DOT/FAA/AM-04/8

Office of Aerospace Medicine
Washington, DC 20591

Methodological Issues in the Study of Airplane Accident Rates by Pilot Age: Effects of Accident and Pilot Inclusion Criteria and Analytic Strategy

Dana Broach
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

May 2004

Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-04/8		

4. Title and Subtitle	5. Report Date
Methodological Issues in the Study of Airplane accident Rates by Pilot Age: Effects of Accident and Pilot Inclusion Criteria and Analytic Strategy	May 2004
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Broach D	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Aerospace Human Factors Research Division (AAM-500) Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Office of Aerospace Medicine Federal Aviation Administration 800 Independence Avenue, S.W. Washington, DC 20591	

15. Supplementary Notes

This work was performed under approved research task AAM-00-A-HRR-520.

16. Abstract

At the direction of the U.S. Senate, Broach, Schroeder, and Joseph (2000a, b) examined accident rates by age for professional air transport and commercial pilots using an analysis of variance (ANOVA) approach. As an extension of that work, this report focuses on methodological issues requiring careful consideration and definition in any analysis of aviation accident rates by pilot age. Three methodological issues are considered: (a) accident inclusion criteria; (b) pilot inclusion criteria; and (c) analytic strategy. Previous studies are interpreted with respect to these issues, and an additional analysis is presented to illustrate the impact of methodological choices on study outcomes. Overall, the comparisons and additional analysis indicate that accident and pilot inclusion criteria and analytic strategy have substantial impact on study outcomes. Recommendations are presented for future studies of the relationship of pilot age to aviation accidents.

17. Key Words	18. Distribution Statement
Pilot Age, Aviation Accidents, Accident Rates, Age 60 Rule, Mandatory Pilot Retirement	Document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	26	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Methodological Issues in the Study of Airplane Accident Rates by Pilot Age: Effects of Accident and Pilot Inclusion Criteria and Analytic Strategy

INTRODUCTION

In 1959, the Federal Aviation Administration (FAA) adopted what has come to be known as the "Age 60 Rule" (24 Fed. Reg. 9,767, December 5, 1959). This regulation prohibits any air carrier from using the services of any person as a pilot or co-pilot, and prohibits any person from serving as a pilot or co-pilot, on an airplane engaged in operations under Part 121 of the Federal Aviation Regulations (FARs) if that person has reached his or her 60th birthday [14 C.F.R. §121.383(c)]. The "Age 60 Rule" has been, and continues to be controversial. The rule has been the subject of commentary, research, and legal challenge since its inception. Most recently, the rule has been the subject of Congressional interest. For example, three bills (Senate 361 and House Resolutions 481 and 1063) were introduced in the 106th Congress to change the rule. The U.S. Senate directed the FAA in 1999 to conduct a study of pilot age and accident rates (U.S. Senate, 1999). The Senate language provided very specific directions as to how to conduct the desired study. In response, the FAA completed four studies. The first study ("Study 1") was an annotated bibliography of the research literature from 1991 to 1999 (Schroeder, Harris, and Broach, 1999). The second study ("Study 2") presented a re-analysis of data included in a study of pilot age, accidents, and incidents reported by the Chicago Tribune in 1999 and a discussion of methodological issues in the study of pilot age and accident rates (Broach, 1999).

The third and fourth reports documented two empirical studies of pilot age and accident rate. Study 3 (Broach, Schroeder, & Joseph, 2000a) examined accident rates by age for professional pilots holding Air Transport Pilot (ATP) and Class 1 medical certificates. The fourth and final study ("Study 4") in the set investigated accident rates by age for professional pilots holding ATP or Commercial Pilot (CP) and Class1 or 2 medical certificates (Broach, Schroeder, & Joseph, 2000b). The results of the analyses of accident rate, with pre-planned comparisons between age groups on either side of the "Age 60 Rule" in the two empirical studies were mixed. On one hand, a significant relationship between age and accident rate was observed in both studies. Specifically, a statistically significant quadratic trend between age and accident rate was reported in both of the empirical studies. That is, accident rates were higher at younger ages (less than 40), lower through the forties and early fifties, then rose again in the late fifties. A linear trend also fit the age-accident rate data, but less well than the quadratic trend. On the other hand, the *a priori* planned comparison of the accident rates for pilots age 55-59 with that for pilots 60-63 was significant in one study but not the other. When the study population was defined as professional pilots holding ATP and Class 1 medical certificates in Study 3, no significant difference was found between accident rates for pilots in the 55-59 and 60-63 year old age groups. But when the study population was defined as professional pilots holding ATP or CP and Class 1 or 2 medical certificates in Study 4, the accident rate for pilots in the 60-63 group (0.52 accidents per 100,000 annualized flight hours) was significantly greater than the rate for pilots in the 55-59 age group (0.27 accidents per 100,000 annualized flight hours; unequal variances, $t(11.18) = 2.34$, $p < .05$).

METHODOLOGICAL ISSUES

The difference between the results reported in Studies 3 and 4 suggest that methodological choices may have substantial influence on study outcomes. As noted by Li in a 1994 review, two key choices in the study of aviation accident rates are (a) the selection of events to include in the numerator and (b) the estimate of exposure in the denominator. Each of these choices entails decisions such as selection of a source database and record inclusion and exclusion criteria. However, another key choice is analytic strategy, as discussed in the previous empirical studies. Particular considerations are data aggregation, data grouping, rates versus counts of events as the dependent variable, and the analytic technique used. The purpose of the present study was to assess the effects of these methodological choices on study outcomes. The previous studies of age and accident rates are compared in terms of events included, exposure estimates, and analytic strategies. An additional analysis of the data set developed by Broach, Schroeder and Joseph in 2000 ("FAA Age 60 data set") is presented to illustrate the sensitivity of results to the methodology. Implications for future studies of pilot age and accident rates are discussed in closing.

Accident Inclusion Criteria

The first methodological choice is the selection of events to analyze. Studies 3 and 4 were constrained by language in the U.S. Senate (1999) report directing those efforts. The critical passage reads:

> The Committee directs the FAA to conduct a survey of all available non-scheduled commercial (and non-commercial, if available) data concerning the relative accident data correlated with the amount of flying by pilots as a function of their age for pilots of age 60–63 and comparing it with all four year groupings of scheduled commercial pilots (and non-commercial pilots, if available) declining from age 60, i.e., 56–59, 55–58, 54–57, * * * to 21–24. etc. In addition, compare the discernable groups in their entirety and track accident frequency as a function of age. (p. 80).

The Senate language focused on accidents. The National Transportation Safety Board (NTSB) maintains the official system of records for aviation accidents. Therefore, the first methodological choice made in both Studies 3 and 4 was to select the NTSB system of accident records ("NTSB database") as the source for event data. The next step was to define event inclusion criteria. Given the Senate language and the fact that the rule applied only to pilots of aircraft engaged in common carriage (e.g. commercial operations), Broach, Schroeder and Joseph focused on accidents in commercial operations. As shown in Figure 1, criteria for extraction of accident records from the NTSB database were: (a) the regulation under which the flight was conducted (Parts 121 or 135); (b) the date of the accident (January 1, 1988 through December 31, 1997); and (c) availability of a final report. Using these criteria, the NTSB extracted 1,359 aviation accident records for analysis by the FAA. Records with incomplete or missing pilot identifiers (24 records) or for events caused by terrorism (one record) were excluded from the data set as shown in Figure 1, resulting in a pool of 1,334 aviation accident records for the studies. The records were further reduced in Study 3 to 680 by selecting those records for accidents where the pilot held an ATP and Class 1 medical certificate at the time of the accident. In Study 4, all 1,334 records were included in the analysis.

Differences in the characteristics of the accidents included in each study were examined as the first step in the investigation of methodological influences on study results. One difference between Studies 3 and 4 was in the proportion of flights conducted under Part 135. Study 3 included 393 flights conducted under Part 135 (58% of accidents), while Study 4 included 1,047 flights conducted under Part 135 (78% of included accidents). Similarly, 391, or just over half (57%) of the flights in Study 3 were scheduled flights, compared with 424, or just under a third (32%), in Study 4. One-third (221, or 32.5%) of operators of accident aircraft were certificated for on-demand/air taxi operations only in Study 3, compared with over half (768, or 57.5%) in Study 4.

There were differences also in the aircraft characteristics between the two studies. For example, 91 (or 13%) of the accidents included in Study 3 involved fixed-wing, single-engine aircraft, compared with 439 (33%) in Study 4. Aircraft with 9 or fewer seats were involved in over a third (258, or 38%) of the accidents in Study 3, compared with two-thirds (864, or 65%) of the accidents in Study 4. Aircraft with reciprocating engines accounted for a third (34% or 229) of the accidents included in Study 3, compared with over half (53%, or 707) of the Study 4 accidents.

This review of the previous studies by Broach et al. indicated that the numerator in Study 4 was dominated by accidents involving smaller aircraft operating under Part 135. Historically, operations with smaller aircraft under Part 135 have had higher accident rates than operations with larger aircraft under Part 121 (Federal Aviation Administration, 1999; National Transportation Safety Board, 2002). It is unclear, therefore, if the analysis of accident rate by pilot age reflected the influence of age, the inherent risk of small aircraft operations characterizing Part 135 operations, or both.

Pilot Inclusion Criteria

The next methodological choice focuses on pilot inclusion criteria. As noted by Li (1994), the denominator in epidemiological studies of aviation accidents typically consists of some measure of exposure (to the risks of flight). Sources for exposure estimates include (a) flight hours documented by NTSB in the accident investigation and (b) self-reported flight hours from the medical examination. Estimates of flight hours based on NTSB accident investigations are, by definition, restricted to accident pilots only, and thus do not provide a proper estimate for the population at risk (e.g., all pilots or some subset, including those not involved in accidents). Self-reported flight hours at the time of the medical examination have been used in several investigations, including Studies 3 and 4. The official system of records for these data is the FAA's Comprehensive Airman Information System (CAIS).

The researcher again faces the problem of defining criteria by which to extract records for a subset of airman of interest from a large, complex database. The pilot inclusion criteria for Studies 3 and 4 are illustrated in Figure 2. The inclusion criteria were: date of medical examination; self-reported occupation; age at the time of the medical examination; type of pilot certificate; and class of medical certificate issued. Employer type was used as an exclusion criterion in both studies after matching the exposure records to NTSB accident records by pilot

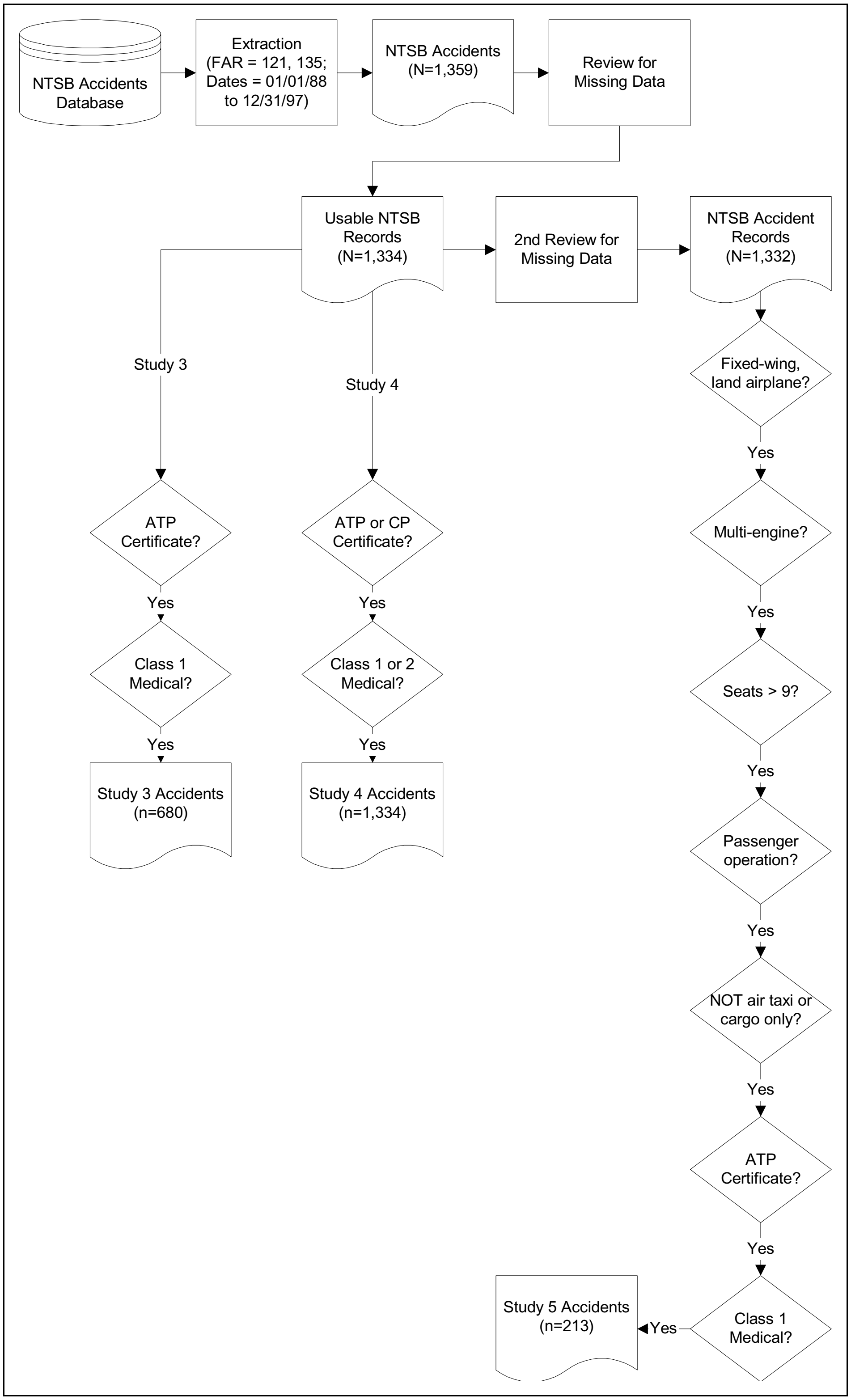

Figure 1
Accident inclusion logic for Study 5 compared with Studies 3 and 4

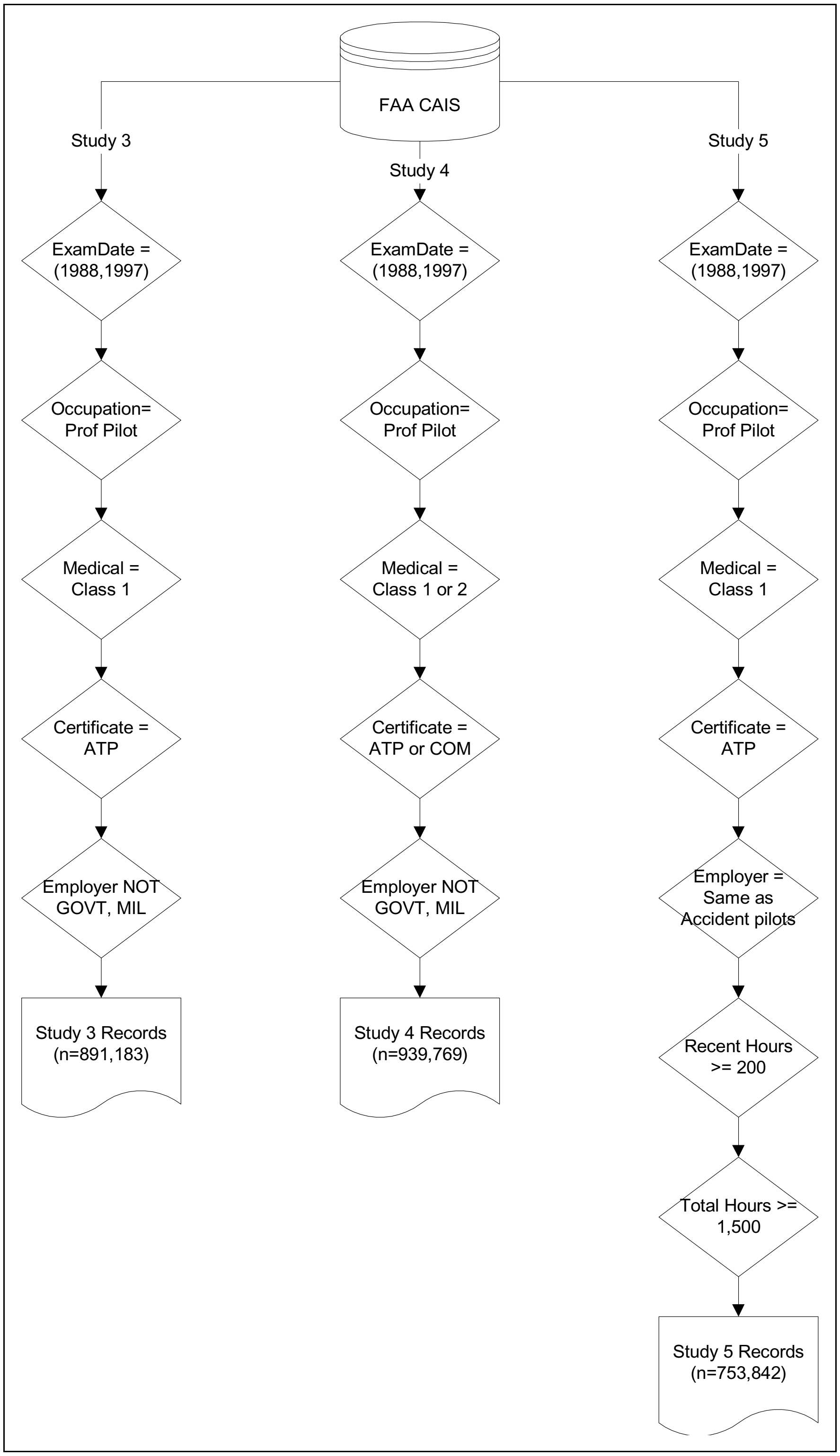

Figure 2
Pilot inclusion logic for Study 5 compared with Studies 3 and 4

identifiers and year. Matched exposure-accident records for pilots age 64 or older were also excluded in view of the Senate direction to compare accident rates for pilots age 60-63 with accident rates for younger pilots.

In both studies, records for examinations conducted between January 1, 1988 and December 31, 1997, were extracted from the CAIS medical database. Only records for pilots reporting "professional pilot" as the occupation were retained in both studies. In Study 3, records for pilots age 23 or greater at the time of their medical and holding ATP certificates were included. In Study 4, records for pilots age 18 or greater at the time of their medical examination and with either ATP or CP certificates were included. Study 3 included pilots with Class 1 medical certificates, while Study 4 included pilots with either Class 1 or 2 medical certificates. The inclusion criteria resulted in a pool of 891,183 records of Class 1 medical examinations for ATPs in Study 3. There were 939,767 records of Class 1 or 2 medical examinations for ATPs or Commercial Pilots available for Study 4. The CAIS medical records were aggregated by year and pilot identifiers and exposure hours annualized and then matched to NTSB accident records as described in the previous reports. Matched exposure-accident records for pilots employed by the government or military and pilots age 64 or older were excluded in both analyses in view of the specific Senate language focusing on pilots age 60 to 63. The characteristics of the resulting samples of pilots by age group and type of employer in each study are presented in Table 1.

Records for pilots indicating employment by an identifiable Domestic, Flag, or Supplemental (Part 121) carrier dominated both matched accident-exposure data sets. In Study 3, records from pilots reporting employment by an identifiable Part 121 carrier accounted for 75% of all matched accident-exposure records from which accident rates were calculated. Even among the oldest pilots (ages 60 to 63), identifiable Part 121 carriers dominated, accounting for 71% of those 7,258 matched accident-exposure records. In Study 4, records for pilots reporting employment by Part 121 carriers accounted for 73% of the total matched accident-exposure records. Even among the oldest pilots age 60 to 63, 67% of the records were for pilots reporting employment by identifiable Part 121 carriers. In other words, the FAA Age 60 data set was dominated by records from pilots of all ages reporting employment by identifiable Part 121 operators, that is, the population most likely impacted by the "Age 60 Rule." At first, this seemed puzzling given the common description of the rule as forcing retirement at age 60 on airline pilots. There are two possible explanations. First, the "Age 60 Rule" prohibits a person who has reached age 60 from serving as the pilot-in-command or co-pilot of aircraft engaged in operations under Part 121; the rule does *not* require mandatory retirement of a pilot or termination of the pilot's employment upon reaching age 60. Thus, it is possible that the older pilots continued working for an air carrier after reaching age 60 in roles other than pilot for flights operated under Part 121. Second, many airline operators are certified for multiple classes of operations. It may be the case that older pilots remained with the reported carrier and served as the pilot for flights conducted under regulations other than Part 121.

While some pilots stayed on, it appears that most had sought other opportunities as evidenced by the ten-fold reduction in the number of records for pilots age 60-63 compared with age 55-59. As shown in Table 1, pilots age 60 to 63 at the time of medical examination represented 1.2% of matched accident-exposure records in both studies. As a result, estimates of exposure hours for this age group are based on far fewer records than for pilots in other age ranges. It is also worth noting that the number of matched accident-exposure records declines with age starting with the 40-44 age group in both studies. Additional research into the "career history" of professional pilots might be warranted. Such research might investigate the reasons for attrition, including health and retirement, from the occupation at different ages.

Inspection of Table 1 also indicates that the distribution of pilots across employer types changes with pilot age in both studies. For example, 86% of the 61,663 accident-exposure records for pilots in the 55-59 age group indicated employment by an identifiable Part 121-certificated operator in Study 3, compared with just 71% of the 7,258 accident-exposure records for pilots in the 60-63 age group who indicated employment by Part 121 operators. The proportion of pilots age 55-59 employed by Part 121 operators was significantly greater than the proportion of Part 121 employee pilots age 60-63 in Study 3 ($Z = 27.27$, $p < .001$). Moreover, the proportion of matched accident-exposure records indicating employment by "Other" for pilots in the 60-63 age group was nearly double the proportion of pilots in the 55-59 age group. A similar pattern of change in employer types with age was also observed in Study 4. It is unclear from review of the CAIS data dictionaries what types of operators are included in the "Other" employer category. Moreover, as shown in Table 1, records for pilots employed by entities other than Part 121 and 135 carriers were included in the matched accident-exposure records in Studies 3 and 4.

The effect of this sampling error (e.g., inclusion of pilots employed by entities other than Part 121 or 135 carriers) was to inflate the exposure estimate in the

Table 1
Number of matched exposure-accident records by employer type and age group for Studies 3 and 4

	Employer Type									
Age Group	Part 135	Part 121	Foreign	Government	Military	Industry	Other	Self	Missing	Total
Study 3[1]										
LE 29	1,648	19,098	334			85	22,957	52	451	44,625
30-34	2,161	61,415	1,157			71	27,802	75	674	93,355
35-39	1,818	86,549	1,656			76	23,716	71	581	114,467
40-44	1,397	85,488	1,249			100	20,614	64	529	109,441
45-49	1,255	84,994	1,039			101	17,641	77	507	105,614
50-54	681	77,466	915			114	11,953	46	445	91,620
55-59	362	53,054	759			61	7,104	58	265	61,663
60-63	47	5,155	149			31	1,746	24	106	7,258
Total	9,369	473,219	7,258			639	133,533	467	3,558	628,043
Study 4[2]										
LE 24	199	1,242	449			34	3,813	26	206	5,969
25-29	1,587	19,406	1,526			86	23,488	64	580	46,737
30-34	2,245	64,339	2,409			90	30,837	112	791	100,823
35-39	1,885	90,258	2,231			98	26,565	106	734	121,877
40-44	1,444	87,881	1,807			126	23,168	85	736	115,247
45-49	1,295	87,494	1,567			123	19,884	105	658	111,126
50-54	715	79,689	1,494			134	13,698	79	630	96,439
55-59	378	54,175	1,375			76	8,103	75	374	64,556
60-63	50	5,396	279			33	2,028	39	206	8,031
Total	9,798	489,880	13,137			800	151,584	691	4,915	670,805

Notes: [1]Study 3 total excluded 1,396 accident-exposure records for pilots age 64 or older.
[2]Study 4 total excluded 1,803 accident-exposure records for pilots age 64 or older.

denominator, leading to an under-estimate of accident rates. For example, if the number of Part 121 or 135 accidents for a given age group is 100, and the number of exposure hours is 25,000,000, then the accident rate is 100/25,000,000 or .400 accidents per 100,000 flight hours. If the exposure hours are inflated by hours contributed by pilots other than those employed by certificated Part 121 and 135 operators by a factor of 1% (250,000 hours), then the accident rate is 100/25,250,000 (.396 accidents per 100,000 flight hours). If exposure hours are inflated by 10%, then the accident rate decreases to .363 per 100,000 flight hours. Overall, it appears that the "true" accident rate for pilots covered by the rule across age groups may have been underestimated in Studies 3 and 4 as a result of inclusion of exposure hours from pilots not in the target population of certificated Part 121 and 135 operators.

Analytic Strategy

Analytic strategy includes the decision to focus on rates or counts as the appropriate unit of analysis. Analysis of rates requires computing and comparing the ratio of events to exposure for definable groups. An analysis of rates also requires that data be grouped by some rule and aggregated within those groups. Studies 3 and 4 analyzed accident rate by age group. The Senate report language directed that the data be grouped in overlapping, 4-year increments (e.g., "… declining from age 60, i.e., 56–59, 55–58, 54–57, * * * to 21–24," U.S. Senate, 1999, p. 80). However, as noted in Studies 3 and 4, such a grouping violates the assumption of independence between groups required for statistical analysis by techniques such as analysis of variance (ANOVA). In both studies, an additional analysis was performed, grouping cases by age at the time of the medical examination into independent age groups, as shown in Table 1. In both studies, accident and exposure data were aggregated by calendar year and age group in order to have more cases than levels on the grouping variable (age group). As noted in those reports, this resulted in 80 year-age group records. The unit of analysis was the year-age group combination, not the individual pilot.

While there was an equal number of "cases" (e.g., the 80 year-age group records) in each study, substantially different numbers of pilots contributed exposure hours to the year-age group combinations. For example, the number of pilots age 60-63 contributing exposure hours to the rate denominator in Study 3 ranged from 406 to 1,057 across the 10 years encompassed by the study. In comparison, about 7 to 10 times as many pilots age 55-59 contributed exposure hours (4,404 to 7,542 each year). The reports for Studies 3 and 4 noted the greater variability in the accident rate for the oldest age group (60-63) and attributed it to the smaller number of pilot records for that age group.

However, the greater variability in the accident rates for older pilots does not completely explain the difference in results reported in Studies 3 and 4. On one hand, a statistically significant quadratic trend across age groups was reported in Study 3, but the *a priori* comparison between pilots in the 55-59 and 60-63 age groups was non-significant. On the other hand, in Study 4, both the quadratic trend across age groups and the *a priori* comparison of accident rates for pilots age 55-59 to that for pilots 60-63 were statistically significant. In reviewing these studies, Wilkening (2002; see also Woolsey, 2003a) suggested that flight time accumulated in Part 121 operations "dominates the denominator" up to age 60, and the numerator includes accidents occurring under both Part 121 and 135. However, after age 60, the numerator is based on Part 135 accidents only, and the "much safer Part 121 flight hours" are missing from the denominator, leading to "artificially higher" accident rates for pilots over age 60 (aged 60 to 63 specifically). Wilkening suggested that the statistical difference in accident rates for the 55-59 and 60-63 age groups reported in Study 4 was an artifact, and may have reflected the historically higher risks associated with operations under Part 135 rather than the risk associated with pilot age. This concern has also been noted in an appellate court decision upholding the FAA's rejection of a petition for exemption from the rule (Baker et al. v. Federal Aviation Administration, 1990).

Another possibility is that the difference is attributable to factors other than age, such as the type of flying conducted by older pilots. For example, it is impossible for pilots over age 60 to accumulate hours as a Pilot-In-Command (PIC) or co-pilot of an aircraft operated under Part 121 in view of the "Age 60 Rule." While direct information on type of flying is not available, the self-reported "employer" at the time of medical examination can serve as a proxy or indicator for the type of flying engaged in by a pilot. To determine if other factors such as type of flying might explain the observed difference in accident rates, the characteristics of pilots age 55-59 and 60-63 in Study 4 were compared. Overall, the proportion of pilots age 55-59 employed by an identifiable Part 121 operator (54,175 of 64,556 records, or 83.9%) was greater than the proportion of pilots age 60-63 (5,396 of 8,031 records, or 67.2%; $Z = 30.78$, $p < .001$). Conversely, fewer pilots age 55-59 in Study 4 reported "Other" employment (8,103 records, or 12.6%) compared with pilots age 60-63 (2,028 records, or 25.3%; $Z = -25.30$, $p < .001$). This suggests that pilots in the 55-59 and 60-63 age groups systematically varied on at least one dimension (self-reported "employer" as a proxy for type of flying) in addition to age. Consequently, the statistical difference in accident rates reported in Study 4 might be attributable in part to a factor other than pilot age.

Discussion

Review of Studies 3 and 4 in terms of accident inclusion criteria, pilot inclusion criteria, and analytic strategy suggest that methodological choices have a substantive effect on study outcomes. In particular, the observed statistical difference in accident rates observed for pilots in the 55-59 and 60-63 age groups in Study 4 might be attributable to at least one factor (employer type, as a proxy for type of flying) other than age. Moreover, the apparent change in accident rate at age 60 might be an artifact of a change in the numerator and denominator (e.g. removal of accidents under Part 121 in the numerator and removal of flight hours accumulated under Part 121 in the denominator). It has been suggested that the apparent change in accident rate may reflect the greater historical risk associated with Part 135 operations rather than the effects of age (Wilkening, 2002; Woolsey, 2003). To explore these issues further, an additional analysis of the data set developed in the course of the previous FAA studies was conducted. This additional analysis illustrates how methodological choices influence study outcomes.

THE IMPACT OF METHODOLOGICAL CHOICES: STUDY 5

The review of earlier studies suggested that factors other than age might influence accident rates. On one hand, the accidents in the numerator for pilots age 60 and older occurred under Part 135. On the other hand, fewer pilots in the older age range (60-63) reported employment by an identifiable Part 121 operator. Moreover, pilots age 60 and older are prohibited from serving as PIC or co-pilot in Part 121 operations. Therefore, the hours contributed by the oldest pilots (age 60-63) to the rate denominator must have been accumulated under other regulations, while hours contributed to the rate by younger pilots were likely to have been dominated by hours accumulated under Part 121. Note that, even here, an assumption is involved. These disparities in exposure suggest that the statistical difference in accident rates for pilots age 55-59 and 60-63 reported in Study 4 might have reflected the historically higher risk associated with Part 135 operations as well as the risks associated with pilot age.

It is precisely because of the historically higher overall accident rate in Part 135 operations that the FAA proposed the "One Level of Safety Commuter Rule" (Federal Aviation Administration, 1995a). Prior to this rule change, scheduled passenger-carrying operations in airplanes with more than 30 seats or more than 7,500 pounds payload capacity were conducted under Part 121. Scheduled passenger-carrying operations in airplanes less than 30 seats or payload capacities of 7,500 pounds or less were conducted under Part 135. The March 1995 Notice of Proposed Rulemaking (NPRM) for the "One Level of Safety Commuter Rule" proposed to eliminate the differences in requirements for scheduled passenger operations conducted with airplanes with 10 or more seats. The rule also proposed that all turbojets used in scheduled passenger-carrying operations under Part 135 comply with Part 121 requirements without regard to seating capacity. However, single-engine airplanes were not included in the proposed "One Level of Safety Commuter Rule" as Part 121 applied only to multiengine airplanes. The proposed rule was founded on the belief that compliance with Part 121 requirements would reduce the accident rate for commuter operations conducted with multi-engine airplanes and either 10 or more seats or turbojet engines. The final rule was published in December 1995 (FAA, 1995b). As a result of the "One Level of Safety Commuter Rule," the "Age 60 Rule" now applies to passenger operations conducted with multi-engine airplanes (a) with 10 or more seats, (b) with turbojet engines, or (c) with more than 7,500 pounds payload capacity.

To operate a multi-engine aircraft with 10 or more seats or one powered by turbojet engines under these rules, the pilot(s) must possess certain certificates, as defined in 14 C.F.R. § 61 (Certification: Pilots, Flight Instructors, and Ground Instructors). Contrary to some characterizations, there are no "Part 121" or "Part 135" pilots *per se* defined by the Federal Aviation Regulations. Rather, there are pilots who possess the pilot and medical certificates and aircraft type ratings required for operation of aircraft under the various parts of the regulations. Under the "old" Part 135 rules, the *minimum* qualifications for PICs of flights conducted under Instrument Flight Rules (IFR) were (a) CP certificate, (b) Class 2 medical certificate, (c) appropriate aircraft type rating, and (d) instrument rating. An ATP certificate could be substituted for the CP certificate and instrument rating. With the implementation of the "One Level of Safety Commuter Rule," the regulations provide that the PIC must hold an ATP certificate, the appropriate type rating (14 C.F.R. § 437(a)), and a Class 1 medical certificate to operate

> (i) Nontransport category turbopropeller powered airplanes type certificated after December 31, 1964, that have a passenger seat configuration of 10-19 seats;
> (ii) Transport category turbopropeller powered airplanes that have a passenger seat configuration of 20-30 seats; or
> (iii) Turbojet engine powered airplanes having a passenger seat configuration of 1-30 seats

in scheduled, passenger-carrying operations (14 C.F.R. § 121.2; 14 C.F.R. § 135.2).

These two sets of rules – those defining the aircraft and operations covered by Part 121 under the "One Level of Safety Commuter Rule," and those defining the certificates required of pilots in those operations – provide a framework for investigating accident rates and pilot age *as if* the "One Level of Safety Commuter Rule" had been in place from 1988 through 1997. This approach offers an escape from the dilemma noted by the 7th Circuit Court of Appeals: "Admittedly, petitioners in this case face a Catch-22: from one perspective they cannot get exemptions until they show they can fly large passenger aircraft[s] safely, and they cannot show they can fly such planes safely until they get exemptions" (Baker et al. v. FAA, 1990, at 322). By using this approach, the accident rates for pilots age 60 to 63 in complex, multi-engine passenger aircraft can be examined. Comparison of the results obtained within this framework to results obtained in previous studies may provide insights into the impact of the analytic methodology used in aviation safety studies and a basis for recommendations for the design of future investigations.

Method

Accident Rate Numerator

The NTSB provided an electronic data file for 1,359 aviation accidents that occurred between January 1, 1988, and December 31, 1997 for flights conducted under Parts 121 or 135. The steps taken to initially prepare these accident records were described in previous reports by Broach et al. (2000a,b). For this study, these accident records were subjected to an additional review, resulting in 1,332 usable accident records[1].

The 1,332 accident records were next screened against the inclusion criteria. The accident inclusion criteria in Studies 3 and 4 were based on the PIC certificates only, as shown in Figure 1. Based on the critique of Study 4 and the "One Standard of Safety" rule, the accident inclusion criteria were expanded to include regulation under which the flight was conducted, type of aircraft, type of operation, and operator certificates, as well as pilot qualifications. The inclusion criteria based on aircraft characteristics were (a) fixed-wing, (b) land airplane, (c) multi-engine, and (d) 10 or more seats. Note that these criteria are slightly stricter than the "new" 121 rule, in that the rule provides that aircraft powered by turbojet engines with 1 to 9 seats are covered by the rule but are excluded from this study. The second inclusion criterion focused on the type of operation. Only records for aircraft engaged in scheduled passenger or combined passenger/cargo type operations were included; accident records for aircraft engaged in cargo- or mail-only types of operations, as categorized in the NTSB record, were excluded. The third inclusion criterion was the type of certificate held by the operator of the accident flight. Specifically, only records for flights operated by carriers with flag, domestic, supplemental (e.g., air carrier) and/or commuter certificates, as coded by NTSB, were included; accident records for flights for operators with a cargo-only or on-demand/air taxi-only certificate were excluded. Next, accident records were included if, and only if, the operator name was identifiable *and* also found in the list of employers in the records of medical examinations extracted from the CAIS. Finally, a record was included if and only if the PIC possessed the ATP *and* Class 1 medical certificates at the time of the event. Just 213 of the original 1,332 records for accidents that occurred under Parts 121 and 135 for the period 1988 through 1997 met these stringent criteria for inclusion in the numerator of the accident rate. The characteristics of the 213 accidents are presented in Table 2 along with the characteristics of the accidents included in Studies 3 and 4. There were no instances of more than one accident per pilot per year.

Accident Rate Denominator

The aviation accident rate denominator generally represents exposure to the risk of flight. The rate may be expressed as accidents per pilot flight hour, similar to the epidemiological notion of illnesses per person-year (Li, 1994). Exposure estimates in previous investigations of pilot age and accident rate have been based on recent (last 6 months) and total flight hours as reported in the course of medical examinations (Broach et al., 2000a,b; Kay et al., 1994; Li & Baker, 1994; Li, Baker, Grabowski, Qiang, McCarthy, & Rebok, 2003). A critical methodological step in the present analysis was to define the inclusion criteria for the pilot records. Pilot inclusion criteria in Studies 3 and 4 as shown in Figure 2, were (a) self-reported occupation, (b) type of pilot certificate, and (c) class of medical certificate. Self-reported employer (categorized) was used as an exclusion criterion in Study 4. The pilot inclusion criteria were revised in the present study, as follows. First, as in previous studies, the occupation had to be coded as "professional pilot." Second, as in Study 3, only pilots holding an ATP were included; medical examination records for pilots with CP certificates were excluded. Third, only records of medical examinations for Class 1 medical certificates were included. Fourth, similar to the Kay et al. study in 1994, records for pilots were included if and only if at least 200 recent and 1,500 total flight hours were reported at the time of the medical examination. The recent hours criterion was based on an examination of the distribution of flight time by employer type; 90% of pilots employed by an identifiable major

Table 2
Characteristics of accidents included in Study 3, Study 4, and Study 5

	STUDY 3 (N=680)	Study 4 (N=1,334)	Study 5 (N=213)
FLIGHT REGULATION			
Domestic, Flag, Supplemental (121)	286	286	185
Air Taxi & On-Demand (135)	393	1,047	28
Missing Data	1	1	
FLIGHT PLAN			
None	36	129	2
VFR	66	190	1
IFR	454	613	203
VFR/IFR	4	6	
Company (VFR)	106	379	3
Missing Data	14	17	4
FLIGHT SCHEDULE			
Scheduled	391	424	213
Unscheduled	288	909	
Missing Data	1	1	
FLIGHT TYPE			
Domestic	596	1,235	180
International	83	97	33
Missing Data	1	2	
OPERATION TYPE			
Cargo	165	386	
Mail	2	5	
Passenger & Cargo	143	234	66
Passenger	368	706	147
Missing Data	2	3	
OPERATOR CERTIFICATES (as coded by NTSB)			
Flag carrier domestic (121)	252	252	183
Supplemental	12	12	
All cargo (418)	20	29	
Commuter air carrier	114	149	28
On-demand air taxi	221	768	
Air carrier + cargo	1	1	
Air carrier + commuter	5	5	2
Supplemental + cargo	2	2	
Supplemental + air taxi		1	
Cargo + air taxi	1	3	

(Table 2 continues)

(Table 2 continued)

	STUDY 3 (N=680)	Study 4 (N=1,334)	Study 5 (N=213)
Helicopter + air taxi		1	
Commuter + air taxi	41	84	
Air carrier + supplemental + cargo	1	1	
Air carrier + supplemental + commuter	1	1	
Air carrier + commuter + air taxi	2	2	
Supplemental + cargo + air taxi		2	
Missing data	7	20	
AIRCRAFT TYPE			
Fixed wing single engine airplane	91	439	
Fixed wing multi-engine airplane	566	732	213
Rotorcraft	22	162	
Missing data	1	1	
ENGINES			
Single engine	109	585	
Multi-engine	570	748	213
Missing data	1	1	
ENGINE TYPE			
Reciprocating	229	707	4
Turboprop	175	214	42
Turboshaft	21	155	
Turbojet/Turbofan	254	257	167
Missing data	1	1	
SEATS			
9 or less	258	864	
10 or more	421	469	213
Missing data	1	1	

airline such as American, Delta, and United reported 200 or more recent flight hours at the time of the semi-annual Class 1 medical examination. The total hours criterion was based on 14 C.F.R. 61.159(a). Fifth, only records for pilots reporting the same employer for medical examinations conducted within a single year were included. This fifth inclusion criterion was introduced to restrict the analysis to the subset of pilots with more stable employment and thus, greater continuity of exposure.

These five inclusion criteria resulted in a pool of 753,842 pilot medical examination records for the period January 1, 1988, through December 31, 1997, compared with the 939,769 used in Study 4. Identifiable large flag, domestic or supplemental carriers operating flights under Part 121 (such as United, Delta, American, and USAir) accounted for 79.3% of the medical examination records while 1.6% were from pilots employed by smaller Part 135 operators. However, employer was coded as "Other aviation operations" for 19.1% of the pool of records.

The pilot records were then aggregated by year and pilot identifier as in the previous studies, resulting in a pool of 522,586 aggregated pilot records for matching to accident records. Recent flight hours were summed across medical examinations for the year for each pilot, and the number of medical examinations conducted for the pilot for that year was counted. The number of examinations ranged from 1 to 3 medical examinations per year for each pilot[2]. Next, the sum of the flight hours reported in the last 6 months across examinations in the year was annualized as follows:

1. For 1 examination in a year, 2 times the summed recent flight hours for that year.
2. For 2 examinations in a year, the summed recent flight hours for that year.
3. For 3 examinations in a year, then 2/3 of the summed recent flight hours for that year (2 times the average reported recent flight hours across the 3 examinations).

Accident Rate and Age Groups

The 213 NTSB accident records were then matched with the aggregated CAIS medical records for each year by pilot identifiers. The resulting file contained 513,240 exposure-accident records. Only those records for pilots age 23 to 63 at the time of the medical examination or accident were retained, reducing the pool of accident-exposure records to 512,076. Finally, only those records for pilots with the same employers as the accident pilots were selected for the present study, resulting a total of 381,413 matched accident-exposure records. In other words, the non-accident pilots worked for the same employers as the accident pilots. Presumably, the non-accident pilots were likely to be flying the same types of airplanes, on roughly the same schedules, and in the same types of operations as the accident pilots working for the same employer. The number of matched accident-exposure records by employer, as reported in CAIS and coded in the NTSB database for accident and non-accident pilots, is presented in Table 3.

The number of accidents was set at zero for pilot records without a matching accident record in any given year. Where flight hours were not available from CAIS data, NTSB estimates of flight time were used (*n*=31). Exposure data were not available from CAIS or NTSB records in 10 instances. Rather than discarding these records, annualized and total flight hours were imputed using the SPSS® Missing Values Analysis (version 7.5) procedure (SPSS, 1997). The SPSS® procedure estimates the expected value for a missing datum on the basis of an iterative maximum likelihood estimation algorithm.

Finally, the 381,413 matched exposure-accident records were coded into non-overlapping age groups: less than or equal to (LE) 29; 30-34; 35-39; … 55-59; and 60-63 years. As in the previous studies, the matched exposure-accident records were then aggregated by year and independent age group. The accident rate for each year-age group combination was computed as the ratio of the count of accidents for the year and age group to the sum of annualized flight hours (in units of 100,000) for the year and age group. The resulting file contained 80 records (8 age groups x 10 years)[3].

Analysis

Descriptive statistics for each Study 5 age group, including the sum of annualized flight hours, total cumulative flight hours, and total accidents across the 10 year time span were calculated. A one-way analysis of variance (ANOVA) was conducted to determine if there was a trend in the accident rates across the independent age groups. A *t*-test was also used to compare the mean accident rates of the 55-59 and 60-63 age groups in a planned comparison to contrast age groups that were immediately adjacent to the current age limit of 60. The trend analysis was conducted in view of previous studies suggesting a "U"-shaped function or quadratic trend across pilot age groups (Broach et al., 2000a,b; Golaszewski 1993; Kay et al., 1994, p. 5-2). All analyses were conducted using the SPSS® version 11.5 statistical package (SPSS Inc., 1999).

Results

Descriptive statistics for each Study 5 age group, including the sum of annualized flight hours, total cumulative flight hours, and total accidents across the 10 year time span are presented in Table 4. As in the previous analyses, the sum of annualized and cumulative total flight hours across the span of the study both took an inverted "U"-shaped distribution across age groups (Figure 3). Annual flight hours peaked between ages 35 to 49 and then declined with age. Cumulative flight hours peaked between ages 50 and 54 and then declined with age. In contrast, the raw number of accidents across the study period appeared to trend upwards through the 55-59 age group (n = 51) but then declined for 60-63 age group (n=7), as shown in Table 4.

The mean accident rate for each Study 5 age group, along with the 5/95% confidence interval, is illustrated in Figure 4. In contrast to the results of Studies 3 and 4, inspection of the graphed data suggested that a linear function might fit the data rather than a "U"-shaped function. The ANOVA indicated that a linear function best described the trend in mean accident rates across age group ($F(1) = 9.79, p \leq .01$; see Table 5 and Figure 4). The planned comparison revealed that the mean accident rate for pilots age 55-59 ($M_{55\text{-}59}$ = .1527 per 100,000 annual flight hours) was not significantly different from that of the 60-63 age group ($M_{60\text{-}63}$ = ..2276 per 100,000 annual flight hours, unequal variances, $t(9.411) = -0.56$, *ns*). In other words, the accident rate for the 60-63 age group was not statistically different from the accident rate for the 55-59 age group.

Inspection of the confidence intervals indicated that the mean accident rates for the youngest and oldest age groups were far more variable than the accident rates for the other age groups (30s through 40s). This observation was supported by rejection of the assumption of equal variances across the age groups (*Levene Statistic*(7, 72) = 12.92, $p < .001$). The number of pilot records aggregated in the denominator of the accident rate varied across age groups by as much as ten-fold, as in the previous analyses, with much the same effect. Estimates of accident rate based on fewer records were far more variable than estimates based on much larger numbers of records.

Table 3
Number of exposure-accidents records by employer and accident status for Study 5

	Record for accident pilot?		
CAIS employer/NTSB operator	No	Yes	Total
Air Nevada	17	1	18
Air Wisconsin	1,450	2	1,452
Alaska Airlines	6,060	2	6,062
Aloha Airlines	1,410	1	1,411
American Airlines	60,640	34	60,674
America West	6,999	6	7,005
Aspen Airways	177	2	179
Atlantic Southeast	3,124	3	3,127
Big Sky Airlines	57	2	59
Britt Airways	339	2	341
Business Express	2,315	1	2,316
Comair	4,636	3	4,639
Contintental Airlines	33,032	15	33,047
Delta Airlines	59,258	27	59,285
Eastern Airlines	6,536	3	6,539
Great Lakes Aviation	11	2	13
Hawaiian Airlines	2,110	1	2,111
Horizon Airlines	3,639	5	3,644
Mesa Airlines	2,168	8	2,176
Mesaba Airlines	2,313	2	2,315
Metroflight Airlines	9	2	11
Northwest Airlines	39,849	8	39,857
Pan American World Airways	6,129	3	6,132
Pennsylvania Airlines	400	2	402
Piedmont Aviation	4,179	4	4,183
Simmons	1,600	6	1,606
Southcentral Air	6	1	7
Southwest Airlines	12,357	8	12,365
Transworld Airlines	21,993	9	22,002
United Airlines	57,998	30	58,028
U.S. Air	37,947	17	37,964
West Air	2,442	1	2,443
Total	381,200	213	381,413

Table 4

Study 5 total pilot records, annual flight hours, total cumulative flight hours, total accidents, and accident rate descriptive statistics by age group

Age Group	Total records[1]	Total annual hours	Total cumulative hours	Total accidents	Accident Rate (per 100,000 annualized hours)			
					Mean	SD	Min	Max
LE 29	14,156	11,188,639	58,935338	4	0.0329	0.0464	0.0000	0.1272
30-34	41,748	31,374,921	243,040,985	18	0.0624	0.0485	0.0000	0.1697
35-39	68,022	49,885,004	488,392,447	22	0.0449	0.0331	0.0000	0.1029
40-44	70,013	50,722,284	632,728,642	31	0.0607	0.0366	0.0000	0.1469
45-49	69,700	50,466,881	780,857,281	40	0.0788	0.0269	0.0450	0.1223
50-54	66,334	46,828,754	917,756,623	40	0.0852	0.0357	0.0232	0.1553
55-59	47,283	33,002,299	796,601,126	51	0.1527	0.0629	0.0714	0.2580
60-63	4,157	2,939,132	79,714,801	7	0.2276	0.4157	0.0000	1.1194

Notes: [1]Number of annualized records for age group from 1988 through 1997

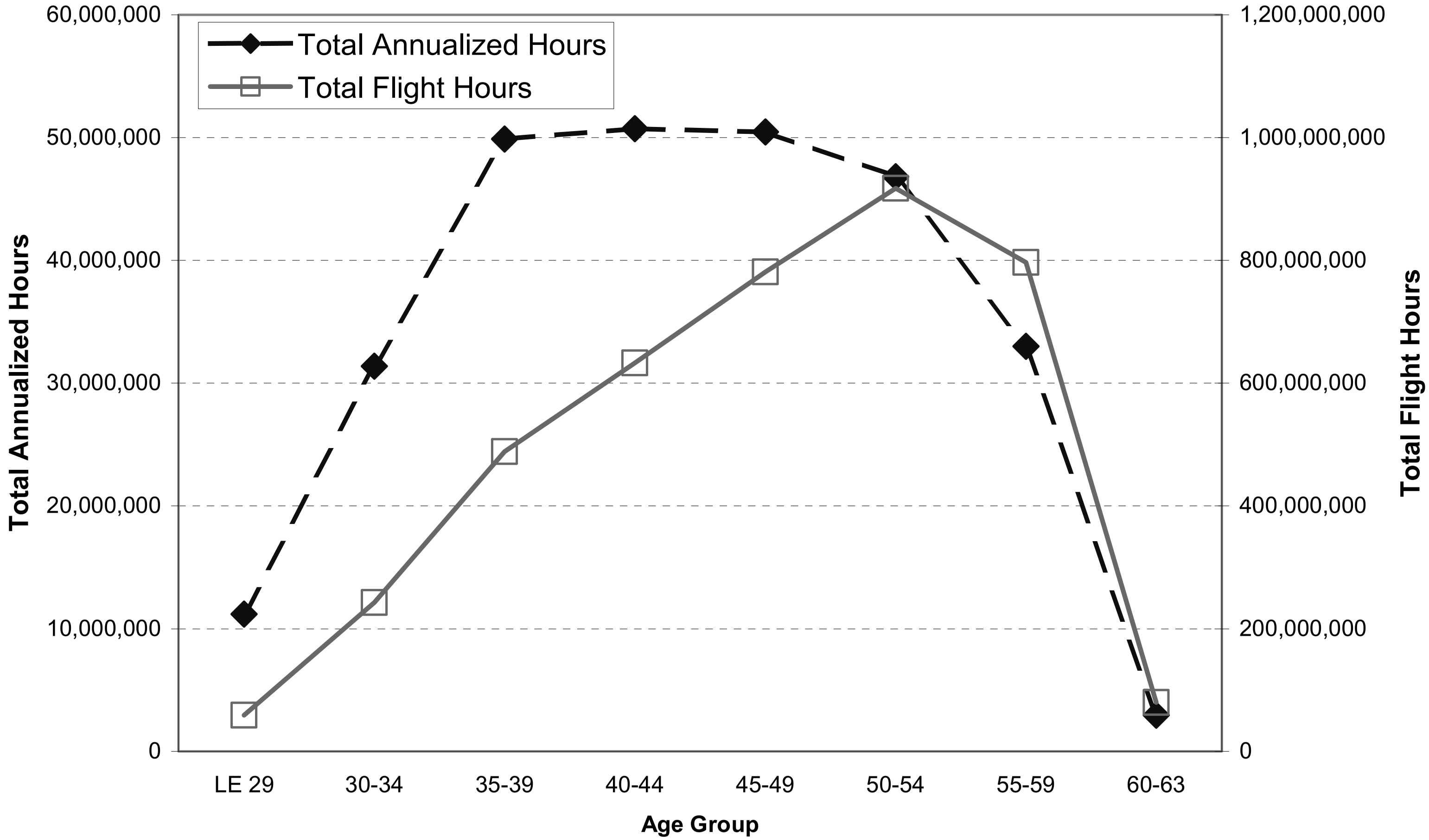

Figure 3
Total annualized flight hours and total flight hours by age group

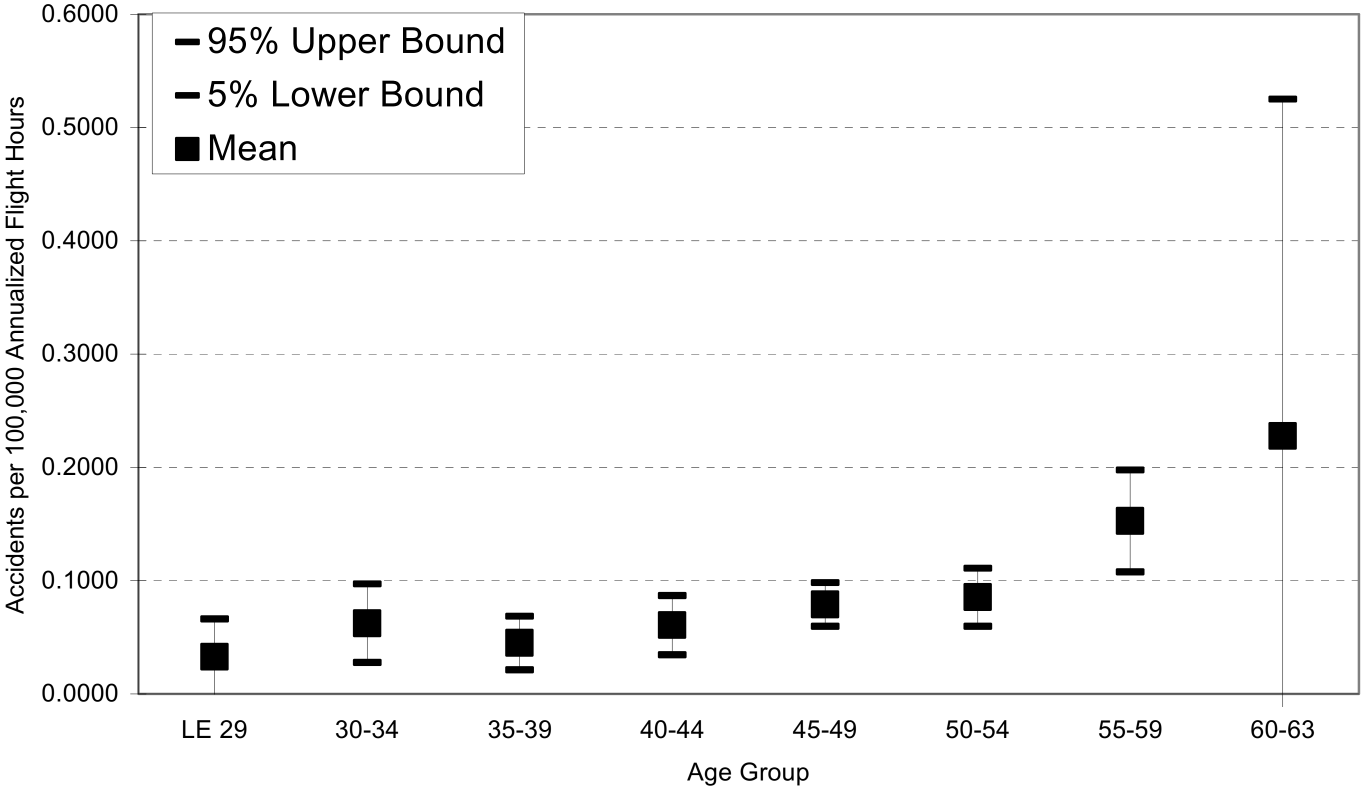

Figure 4
Study 5 mean accident rate and 5%/95% confidence intervals by pilot age group

Table 5
Study 5 results for ANOVA of accident rate by age group

		Sum of Squares	*Df*	Mean Square	*F*	*p*
BETWEEN GROUPS	(Combined)	.299	7	.043	1/838	.093
Linear Term	Contrast	.227	1	.227	9.791	.003
	Deviation	.071	6	.012	.512	.797
Quadratic Term	Contrast	.054	1	.054	2.318	.132
	Deviation	.018	5	.004	.151	.979
Within Groups		1.671	72	.023		
Total		1.969	79			

Table 6
Comparison of Age 60 studies conducted on behalf of or by the FAA

Study	Trend with Age	55-59 vs. 60-63
Kay et al. (1994)	Linear trend – Downward with age	no comparison made
Broach et al. (2000a)	Quadratic trend – U-shaped	$Rate_{60-63} = Rate_{55-59}$
Broach et al. (2000b)	Quadratic trend – U-shaped Linear trend Cubic trend	$Rate_{60-63} > Rate_{55-59}$
Broach (2003)	Linear trend –upward with age	$Rate_{60-63} = Rate_{55-59}$

Discussion

Comparison of Study 5 Results with Other Studies

On one hand, the results of Study 5 supported the first alternative hypothesis ($H1_{alt}$) of a positive trend in fixed-wing, multi-engine airplane accident rates across age groups: the non-zero slope indicated that accident rate increased with age in this sample of pilots. The trend was best described by a linear (straight-line) rather than a quadratic ("U"-shaped) function reported in previous studies on pilot age and accident rates, including Kay et al. (1994) and Broach et al. (2000a, b). On the other hand, the null hypothesis ($H2_{null}$) of no difference in accident rates for the 55-59 and 60-63 age groups could not be rejected. That is, the accident rate for these two age groups appeared to be statistically the same. However, *post-hoc* comparisons indicated that the accident rate for pilots in the 55-59 age group ($M_{55\text{-}59}$ = .1527 per 100,000 annual flight hours) was statistically greater than the accident rates for pilots age 29 or younger ($M_{LE\,29}$ = .0329), 30-34 ($M_{30\text{-}34}$ = .0624), age 35-39 ($M_{35\text{-}39}$ = .0449), and age 40-44 ($M_{40\text{-}44}$ = .0607).

The observation of a linear trend with age is not consistent with previous research conducted by or on behalf of the FAA (Table 6). For example, Kay et al. (1994) found in their study of pilots holding Class 1 medical certificates that "… accident rate decreased with increased age for the younger pilots leveling off for the older pilots … " (p. 5-2). While Kay et al. noted that exposure for pilots employed by Part 121-certificated carriers could not be estimated directly, they used total and recent flight time to define a subset of pilots that would be "reasonably comparable" to air carrier pilots. Based on their analysis of pilots holding Class 1 medical certificates, 2,000 or more hours total flight time, and at least 700 hours of recent flight time, they went on to conclude that their analyses "… provided no support for the hypothesis that the pilots of scheduled air carriers had increased accident rates as they neared the age of 60" (p. 6-2). Kay et al. concluded that they "… saw no hint of an increase in accident rate for pilots of scheduled air carriers as they neared their 60th birthday" (p. 6-2). In contrast, the work by Broach et al. (2000a, b) reported that a "U"-shaped function fit the trend in accident rate across age groups. Moreover, the accident rate for pilots in the 60-63 age group was statistically greater than the accident rate for pilots in the 55-59 age group in Broach et al.'s Study 4 (2000b).

A different result was obtained in the present analysis, with an overall upward linear trend, suggesting more than a hint of an increase in accident rate for pilots identifiable scheduled air carriers as they neared their 60th birthday. But the accident rate for the 60-63 age group was not significantly different from that of the 55-59 age group. As noted in Studies 3 and 4, the greater variability in accident rate for the oldest age group (compared with that of the next younger (55-59) age group) was attributed to the relatively fewer records for the older pilots. This greater variability reduced the likelihood of detecting any difference between the age groups that may in fact exist. Moreover, the differences to be detected were very small in absolute terms. For example, the difference in mean accident rates for the 55-59 and 60-63 age groups in Study 3 was just .0443 accidents/100,000 flight hours. This small difference relative to the wide variability in accident rates within the two age groups would be difficult to detect with conventional significance testing. *Post-hoc* power analysis supported this line of reasoning (Table 7).

The standardized effect size for age in Study 3 was d=.20. With just 10 cases per comparison group, *post-hoc* power analysis indicated very low (.09) statistical power to detect a difference of this magnitude using conventional significance testing. In other words, while the risk of a false positive (Type I error – finding a difference in accident rates that was not real) was held at 5% (e.g., α=.05), the likelihood of a false negative (Type II error – failing to detect a difference in accident rates that was real) was about 91%. In contrast, the effect size in Study 4 was d= 1.16, which resulted in greater available statistical power of .71. That is, there was a greater likelihood of detecting

Table 7
Post-hoc power analysis for planned comparison of accident rates at α=.05 and n=10 in each age group by study

Study	Age Group	M	SD	5%	95%	*d*	Power
3	55-59	0.2057	0.0959	0.1370	0.2740		
	60-63	0.2500	0.3465	0.0020	0.4980	0.20	.09
4	55-59	0.2667	0.1138	0.1853	0.3482		
	60-63	0.5211	0.3246	0.2889	0.7533	1.16	.71
5	55-59	0.1527	0.0629	0.1077	0.1976		
	60-63	0.2276	0.4157	-0.0697	0.5250	0.47	.12

the difference in accident rates on either side of the "Age 60 Rule" in Study 4 than in Study 3.

The difference in accident rates in the present study for the pilots on either side of the "Age 60 Rule" was equally small at .0749 accidents/100,000 recent flight hours ($M_{60\text{-}63}$=.2276, $M_{55\text{-}59}$=.1527), or an effect size of d=.47. Holding the likelihood of a false positive (Type I error) at 5% through conventional significance testing, the likelihood of a false negative (Type II error) in the present study was about 88%. The difference in accident rates for the 55-59 and 60-63 age groups was not statistically significant in the present study. The *post-hoc* power analysis suggested that the design provided little statistical power (.12) to detect the small difference in accident rates between the two age groups. This line of reasoning is buttressed by (a) the overall trend toward increasing accident rate with age, and (b) the finding that the accident rate for the 55-59 age group was statistically greater than the accident rate for younger pilots up through age 44.

Finally, the results of this study differ sharply from those recently reported by Li et al. (2003). In their study, they followed a cohort of 3,306 commuter air carrier and air taxi pilots from 1987 through 1997. The pilots were 45 to 54 years of age at the start of the study and were employed by Part 135 operators. Baseline characteristics included age, sex, total flight hours at baseline, recent flight time (in previous 6 months), use of corrective lenses, and any medical pathology. The effects of these baseline characteristics and cumulative exposure on accident rates were examined through the proportional hazards model (e.g., Cox regression). Overall, the cohort experienced 66 accidents while accumulating 12.9 million flight hours. There were just 3 accidents for pilots age 60-64 during the study period. Although the accident rate for the oldest pilots of 11.05 per million flight hours was approximately twice the rate for younger pilots (5.47 per million flight hours), the difference in relative risk was not statistically significant. Li et al. concluded that accident risk was not significantly associated with advancing age.

Possible Methodological Explanations for Differences in Results

The differences between the results of the present study, previous FAA research as summarized in Table 6, and the work of Li et al. (2003) should be considered in light of methodological differences in the studies. These methodological differences include (a) accident inclusion criteria (b) pilot inclusion/exclusion criteria, (c) method for annualizing flight hours, and (d) analytic strategy, including statistical power available in an analysis.

Accident inclusion criteria. The study by Kay et al. in 1994 included 762 NTSB accidents from 1976 through 1988 that involved pilots holding Class 1 medical certificates without regard to the regulation under which the flight was operated or aircraft characteristics (see Figure 5-5 and p. B-6 in Kay et al.). In other words, their data included accidents occurring under Parts 121 (domestic, flag, and supplemental), 135 (on-demand and air taxi), 91 (general aviation), and other regulations. In contrast, the previous studies conducted by Broach and colleagues included 1,334 accidents that occurred between 1988 and 1997 for flights operating under 14 C.F.R. §121 or §135 only, or approximately 98% of the 1,359 accidents reported by NTSB under these flight regulations. However, the data set for Studies 3 and 4 included rotorcraft, single-engine airplanes and cargo-only operations. The only criterion for inclusion in the Li et al. survival analysis was that the accident involved a pilot from the cohort being followed. The 66 accidents reported for the cohort represented just 0.3% of the accidents reported by NTSB for flights conducted under Part 135 (n=1,1,27) and Part 91 (n=21,797) during the study period.

The present study refined the accident inclusion criteria previously used by Broach et al. in light of the "One Level of Safety Commuter Rule" and included only fixed-wing, multi-engine land airplanes with 10 or more seats engaged in scheduled air carrier or commuter passenger operations. The 213 accidents in the present study accounted for 15.6% of accidents reported by NTSB for flights conducted under Part 121 or 135 for the period 1988-1997. Given the sample sizes used in the studies, it is possible that the differences in results may be attributable, at least in part, to sampling error[4].

Pilot inclusion criteria. Another possible explanation of differences might be in the criteria for including pilots from whom estimates of exposure were derived. Kay et al. (1994) initially defined their sample as pilots between the ages of 20 and 74 who held a first-, second-, or third-class medical certificate and had recent and total flight time greater than zero (p. 3-7). Kay et al. argued that data for pilots with Class 1 medical certificates would be pertinent to accident rates for pilots employed by Part 121-certificated air carriers (p. 4-1). In their view, only pilots younger than age 60 should have been included in the analyses "because no Part 121 pilots flew after 60" (p. 4-1). In particular, they focused their attention on "… those Class I pilots most like pilots of scheduled air carriers by considering only those pilots who had the necessary minimum total flight hours [2,000] and who had the number of recent flight hours [700] characteristic of pilots of scheduled air carriers" (p. 4-2). As a result, they did not include pilots with first-class medical certificates over age 60 in their analyses.

However, not all pilots holding Class 1 medical certificates are employees of air carriers certified for operations under Part 121. Even with the requirement for 2,000 total and 700 recent flight hours, it may be the case that there was extraneous variance in exposure hours attributable to pilots not working for air carriers. As noted previously, inclusion of exposure hours from pilots not in the target group would tend to depress the observed accident rate. In other words, the decrease in accident rates for Class 1 pilots with at least 2,000 total and 700 recent flight hours illustrated in Figure 5-5 of Kay et al.'s report might be an artifact of the pilot inclusion criteria rather than age.

In comparison, three pilot inclusion criteria were used in the previous study on the "Age 60 Rule" (Broach et al., 2000b) to identify the pilot population required by Senate Report 106-55: ATP or CP certificates; Class 1 or 2 medical certificates; and "professional pilot" reported as the occupation. As noted in the reports for Studies 3 and 4, these criteria resulted in samples that represented approximately about 50% to 85% of pilots issued ATP or Class 1 medical certificates. However, these inclusion criteria did not fully eliminate the possibility of inclusion of extraneous pilots in the analyses.

Pilots were eligible for inclusion in the Li et al. prospective cohort study if, in 1987, they (a) held a Class 1 medical certificate, (b) were employed by an identifiable Part 135 operator, (c) were 45 to 54 years of age, (d) flew for business or both business and pleasure, (e) listed "pilot" or "commercial pilot" as their occupation, (f) had 20 or more hours recent (in the last 6 months) flight time, and (g) had 500 or more hours of total flight time. Their sample of 3,306 represented about 5% of the approximately 65,000 pilots they reported as flying in Part 135 operations, and about 5% of the ATP and Class 1 certificates issued in 1987.

The present study refined the inclusion criteria used in Studies 3 and 4 (Broach et al., 2000a,b) by requiring (a) at least 200 recent flight hours in the last six months, (b) at least 1,500 total flight hours as of the medical examination, (c) the same employer for medical examinations conducted in a given calendar year, and (d) the same employer as the accident pilots. The flight hours criteria were based on examination of the distribution of total and recent flight time by type of employer (identifiable Part 121 or 135 operator). The same employer criterion focused on pilots with stable employment. The "same employer as the accident pilots" criterion ensured an apples-to-apples comparison, that is, of accident to non-accident pilots working for the same employers. As a result, the majority (88%) of the medical examination records that served as the basis for estimating exposure came from pilots working for identifiable large flag, domestic, or supplemental carriers; the other 12% came from pilots employed by identifiable, smaller operators. Overall, between 63% and 75% of pilots for identifiable Part 121 and 135 carriers each year, as listed in the FAA CAIS, were included in Study 5 (Table 8). This represents a larger sample than the cohort studied by Li et al., and would be much less susceptible to sampling error. It is also a much more rigorously defined sample than the one examined by Kay

Table 8
Comparison of number of ATP Certificates, Class 1 medical certificates, airline pilots, and number of CAIS records available in Study 5 for analysis for each year, 1988-1997

Year	ATP Certificates[1]	Class 1 Certificates[2]	Airline Pilots[3]	Study 5 Pilots
1988	96,968	70,388	46,701	34,980
1989	102,087	83,254	49,380	34,041
1990	107,732	81,055	59,259	38,795
1991	112,167	90,859	58,962	40,652
1992	115,855	89,879	57,185	41,414
1993	117,070	87,654	56,715	37,383
1994	117,434	75,662	55,413	35,220
1995	123,877	78,662	57,443	40,680
1996	127,486	82,200	59,164	40,260
1997	130,858	84,732	60,741	37,988

Notes: [1]As reported each year in the annual report, *U.S. Civil Airmen Statistics*

[2]As reported each year in the annual report, *Aeromedical Certification Statistical Handbook*, Table IV.A, for Class 1 certificates that have not lapsed (e.g., are "effective")

[3]As reported each year in the annual report, *Aeromedical Certification Statistical Handbook*, Table IV.N or IV.M

et al. (1994), and represents a sizable proportion of the population of pilots covered by the "Age 60 Rule."

Moreover, it is reasonable to assume that pilots working for the same employers flew similar aircraft, routes, and schedules. This would result in more uniform exposure and less extraneous variance in the denominator. As the employer in the present study is known rather than assumed to be a certificated air carrier, it was unlikely that pilots *not* working for air carriers contributed any exposure hours. Therefore, the accident rates analyzed in Study 5 are unlikely to be artificially depressed by inclusion of extraneous exposure hours for pilots not in the target population. Finally, the sample of pilots in the present study was drawn from the population of working airline pilots most likely to be covered by the "Age 60 Rule" as of 1999.

Another factor that may explain finding a linear trend in accident rates with increasing age in Study 5 rather than the quadratic ("U"-shaped) trend reported in Studies 3 and 4 might be the relative sparseness of data for younger pilots. The pilot inclusion criteria for the present study resulted in substantially fewer younger (age 29 or less) pilots contributing exposure hours to the accident rate denominator than in the previous Congressionally-mandated studies. There were 44,625 records for medical examinations of pilots age 29 or younger in the analysis of accident rates for professional pilots holding ATP and Class 1 medical certificates (Broach et al., 2000a). Exposure estimates in the analysis of accident rates for professional pilots holding ATP or CP and Class 1 or 2 medical certificates (Broach et al., 2000b) included 52,706 records for medical examinations of pilots age 29 or younger (see Table 1). In contrast, the present study was based on just 14,213 records of medical examinations for pilots age 29 or younger reporting employment by the same certificated air carrier or commuter operators as the accident pilots. The relative sparseness of the data for the younger pilots, compared with older pilots, may explain why a significant linear, rather than the classic "U"-shaped relationship between age and performance, was observed in the present study. However, the more important point to be made is that, whether the relationship is linear or quadratic, accident rates increased with pilot age starting in the late 40s in the present study and in the previous studies (Studies 3 and 4) conducted for Congress.

As in all other previous studies, the exposure data were based on self-reported recent and total hours without regard to type of operation. Therefore, as noted in Studies 3 and 4, the exposure estimates were likely inflated in some degree relative to actual hours flown under 14 C.F.R. §121 and §135. Accident rates computed from these inflated exposure estimates were likely to underestimate the actual accident rates. Note that *every* estimate of exposure to the risks of flight based on self-reported recent and total flight hours at the time of medical examination for airline pilots has the same problem of possible heterogeneity. However, it is reasonable to assume that most flight hours for professional airline pilots were accumulated through their employment rather than other types of flying[4]. Given that assumption, Study 5 differed from the previous studies by selecting records for non-accident pilots reporting employment by the same certificated carriers as the accident pilots and who held both an ATP certificate and Class 1 medical certificate. This resulted in the aggregation of exposure data from a substantially more homogenous group of pilots than in previous analyses, resulting in less unmeasured heterogeneity in the flight hours comprising the denominator of the accident rate. Moreover, the accidents in the numerator of the accident rate were also more homogenous than in previous analyses. For example, rotary wing and single-engine aircraft were included in the previous analyses by Broach et al. (2000a, b). The accidents included in the rate numerator in Study 5 were for multi-engine, fixed-wing land aircraft with 10 or more seats. It may be the case that heterogeneity – in both the denominator and between numerator and denominator – masked the relationship of accident rate to age in previous studies. In other words, by enforcing some degree of homogeneity in the data from which accident rate was derived, an overall positive trend in accident rate with age was more easily detected in the present analysis.

Annualizing flight hours. Differences in how flight hours were annualized might also contribute to differences in results between studies. Previous studies annualized recent flight hours for pilots by multiplying by 2 the self-reported hours in the last six months. This approach was based on the assumption that, on average, pilots holding a Class 1 medical certificate took 2 medical examinations per year. Doubling the self-reported recent flight hours for pilots with just 1 examination in a given year, as in previous studies, was a reasonable rule for estimating annualized flight hours for those pilots. However, doubling those hours for pilots with 2 examinations in a year would likely result in an overestimate. Therefore, as described in Broach et al. (2000a,b), the present study (Study 5) adopted a more complex set of rules for annualizing flight hours. The different approach to annualizing flight hours in this study may have resulted in different exposure estimates for the accident-rates denominator. Clearly, development and adoption of a standard set of rules for annualizing recent flight hours is warranted to ensure comparability between studies of aviation safety.

Analytic strategy. Differences in analytic strategies are another possible explanation for differences in study outcomes as well as the results of an overall trend across age groups. The analytic strategy for this study (Study 5) differed from the work of Kay et al. (1994) in technical details of conducting the ANOVA of accident rates by age. Specifically, the ANOVA design they used treated the data as proportions. In their analysis, the degrees of freedom for the denominator were assumed to be infinite, as the estimate of the variance was exact. The ANOVA strategy used in the present analysis was more conservative by treating accident rate as a rate rather than a proportion. The degrees of freedom associated with the denominator were defined in terms of the number of aggregated observations available. For example, Study 5 analyzed 80 observations (8 independent age groups x 10 years), resulting in 79 degrees of freedom in the denominator of the overall test for the main effect of age. This conservative approach resulted in a design with limited statistical power to detect significant differences between age groups. The limited statistical power resulted in a greater likelihood of a Type II (false negative) error for the planned comparison, as shown in Table 7, while controlling the likelihood of a Type I error (false positive) at the conventional 5% level. Extension of the data set over more years may result in a design with more statistical power to detect any small differences in accident rate across age and thereby ensure the stability and generalizability of the results.

GENERAL DISCUSSION

Previous studies of pilot age and accident rates in the context of the "Age 60 Rule" have yielded mixed results. On one hand, Kay et al. (1994) found no evidence of an increase in accident rate as pilots holding Class 1 medical certificates neared age 60. On the other hand, Broach et al. (2000a,b) reported that a "U"-shaped function best described the Part 121 and 135 accident rate for professional pilots holding ATP or COM pilot and Class 1 or 2 medical certificates as a function of pilot age. Moreover, Broach and his colleagues reported that the accident rate for the 60-63 age group was significantly higher than the rate for the 55-59 age group. However, Wilkening (2002) raised methodological concerns about that study. In particular, she suggested that the observed difference was more likely attributable to differential exposure to the historically higher risks associated with Part 135 operations than pilot age in and of itself (p. 200). Moreover, the inherent heterogeneity of exposure hours, due to how flight hours are reported, may result in an apparent mismatch between the numerator and denominator of the accident rate particularly for pilots age 60-63 compared with younger pilots. Comparison of employer type (as a proxy for type of flying) for pilots age 55-59 and 60-63 in Studies 3 and 4 suggested that the groups differed significantly on at least one dimension other than age (employer type). This difference in employer type suggested heterogeneity of exposure between the age groups of interest. The observed statistical difference in accident rate for pilots age 55-59 and 60-63 reported by Broach et al. (2000b) might therefore be attributable to employer type (as a proxy for type of flying), a mismatch between numerator and denominator between groups, as well as age. It has been argued that pilot age is confounded with type of flying as an inevitable consequence of the "Age 60 Rule" itself (Woolsey, 2003a).

The present study addressed some of this criticism by refining the accident and pilot inclusion criteria to ensure greater homogeneity of exposure and closer match between the numerator and denominator of the accident rate between age groups. This study also serves to illustrate the impact of methodological choices on study outcomes. The numerator for the accident rates included only accidents involving fixed-wing, multi-engine land airplanes with 10 or more seats engaged in scheduled air carrier or commuter passenger operations under Part 121 or 135 at the time of the accident. The denominator, representing exposure, was derived from self-reported hours flown by professional pilots employed by the same identifiable operators as the accident pilots. In addition, the pilots contributing hours to the denominator held (a) an ATP certificate, (b) a Class 1 certificate, and (c) reported at least 200 recent and 1,500 total flight hours. Selecting exposure records for pilots employed by the same operator reduced heterogeneity in both the numerator and denominator of the accident rate as well as between pilots on the premises that (a) pilots working for the same airline were likely to fly similar aircraft on similar routes on similar schedules, and (b) most, if not all, flight hours would have been accumulated on the job for most of the pilots. Accident and exposure records for the period 1988 through 1997 were matched by year and pilot identifier, and then aggregated by age group. Analysis of variance (ANOVA) found an overall linear trend in accident rate across age groups. On one hand, the *a priori* test found that the accident rate for the 60-63 age group was not significantly different from the accident rate for the 55-59 age group. On the other hand, the *post-hoc* comparisons found that the accident rate for pilots age 55-59 was statistically greater than the rate for pilots age 44 and younger.

The findings of the present study were compared with previous studies by Kay et al. (1994), Broach et al. (2000a, b), and Li et al. (2003). The most striking difference is that the present study found a linear trend of increasing accident rate with age while Kay et al. reported a declining accident rate with age, Broach et al. reported a "U"-shaped relationship, and Li et al. reported no relationship. Possible explanations for differences in results included (a) accident inclusion criteria, (b) pilot inclusion criteria, (c) rules for annualizing recent flight hours, and (d) analytic strategies. Comparison of results across studies suggest that outcomes of studies on the topic of accidents and pilot age are sensitive to sample definitions as represented by the accident and pilot inclusion criteria and analytic strategies. However, while study outcomes vary, the overall pattern of results suggest that there may be some risk associated with allowing pilots age 60 and older to operate complex, multi-engine with 10 seats or more in passenger operations. Therefore, changes to the "Age 60 Rule" should be approached cautiously.

REFERENCES

Baker et al. v. Federal Aviation Administration, 917 F.2d. 318, 7th Circuit, 1990.

Broach, D., Joseph, K., & Schroeder, D. (2000a). *Pilot age and accident rates report 3: An analysis of professional air transport pilot accident rates by age.* (Unpublished Civil Aeromedical Report prepared for the U.S. Congress). Oklahoma City, OK: Federal Aviation Administration Civil Aerospace Medical Institute Human Resources Research Division[5].

Broach, D., Joseph, K., & Schroeder, D. (2000b). *Pilot age and accident rates report 4: An analysis of professional ATP and commercial pilot accident rates by age.* (Unpublished Civil Aeromedical Report prepared for U.S. Congress). Oklahoma City, OK: Federal Aviation Administration Civil Aerospace Medical Institute Human Resources Research Division.

Federal Aviation Administration. (1995a). Commuter operations and general certification and operations requirements; Proposed rule. *Federal Register, 60*(60), 16,229–296, March 29, 1995.

Federal Aviation Administration (1995b). Commuter operations and general certification and operations requirements; Final rule. *Federal Register, 60*(244), 65,831–940, December 20, 1995.

Federal Aviation Administration. (1999). *Aviation safety statistical handbook.* Washington, DC: FAA Air Traffic Resource Management Program Planning, Information, and Analysis Division (ATX-400).

Golaszewski, R.S. (1993). *Additional analysis of general aviation pilot proficiency.* Jenkintown, PA: Gelman Research Associates.

Kay, E.J., Hillman, D.J., Hyland, D.T., Voros, R.S., Harris, R.M., & Deimler, J.D. (1994). *Age 60 rule research, Part III: Consolidated data base experiments final report.* (DOT/FAA/AM-92/22). Washington, DC: Federal Aviation Administration Office of Aerospace Medicine[5].

Li, G. (1994). Pilot-related factors in aircraft crashes: A review of epidemiologic studies. *Aviation, Space, and Environmental Medicine*, *65*, 944-52.

Li, G., & Baker, S.P. (1994). Prior crash and violation records of pilots in commuter and air taxi crashes: A case-control study. *Aviation, Space, and Environmental Medicine*, *65*, 979-85.

Li, G., Baker, S.P., Grabowski, J.G., Qiang, Y., McCarthy, M.L., & Rebok, G.W. (2003). Age, flight experience, and risk of crash involvement in a cohort of professional pilots. *American Journal of Epidemiology*, *157*, 874-80.

National Transportation Safety Board. (2002). *Annual review of aircraft accident data: U.S. air carrier operations calendar year 1998.* (NTSB/ARC-02/02). Washington, DC: Author.

SPSS, Inc. (1997). *SPSS Missing Values Analysis*™ 7.5. Chicago, IL: Author.

SPSS, Inc. (1999). *SPSS 11.5.* Chicago, IL: Author.

U.S. Senate. (1999). *Department of Transportation and related agencies appropriations bill, 2000.* (Senate report 106-55). Washington, DC: Government Printing Office.

Wilkening, R. (2002). The Age 60 rule: Age discrimination in commercial aviation. *Aviation, Space, and Environmental Medicine*, *73,* 194-202.

Woolsey, S. D. (2003a). *Data quality complaint and request for correction of Age 60 studies, dated January 15, 2003.* (DOT Docket FAA-2003-14951-1). Washington, DC: Department of Transportation. (Available from http://dms.dot.gov/search/searchFormSimple.cfm).

Woolsey, S. D. (2003b). *Second amendment to request for reconsideration, dated November 7, 2003.* Danville, CA: Author. (Available from http://www.age60rule.com).

ENDNOTES

[1]The following accidents were eliminated from the data set for this analysis: ANC97LA145B; and LAX94T#A02. ANC97LA145B: Bering Air Inc. (ANC97LA145B) aircraft was standing when Hageland Aviation Services (ANC97145A) aircraft turned on taxi and its rudder impacted the Bering Air aircraft. The record for "offending" pilot (e.g., pilot who made error in turn resulting in accident – ANC97145A) was retained, and the record for "victim" pilot (e.g., standing aircraft – ANC97145B) was removed. The LAX94T#A02 accident record listed "PUBLIC USE" for "regulation under which flight was conducted" and was missing data for the type of operation. Moreover, the NTSB record indicated that while a computer report was filed, the NTSB did not conduct an investigation.

[2]Class 1 medical examinations are required every 6 months, so the number of exams expected each year should be two. However, in some cases the interval between examinations was slightly less than 6 months, resulting in 3 examinations in a year. In other cases, only one examination record was available for some pilots in a given year. As noted in Table 8, the medical examinations data represented a large proportion of examinations given, but did not include every record for every pilot.

[3]Matched accident-exposure records (de-identified) and aggregated data are available from the author on request.

[4]The premise that most exposure hours are likely to have been accumulated in occupational rather than recreational or personal flying can be partially tested by comparing the actual distribution of flight hours to (a) average flight hours for pilots in commercial aviation as reported by the federal Bureau of Labor Statistics and (b) maximum occupational hours allowed under Parts 121 and 135. The BLS indicates that commercial pilots, on average, fly about 75 hours per month for airlines, or about 900 hours annually

http://www.bls.gov/oco/ocos107.htm

The maximum flight hours allowed in operations under Part 121 is 1,000 annual hours, and 1,200 under Part 135. Overall, pilots included in this study reported an average of 725 annualized flight hours. The mode for annual flight hours was 712 hours. As shown in the table below, 75% of the exposure records reported between 500 and 899 annual hours. In view of contractual provisions and seniority, it is more likely than not that most of these annual hours are occupational. Moreover, just 8.7% of the records were for pilots reporting more than the regulatory maximum limits under Parts 121 and 135; flight hours in excess of the regulatory maxima are likely to be recreational. If one accepts the premise that employers will schedule the pilots near or at the maximums allowed by contract and regulation, then it appears that most of the hours are more likely to have been occupational rather than recreational for most (75% or more) of the pilots included in this study. In other words, the assumption that most flight hours are occupational for most pilots is reasonable for this dataset. Woolsey (2003b) also argues, based on his review of Kay, et al., that "… the inflation of denominator values by recreational flight hours by these professional pilots can only be miniscule" (p. 7, footnote 13).

Flight Hours Range	N	%
LE 499 AHrs	27,233	7.1
500-699 AHrs	128,439	33.7
700-799 AHrs	66,488	17.4
800-899 Ahrs	91,171	23.9
900-999 AHrs	35,007	9.2
1000-1199 AHrs	28,066	7.4
GE 1200 AHrs	5,009	1.3
Total	381,413	100.0

[5]This publication and all Office of Aerospace Medicine technical reports are available in full-text from the Civil Aerospace Medical Institute's publications Web site at http://www.cami.jccbi.gov/aam-400A/index.html