aviation crash ("accident" in NTSB terminology) as "an occurrence associated with the operation of an aircraft which 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." "Death" is any fatality that occurs within 30 days of the crash, and "serious injury" refers to any injury that requires hospitalization for more than 48 hours, that results in a fracture of any bone (except simple fractures of fingers, toes, or nose), that causes severe hemorrhage, nerve, muscle or tendon damage, that involves any internal organ, or that involves second- or third-degree burns or any burns affecting >5% of the body surface. "Substantial damage" to the aircraft means damage or failure that would normally require major repair or replacement of the affected component.

The NTSB has regional offices throughout the United States. When a crash occurs, a regional office is informed immediately and an investigation team is assembled and dispatched. Data gathered through the field investigation are recorded in the core Factual Report (NTSB Form 6120.4) and a set of supplemental forms. The core Factual Report contains over 200 data items, with detailed information about the crash circumstances, aircraft, and pilot involved in the crash. Among the many strengths of the NSTB data system are its high quality and technical depth. Procedures for notifying, investigating, and reporting aviation crashes are prescribed in detail by the Federal government (FAA Order 8020.11B). To ensure its objectivity in crash reporting and investigation, the NTSB has neither regulatory nor enforcement powers.

The NTSB recorded a total of 53,687 aviation crashes occurring between 1983 through 2005. Excluded from the study were 1,896 crashes involving gliders, balloons, blimps or dirigibles, ultra-lights, and gyroplanes, and 4,735 crashes involving flight operations other than major airlines (14 CFR Part 121), commuters and air taxis (14 CFR Part 135), and general aviation (14 CFR Part 91). Of the 47,056 crashes eligible for the study, 2,228 (5%) were excluded from the analysis because of missing data on fire, basic weather condition, or crash location and 11 were excluded for other reasons (e.g., terrorist attacks and bomb threats). The research protocol was approved by the institutional review board of the Johns Hopkins University School of Medicine via exemption.

Risk Index Construction

We constructed the FIA Score as a four-point risk index using the three well-recognized risk factors for crash survival: fire, IMC, and being away from airport. The FIA Score ranges from 0 (none of the 3 risk factors present) to 3 (all 3 risk factors present). The FIA Score is constructed under two assumptions: (1) each of the three risk factors has the same degree of influence on crash fatality; and (2) all combinations of these three risk factors have an additive effect on crash fatality. We evaluated the first assumption by assigning different weights to the fire factor, and the second assumption by comparing crash fatality rates in different strata of crashes according to the combination of the three risk factors.

Statistical Analyses

We calculated the FIA Score for each of the 44,828 aviation crashes included in the study. The validity of the FIA Score in measuring fatality risk was assessed by computing the sensitivity, specificity, and area under the receiver operating characteristic (ROC) curve. The ROC curve, graphed using sensitivity and 1—specificity for different points of the FIA Score, was used to measure the ability of the FIA Score to discriminate between fatal and nonfatal crashes. The area under the ROC curve, which ranges from 0.5 to 1, represents the probability that a fatal crash selected at random is rated higher by the FIA Score than a randomly chosen nonfatal crash.[15]

We performed the statistical analyses in three steps. First, we examined the associations of fire, IMC, and off-

Table 1 Pilot Crash Fatality Rates (CFRs) in Aviation Crashes by Major Risk Factors and by Type of Flight Operations, United States, 1983–2005

Risk Factors	Major Airlines				Commuters and Air Taxis				General Aviation				Total CFR (%)
	Number of Crashes	Pilots Killed	CFR (%)	p	Number of Crashes	Pilots Killed	CFR (%)	p	Number of Crashes	Pilots Killed	CFR (%)	p	
Aircraft fire													
Yes	81	25	30.9	<0.0001	370	235	63.5	<0.0001	4,224	2,620	62.0	<0.0001	61.6
No	577	6	1.0		1,906	228	12.0		37,670	4,775	12.7		12.5
Basic weather condition													
Instrument	116	10	8.6	0.03	476	197	41.4	<0.0001	3,212	1,966	61.2	<0.0001	57.1
Visual	542	21	3.9		1,800	266	14.8		38,682	5,429	14.0		13.9
Location of crash													
Away from airport	266	20	7.5	0.005	1,336	405	30.3	<0.0001	22,149	6,403	28.9	<0.0001	28.7
On airport	392	11	2.8		940	58	6.2		19,745	992	5.0		5.0
Total	658	31	4.7		2,276	463	20.3		41,894	7,395	17.7		17.6

airport location with crash fatality using bivariate and multivariate statistical techniques. Second, we assessed the validity of the FIA Score in predicting crash fatality among different categories of flight operations (major airlines, commuters and air taxis, and general aviation) based on sensitivity, specificity, and area under the ROC curve. Finally, we evaluated the robustness of the FIA Score in measuring fatality risk by replicating the analyses according to different outcome measures (pilot fatality and any fatality) and by testing different scoring schemes. In this study, "pilot" refers to the pilot-in-command of the crashed aircraft. Data analyses were conducted with the Statistical Analysis System software (SAS Institute, Cary, NC).

RESULTS

Pilot Fatality

The study sample consisted of 44,828 aviation crashes, in which 7,889 (18%) pilots were fatally injured (Table 1). General aviation accounted for 93% of the crashes and 93% of pilot fatalities. The crash fatality rate was lowest (5%) for major airline pilots and highest (20%) for commuter and air taxi pilots (Table 1). Fire, IMC, and off-airport location were each associated with significantly increased crash fatality rates in each of the three aviation categories (Table 1). Overall, the crash fatality rate for pilots was 62% if fire was present, 57% if the crash occurred in IMC, and 29% if the crash occurred away from the airport (Table 1). Multivariate logistic regression modeling revealed that the adjusted odds ratios for pilot fatality were 10.5 (95% confidence interval [CI]: 9.7–11.3) for fire, 6.0 (95% CI: 5.5–6.5) for IMC, and 6.4 (95% CI: 6.0–6.9) for off-airport location. Other variables included in the multivariate logistic regression model were time of crash, pilot age, total flight time, and type of aircraft; none of these variables had an odds ratio greater than 1.6.

Crash fatality rates for pilots increased progressively with the FIA Score, regardless of the aviation category (Fig. 1). Overall, the crash fatality rates for pilots were 3%, 18%, 62%, and 89%, respectively, for FIA Scores 0, 1, 2, and 3. The sensitivity and specificity were similar across aviation categories (Table 2). The area under the ROC curve ranged from 0.81 for general aviation crashes to 0.86 for air carrier crashes (Fig. 2).

Any Fatality

When the outcome was measured by whether or not the crash resulted in any fatality, the FIA Score performed similarly well as in predicting pilot fatality. The crash fatality rates were 7% for major airline crashes, 23% for commuter and air taxi crashes, and 19% for general aviation crashes. The areas under the ROC curve were 0.82 (95% CI, 0.75–0.90) for major airline crashes, 0.82 (95% CI 0.79–0.84) for commuter and air taxi crashes, and 0.81 (95% CI 0.81–0.82) for general aviation crashes.

Alternative Scoring Schemes

The four-point FIA Score presented above treats the three risk factors equally. Given that fire is known to be more hazardous to occupant survival than IMC and off-airport location, we examined alternative scoring methods by assigning greater weights to fire than to IMC and off-airport location. The sensitivity, specificity, and area under the ROC curve did not change appreciably from the simple, four-point system. For instance, when the presence of fire was given two points (instead of 1), the area under the ROC curve for predicting pilot fatality across all aviation crashes combined increased only slightly from 0.81 to 0.82.

Another assumption with the four-point FIA Score is that any combination of the three risk factors would have an additive effect on crash fatality. That is, there is no significant interaction among the three risk factors. To assess this assumption, we examined crash fatality rates in different strata and fitted a series of logistic regression models with different two-way and three-way interaction terms to screen for potential significant interactions among the three risk factors. The results revealed that the effect of fire in combination with the other two risk factors on crash fatality was significantly smaller than predicted by the additive model.

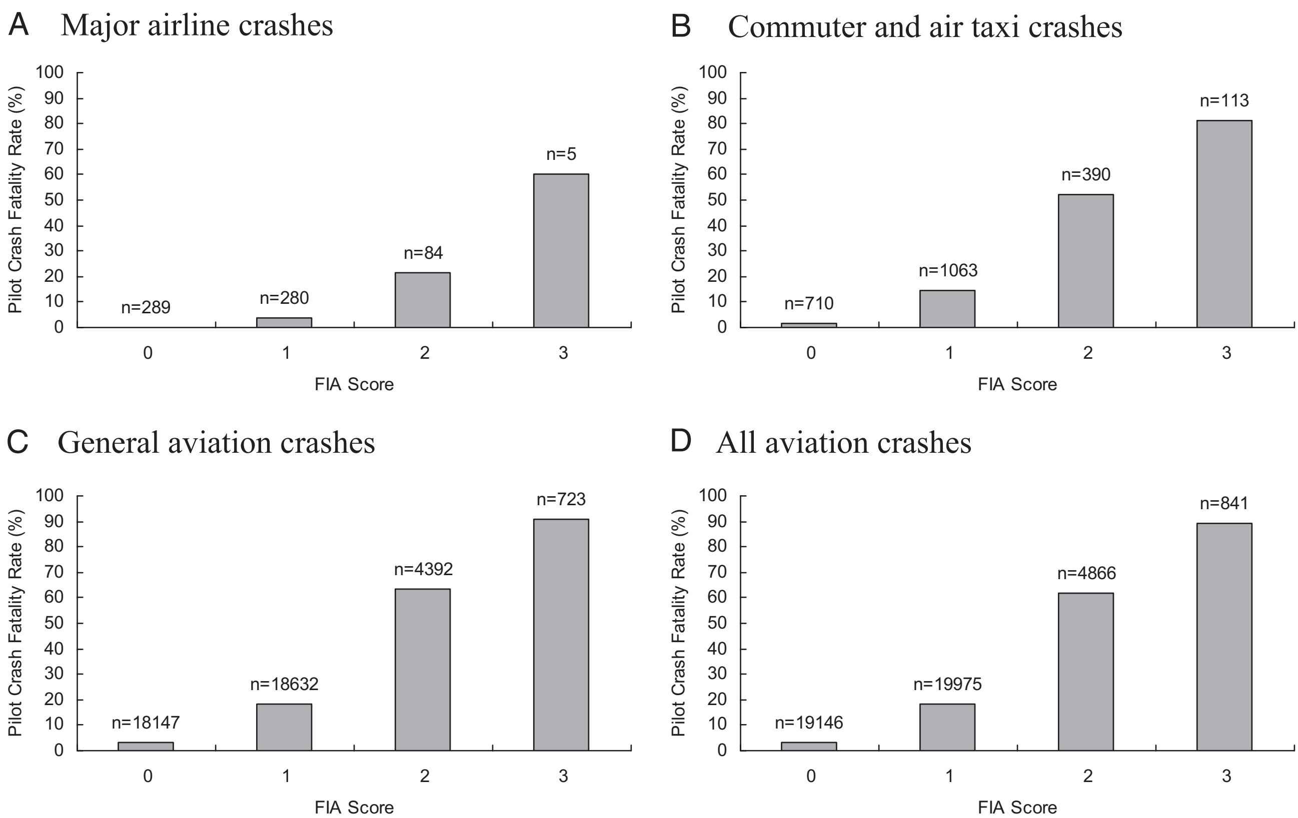

Fig. 1. *Pilot crash fatality rates by FIA score and by type of flight operation, United States, 1983 to 2005. (A) Major airline crashes. (B) Commuter and air taxi crashes. (C) General aviation crashes. (D) All aviation crashes.*

Table 2 **Sensitivity and Specificity of FIA Score for Predicting Pilot Crash Fatality, United States, 1983–2005**

FIA Points	Major Airlines		Commuters and Air Taxis		General Aviation		Total	
	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
0	1	0	1	0	1	0	1	0
1	1	0.44	0.97	0.31	0.92	0.43	0.93	0.42
2	0.68	0.87	0.64	0.78	0.45	0.88	0.47	0.87
3	0.10	0.99	0.20	0.95	0.09	0.98	0.09	0.98

DISCUSSION

The results of this study indicate that the FIA Score is a valid tool for measuring fatality risk in aviation crashes. This simple risk index performed consistently well across different aviation categories. In general, FIA Scores 0, 1, 2, and 3 correspond to 3%, 18%, 62%, and 89% of crash fatality risk, respectively. Given the large study sample and robustness of the results, the reported validity of the FIA Score is likely to be widely generalizable. In addition to its validity, the FIA Score has the considerable advantage of simplicity. Computation of the FIA Score does not require any sophisticated formula. Rather, it is so straightforward that it involves only counting the number of the three risk factors (fire, IMC, and being away from the airport) present in a given crash. Moreover, information about the three risk factors is almost always readily available.

The FIA Score could also be used as a measure of crash severity as postcrash fire, IMC, and off-airport location are likely proxies for impact forces. Previous studies have documented that 76% to 86% of aviation fatalities result from blunt trauma by deceleration forces.[16,17] Despite the apparent utility for crash investigation and safety research, quantitative estimates of the impact forces are difficult to make and rarely available. The FIA Score may help close this information gap if used as a proxy of the impact force.

It is noteworthy that the FIA Score is constructed based on three major risk factors for occupant fatality in aviation crashes and does not take into account other risk factors. In addition to fire, IMC, and off-airport location, previous studies[4–6,9,12] have revealed a host of factors that may influence occupant survival in aviation crashes, including time of crash, type of aircraft, usage of restraint systems, and pilot

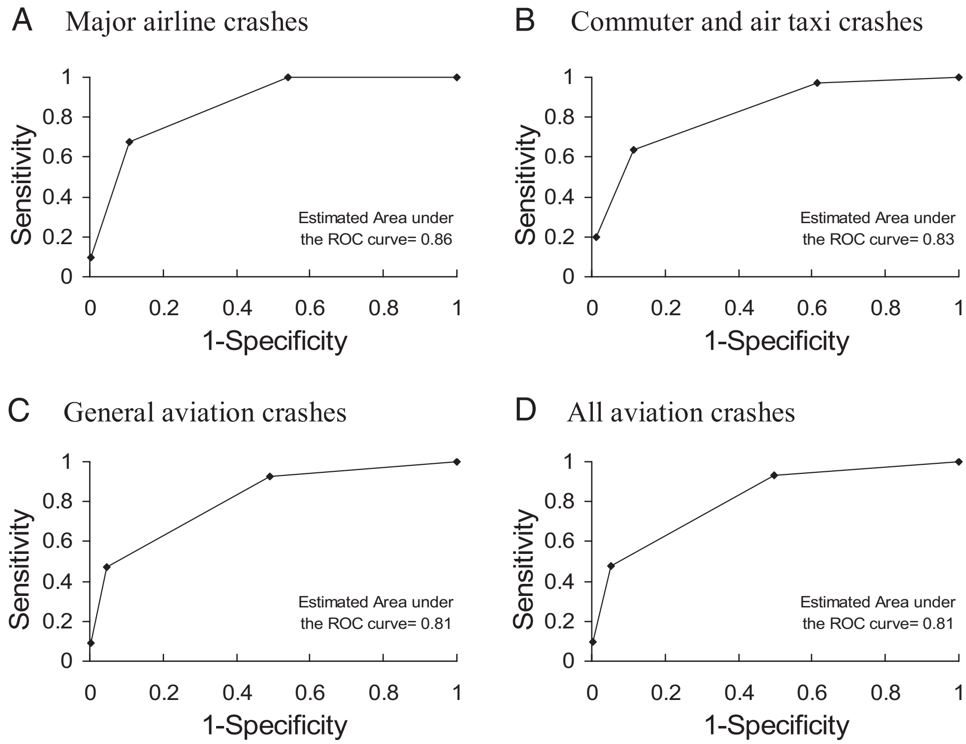

Fig. 2. *Area under the receiver operating characteristic (ROC) curve of FIA score for predicting pilot fatality in aviation crashes by type of flight operation, United States, 1983 to 2005. (*A*) Major airline crashes. (*B*) Commuter and air taxi crashes. (*C*) General aviation crashes. (*D*) All aviation crashes.*

age. For instance, Rostykus et al.[12] found pilots who were not wearing seatbelts and shoulder harnesses had a 70% higher risk of sustaining fatal injuries in general aviation crashes at landing. The effects on fatality risk of occupant characteristics, restraint systems, and other crash circumstantial factors, however, are much smaller than aircraft fire, IMC, and off-airport location. Data on some of those variables are often not as readily available as for the three risk factors making up the FIA Score.

Designed to serve as a simple index for measuring fatality risk in aviation crashes, the FIA Score could be used in trauma research and prevention. Cullen and Turk[18] described the value of examining injuries sustained by occupants in three substantive areas: crash reconstruction, evaluation of safety equipment, and resolving medicolegal issues. Within this context, the FIA Score could serve as a valuable tool in the analysis of aviation-related trauma and in safety program development and evaluation. The risk of postcrash fire has been virtually eliminated from United States Army helicopters through the installation of crash-resistant fuel systems.[19] Similar technology appears to be effective for civil aircraft as well.[20] Safety programs aimed at mitigating major risk factors for crash fatality may have a significant impact on the validity and utility of the FIA Score over time. Revision of the risk index would be warranted when technology advancement has significantly modified the profile of risk factors for occupant fatality in aviation crashes.

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