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Pilot Age and Accident Rates Report 4: An Analysis of Professional ATP and Commercial Pilot Accident Rates by Age

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EXECUTIVE SUMMARY

In response to continuing controversy over the Age 60 Rule (14 **CFR** §121.383(c)), the United States Senate directed further study by the FAA of pilot age and accidents. This report presents the fourth of the four studies proposed by the agency.

Accident rate was defined in this study as the ratio of the number of fatal and nonfatal accidents, as reported by the National Transportation Safety Board (NTSB), occurring under 14 **CFR** §121 and §135 to annual hours flown by professional pilots holding air transport pilot (ATP) or commercial and first- or second-class medical certificates for the period 1988 through 1997. Accident data were provided by the NTSB. Annual hours flown were estimated from medical examination records extracted from the FAA Comprehensive Airman Information System.

Three analyses were conducted. As directed by the Senate request, the first analysis examined accident rates as a function of one unique (60-63) and 36 overlapping, four-year age groups declining from age 59 for pilots holding ATP or commercial and first- or second-class medical certificates (i.e., 60-63, 56-59, …, 24 or less). The second analysis examined accident rates by overlapping, four-year age groups declining consistently from age 63 (i.e., 60-63, 59-62, …, 24 or less). The third analysis examined accident rates for the 60-63 age group and non-overlapping (or independent) five-year age groups (i.e., 55-59, 50-54, …, less than or equal to 29) for comparison with previous studies.

The findings are consistent across the three analyses. First, for accidents occurring under 14 **CFR** §121 and §135, the analyses supported the hypothesis that a "U"-shaped relationship exists between the age of professional pilots holding ATP or commercial and first- or second-class medical certificates and their accident rate. Second, the accident rate for the 60-63 age group was statistically greater than the accident rate for 55 or 56 to 59 year old pilots in the *a priori* planned comparisons. Third, the main effect for age was statistically significant in all analyses. These findings suggested that the probability of an aviation accident under §121 and §135, as a function of pilot annual flight hours, was related to pilot age.

The results of this study are generally consistent with the conclusions reported by Golaszewski (1983, 1991, 1993) despite the use of different methods and samples. The results differ from the findings of the Hilton Systems, Incorporated. Kay et al. (1994) found that the accident rate decreased for younger pilots as they aged and then leveled off in the middle years. However, Kay et al. did not examine accident rates for Class 1 pilots older than age 59. The trend analyses in the present study detected a "U"-shaped relationship between accident rates and age when pilots age 60 to 63 were included in the sample. The analyses in this study also found that the accident rate for pilots age 60-63 was statistically greater than the accident rate for pilots age 55 or 56 to 59.

Three recommendations are presented in closing. First, the development and implementation of a unique identifier for each pilot that can be used consistently across all aviation safety and regulatory databases is recommended. Second, collection of additional voluntary information from pilots such as the number of cycles (take-offs and landings) and proportion of hours accumulated under the major flight regulations (e.g., §121, §135, §91, and other) is recommended. Finally, alternative statistical techniques for the investigation of the relationship of pilot age to accidents are recommended.

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CHAPTER 1: INTRODUCTION

In 1959, the Federal Aviation Administration (FAA) adopted what has commonly been referred to as the Age 60 Rule (24 **FR** 9767, December 5, 1959). This regulation prohibits any air carrier from using the services of any person as a pilot, and prohibits any person from serving as a pilot, on an airplane engaged in operations under Part 121 of the Federal Aviation Regulations (FAR) if that person has reached his or her 60^{th} birthday [14 **CFR** §121.383(c)]. In 1997, the FAA initiated a regulatory action as part of the Commuter Safety Initiative. The rule changes required commuter airlines to meet the same operational, equipment, and performance safety standards as major carriers (FAA, 1995). As part of that standardization, the Age 60 Rule was extended to cover pilots employed by commuter airlines operating under Part 135 as of December 1999.

Considerable controversy has surrounded the Age 60 Rule, as is evidenced by a number of legal actions (Schroeder, Harris, & Broach, 1999). For example, several pilots challenged the rule under the Age Discrimination in Employment Act and Administrative Procedures Act in 1995. The U.S. Court of Appeals for the District of Columbia found the assertions to be without merit in 1997, holding that the courts should not second-guess the FAA retirement rule (*Professional Pilots Federation et al. v. Federal Aviation Administration*, 1997). The U.S. Supreme Court rejected a subsequent appeal by the pilots without comment (*USA Today*, May 19, 1998). Most recently, a group of current and former commercial airline captains petitioned for exemption from the Age 60 Rule. They are seeking to work beyond age 60 on the basis of their successful completion of extensive medical and neuropsychological testing based on a protocol developed by a panel of "…nationally and internationally recognized experts in the fields of aerospace medicine, cardiology, internal medicine, geriatrics, and neuropsychology…" (*Petition for Exemption to the Age 60 Rule*, 2000). A central issue in these challenges has been the relationship of aging to safety.

Relevant Research

Aging

Aging has been characterized as a set of progressive changes in the physiological and psychological functioning of an individual. Age-related changes are largely continuous and subtle rather than discrete and dramatic (Czaja, 1990). Theories of aging suggest a generalized decline in the rate of central processing speed and a reduction in working memory capacity (Salthouse, 1985, 1990) that are more likely to affect performance of complex tasks. Both laboratory and simulator studies appear to support this general prediction in piloting tasks (Morrow & Leirer, 1997, p. 221). Research on performance in other domains such as automobile safety suggests that there may be a "U"-shaped relationship between age and performance. For example, Massie, Campbell, and Williams (1995) found that automobile accident risk was greater for younger and older drivers than for drivers aged 25 to 65. However, changes in performance associated with aging are characterized as much by increased variability between individuals as by a decline in performance (Landy, 1992; Salthouse, 1985, 1990). These findings in cognitive research and other transportation modes suggest that the longitudinal effects of aging on aviation safety outcomes such as accidents will be relatively subtle rather than dramatic. Changes in outcomes might be best described in terms of a trend across age groups.

Aviation safety and age

Several studies have examined aviation safety outcomes such as accidents in relation to age, with mixed results. For example, Guide and Gibson (1991) analyzed NTSB accident records for the period 1982 through 1988. These researchers investigated the number of accidents per 1,000 active airmen and accidents per 100,000 annual hours flown across age groups for pilots holding air transport pilot (ATP), commercial, or private pilot certificates. Age groups were defined in five-year increments, ranging from 20-24 to 55-59. Guide and Gibson did not conduct formal statistical analyses of accident rates by age. However, the figure illustrating accident rates of Part 135 operators per 100,000 annual flight hours suggests minimal differences between age groups. In contrast, rates based on 1,000 active ATPs or active Commercial Pilots evidence a "U" shaped relationship across age groups. In 1990, the FAA contracted with Hilton Systems, Incorporated, for a study of accident rates, flying experience, and age. Accident rates for the period 1976 through 1988 were analyzed for pilots holding first-, second-, or third-class medical certificates and operating under Parts 91, 121, or 135. Based on their analysis of accident rates for pilots holding first-class medical certificates, Kay, Hillman, Hyland, Voros, Harris and Deimler (1994) reported "… no hint of an increase in accident rate for pilots of scheduled air carriers as they neared the age of 60" (p. 6-2).

Finally, Rebok, Grabowski, Baker, Lamb, Willoughby, and Li (1999) examined causal factors in accidents for a historical cohort of 3,592 air carrier and air taxi pilots. Rebok et al. compared causal factors in crashes involving pilots aged 40 to 47 ($n = 65$), 48 to 55 ($n = 73$), and 56 to 63 ($n = 27$) for the years 1983 through 1997. The authors concluded that there were no significant differences by age in pilot performance factors contributing to crashes.

Other studies have found changes in aviation safety outcomes with age. Golaszewski (1983) examined the relationship between age, experience, and pilot performance. He found that older pilots exhibited higher accident rates under some conditions. The accident rate for pilots holding third-class medical certificates declined until age 60 and then increased for pilots over the age of 60. The Office of Technology Assessment (1990) reached a similar conclusion when reviewing aviation accident data. Similarly, an analysis by Mortimer (1991) reported that private pilots age 60 and older had accident rates approximately twice that of private pilots between the ages of 16 and 59, based on an analysis of 1,034 National Transportation System Board (NTSB) accident records for 1985 and 1986. An analysis of accidents for pilots holding third-class medical certificates by Kay et al. found "… a hint, and a hint only, of an increase in accident rates for Class 3 pilots older than 63 years of age" (p. 6-3). Li and Baker (1994) used a case-control design to assess the relationship between crash/incident history, violation history, pilot age, flight experience, and recent flight time. Cases were commuter and air taxi pilots (N = 725) involved in crashes during 1983 and 1988, with 1,555 pilots as controls. The multivariate logistic regression model "…revealed that every 10-year increase in age was associated with a 36% increase in the risk of being involved in a commuter aircraft or an air taxi crash" (p. 983). While Li and Baker interpreted the analysis as indicating that "…greater experience keeps older pilots from being at excess risk" (p. 984), the statistics presented in their Table III (p. 983) indicate that the likelihood of crash involvement increased with age, even after the effects of all other variables in the analysis, including total and recent flight experience, were taken into account.

In summary, previous research on aviation safety outcomes in relation to age has produced mixed results, with some studies indicating a trend across age and others failing to detect any relationship of age to safety outcomes such as accidents. As Li and Baker (1994) noted, "… no consensus has emerged in the literature" on the effect of pilot age on aviation safety. Further research is often recommended.

Overview of Study Design

The continuing controversy surrounding the Age 60 Rule, the mixed results from studies of accident rates, and calls for continuing research prompted the United States Senate to request further study by the FAA of pilot age and accidents (Appendix A). The critical passage read:

> "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."

The FAA responded by proposing a series of four studies:

- An annotated bibliography of the research literature from 1991 to the present (Schroeder, Harris, and Broach, 1999);
- A re-analysis of the data included in a study reported by the *Chicago Tribune* (Broach, 1999);

- An investigation of accident rates for professional air transport pilots (Broach, Joseph, and Schroeder, 2000); and
- An investigation of accident rates for professional air transport and commercial pilots.

The purpose of the annotated bibliography was to update the Hyland et al. review of the scientific literature relevant to the Age 60 Rule. The purposes of the second study were to (a) replicate and correct the analysis of 450 accidents and incidents, and (b) evaluate the statistical conclusions reported by the *Tribune*. The purpose of the third study was to begin focusing on the population of pilots likely to be included in the phrasing "non-scheduled commercial (and non-commercial, if available)" and "scheduled commercial pilots (and non-commercial pilots, if available)." Therefore, the third study examined accident rates for pilots holding first-class medical and air transport pilot (ATP) certificates. The third study (Broach, Joseph, & Schroeder, 2000) reported a statistically significant "U"-shaped trend between accident rates and age. However, the accident rate for pilots holding first-class medical and ATP certificates age 60 to 63 was not statistically different than the accident rate for pilots age 56-59.

This fourth study broadens the operational definition of the relevant population to professional pilots holding ATP or commercial and first- or second-class medical certificates. This represents the broadest definition of the population most likely to be piloting aircraft under 14 **CFR** §121 and §135, and thus, covered by the extended Age 60 rule. The focus of the study was on accident rates for professional pilots holding ATP or commercial and first- or second-class medical certificates. Specifically, the ratio of the number of accidents occurring for flights operating under 14 **CFR** §121 and §135 to annual hours flown by professional pilots holding an ATP or commercial and first- or second-class medical certificates was analyzed by age group for the period 1988 through 1997.

This report is organized into six chapters. The first chapter, as presented above, provides an introduction to the Age 60 Rule and relevant research. The second chapter describes methodological considerations for the analysis of accident rates. Statistical analyses are presented in the third, fourth, and fifth chapters. The analysis presented in the third chapter of this report compares accident rates for pilots holding ATP or commercial and first- or second-class medical certificates age 60 to 63 with the accident rates of pilots by overlapping 4-year age groups, declining from age 59 (e.g., 56-59, 55-58, … less than or equal (LE) 24), for the period 1988 through 1997. The fourth chapter focuses on the accident rate for the same category of pilots by consistently overlapping 4-year age groups, declining from age 63 (e.g., 60-63, 59-62, 58-61, 57-60, 56-59, … LE 24) for the period 1988 through 1997. The fifth chapter examines accident rates by non-overlapping 5-year age groups for pilots over the same time period. The final chapter (a) summarizes and compares the reported analyses, (b) compares the results of the present studies to previous research, (c) assesses the strengths and weaknesses of the present analyses, and (d) presents recommendations for future research.

CHAPTER 2
METHODOLOGICAL CONSIDERATIONS

The Senate initially requested a specific analysis: "… 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 …" In effect, the Senate posed the following questions:

1. Broadly, to what degree does the accident rate vary as a function of age?
2. And specifically, to what degree are the accident rates for pilots between 60 and 63, in operations not previously covered by the Age 60 Rule, similar to or different from the accident rates for pilots 59 and younger, in operations previously covered by the rule?

Previous research on aging and performance in general, aging and pilot cognitive performance, and pilot age and safety outcomes specifically provided a basis for framing the research questions. We expected that we might find a trend in accident rates across age, perhaps taking the "U" shape observed in automobile accident involvement. We also expected differences in accident rates by age to be generally small, with substantial variability in younger and older age groups. As a consequence, we did not necessarily expect statistically significant differences in accident rates between adjacent age groups.

Caution is necessary in the analysis of infrequent events such as aviation accidents because there are substantive methodological considerations in such analyses (Broach, 1999; Hulin & Rousseau, 1980; Li, 1994). These considerations include (a) the definition of the population of interest, (b) the time span of the observation period, (c) the use of age as either a continuous or grouped independent variable, (d) the definition of the events to include in the numerator of the ratio, (e) the definition of the hours flown to include in the denominator of the ratio, as an estimate of exposure to the risks of flight, and (f) the statistical method(s) for analyzing the resulting ratio(s).

Definition of the Population of Interest

The first issue confronted was the definition of the population to be studied. For example, the Senate directive requested a comparison of accident rates by age for "non-scheduled commercial" and "scheduled commercial" pilots. "Non-commercial" pilots were to be included as available. This implied defining the pilot population in terms of types of operation (scheduled versus unscheduled) and employer (commercial and non-commercial). However, the data required to segment the pilot population along these lines were not available from FAA pilot records. The available FAA data source is the Comprehensive Airman Information System (CAIS), which describes (a) the type(s) of certificate(s) issued to a pilot, (b) aircraft type ratings for a pilot, (c) class of medical certificate issued, (d) self-reported employer, and (e) self-reported hours flown. The official system of FAA records does not capture the types of operation (scheduled or unscheduled, commercial or non-commercial) in which a pilot has engaged.

Given the limits of available data, therefore, the definition of the population of pilots to be studied had to be based on the type of certificates held by a pilot. The broadest operational definition of the population likely to be included in the phrasing "non-scheduled commercial (and non-commercial, if available)" and "scheduled commercial pilots (and non-commercial pilots, if available)," based on available data, was pilots holding air transport pilot (ATP) or commercial and first- or second-class medical certificates. Pilots holding these certificates can conduct scheduled and non-scheduled flights for air carriers and commercial operators under 14 **CFR** §121 and §135. Depending on the employer, they may also engage in commercial or non-commercial operations.

Time Span

The second methodological issue was the time span to be encompassed by the research. A common strategy for research on infrequent or rare events is to extend the data collection period (Hulin & Rousseau). For example, Golaszewski (1983) examined accident rates as a function of age for a five-year period, 1976 through 1980. A subsequent investigation by Golaszewski (1991, 1993) also covered a five year span (1983 to 1988), as did the work by Li and Baker (1991). The study by Kay et al. (1994) spanned 12 years (1976 to 1988), overlapping with both of the analyses by Golaszewski. The recent longitudinal study of 3,592 pilots by Rebok et al. (1999) covered a 15-year period (1983 through 1997). The present study selected the period 1988-1997, which included the most recent set of complete data for a ten-year period.

Age as Continuous or Grouped Independent Variable

The third methodological issue was a choice of the treatment of age as the independent variable. Age could be treated as a continuous or grouped variable. The Senate specifically described grouping cases by 4-year age increments, declining from age 59. The Senate direction results in a unique age group (60 to 63), and 36 overlapping age groups, declining from age 59 (e.g., 56-59, 55-58, 54-57, … 23-26, 22-25, 21-24). This approach results in comparing the accident rate for the 60-63 age group to all consecutive age groupings below age 60. The statistical analysis reported in Chapter 3 groups pilots by age in the specific manner requested by the Senate.

However, this approach has two consequences. First, there is a discontinuity at age 60. Second, in some sense, the grouping of pilots in overlapping age ranges is similar to a moving average computed on a four-year period. The result is a smoothing of the data. Therefore, we also grouped pilots by age in four-year brackets declining from age 63. This resulted in 40 overlapping age groups without the discontinuity noted above. This alternative analysis is reported in Chapter 4.

These approaches to grouping pilots by age result in groups that are not independent of one another. For example, data from a pilot aged 45 in 1992 would be incorporated with pilots aged 42 to 45, 43 to 46, 44 to 47, and 45 to 48 in that year. The pilot data would be reflected in the data for four age groups, rather than one age group. This violates the assumption of the statistical methods commonly used for analyzing group differences that the groups are independent of one another. That is, statistical methods for analyzing differences between groups assume that a pilot in 1992, for example, belongs to one, and only one, age group. The grouping method described by the Senate results in a pilot record being counted in several age groups.

Therefore, we conducted a third analysis in which pilots were grouped by age in a manner consistent with both common statistical assumptions and previous research. Typically, pilot records for a given year are grouped into non-overlapping age ranges, such that the data for a pilot are incorporated into just one age range. Five year age ranges have been used in previous research (e.g., 55-59, 50-54, … 25-29, 20-24). We used the following age groups to be consistent with previous research and the Senate direction: less than or equal to (LE) 29, 30 to 34, 35 to 39, 40-44, 45-49, 50-54, 55-59, and 60-63 (required by the Senate). The minimum age for an ATP certificate is 23 (14 **CFR** §61.151(a)), compared to 18 for the commercial certificate (14 **CFR** §61.123(a)). There is no maximum age at which either pilot certificate may be issued. The primary advantages of this approach are (a) compliance with the assumptions of common statistical methods, and (b) comparability of the analyses to previous research.

There are at least two disadvantages to grouping the data by age. First, the statistical power of the analysis to detect subtle effects associated with age is reduced. Conceptually, statistical power is the probability that a test will detect, for example, a difference between age groups, if such a difference exists (Cohen, 1988). The statistical power of a given analysis depends upon three parameters: (a) the size of the difference between groups (effect size); (b) the size of the sample (e.g., the number of groups being compared); and (c) the acceptable probability that a result did not occur by chance alone (e.g., the level of statistical significance, or α, commonly set at less than or equal to 5%). Previous research suggested that any differences in accident rates by age group will be small. When small effect sizes are expected, larger sample sizes are required to have an acceptable probability of detecting any differences by age group. However, aggregating the data reduces the number of cases being analyzed to the number of years encompassed by the study. Therefore, keeping the acceptable level of statistical significance at the common 5% threshold ($p \leq .05$) and aggregating the data by age group will reduce the power of the analysis to detect small differences in accident rates between age groups.

Second, grouping the data by age ranges reduces the precision of the resulting statistical model of age-outcome relationships. That is, any differences detected by the analysis are attributable to an age range rather than to a specific age. For example, given a statistically significant difference between some age groups, one might be justified in inferring that the accident rate increases for ages *x* to *y* compared to ages *a* and *b*, but one cannot say at which specific age the rate statistically changes on the basis of the analysis.

Numerator: Accidents Selected for Analysis

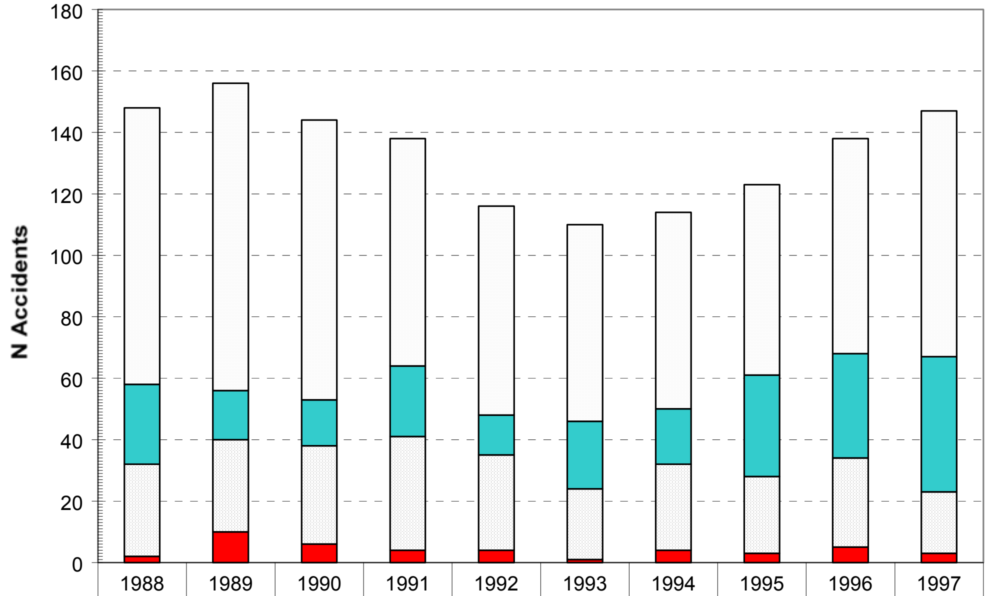
The NTSB maintains the official system of federal records for aviation accidents. An "aircraft accident" is an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and until all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage (National Aviation Safety Data Analysis Center, 2000).

The criteria for selecting accidents from the NTSB database to be included in the numerator for this study were (a) the accident occurred for a flight operating under 14 **CFR** §121 and §135, which includes scheduled and non-scheduled operations; and (b) availability of pilot identifying information. The NTSB provided the Civil Aeromedical Institute (CAMI) with an electronic data file for 1,359 aviation accidents that occurred between January 1, 1988, and December 31, 1997. The variables of interest in this data file included pilot-in-command (e.g., first pilot or "pilot") identifiers (i.e., pilot certificate number and date of birth), pilot age at the date of the accident, and certificates held. Other descriptive information included the date, local time, and meteorological conditions, applicable regulation under which the flight was operating, and deaths and injuries resulting from the accident.

Not all NTSB accident records provided complete first pilot identifiers. For example, name information was not available initially for 40 records. Pilot certificate numbers were missing for 18 accident records. Type of certificate was missing for 53 accidents. Date of birth was missing for 176 accident records. The NTSB case files (e.g., "dockets") for the accident records without pilot identifiers were examined in April 2000 at the NTSB office in Washington, DC. The FAA Comprehensive Airman Information System (CAIS) certificate database was used to obtain dates of birth and type of certificate, based on pilot name and certificate number for those accident records with missing dates of birth. Identifying information was not available from either source for 25 accident records, resulting in 1,334 usable accident records involving pilots holding ATP or Commercial certificates. Figure 1 shows that the number of accidents ranged from 110 to 156 per year. There were 327 fatal accidents with 1,964 fatalities between 1988 and 1997 for flights operating under Parts 121 or 135.

Denominator: Hours Flown as Exposure

Annual and total hours of flight time are used frequently as measures to represent exposure to the hazards of flight. For example, Golaszewski (1983, 1991, 1993) and Kay et al. (1994) used annual and total flight hours (i.e., expressed in units of 100,000 flight



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
135 Non-Fatal	90	100	91	74	68	64	64	62	70	80
121 Non-Fatal	26	16	15	23	13	22	18	33	34	44
135 Fatal	30	30	32	37	31	23	28	25	29	20
121 Fatal	2	10	6	4	4	1	4	3	5	3

Figure 1: Number of nonfatal and fatal accidents under 14 **CFR** §121 and §135 involving pilots holding ATP or commercial and first- or second-class medical certificates, 1988-1997.

hours) as a measure of exposure to the hazards of flight. To be consistent with previous research, 100,000 annual flight hours was used as the unit of the denominator for accident rates in these studies of the Age 60 Rule. The source most often used for estimates of flight hours for pilots is the self-report of hours flown at the time of medical examination. These estimates are typically obtained from CAIS, which is the official system of federal records for airman medical certificates maintained by the Flight Standards Service.

There is no upper age limit on either the medical or pilot certificates. A first- or second-class medical certificate can be issued to a pilot over age 60 so long as he or she meets the published medical criteria. Similarly, an ATP or Commercial pilot certificate may be issued to a person over age 60 so long as he or she meets the published criteria. Therefore, we expected to find medical certificate records with estimates of flight hours for some pilots over age 60 in the CAIS.

A total of 943,483 records of first- or second-class medical examinations between January 1, 1988, and December 31, 1997 for persons age 18 and older were extracted from the CAIS medical certificate data as provided to CAMI by Flight Standards. The self-reported employer field from the medical examination was used to exclude records for military and government pilots from the data set, reducing the pool to 939,767 records. The medical examination records were then matched by SSN, name, and date of birth with CAIS certificate data for the 133,876 individual pilots holding ATP or Commercial certificates between 1988 and 1997. The number of pilots for whom certificate records were available each year ranged from 58,768 to 72,037. The number of pilots for whom certificate records were available are compared in Table 1 to the number of ATP and effective[1] first-class medical certificates reported annually by the FAA in the *FAA Aeromedical Certification Statistical Handbook*. It is important to remember in examining Table 1 that (a) pilots may hold both types of pilot certificates, and (b) historically, less than 50% of the pilots report their profession as "professional pilot," as shown in Table 1. The proportion of pilots reporting their job as "professional pilot" in Table IV.I of the annual *FAA Aeromedical Certification Statistical Handbook* was used to develop a very crude estimate of the target population of professional pilots. The number of pilots holding commercial certificates and the number of pilots holding second-class medical certificates were multiplied by the proportion reporting "professional pilot" to develop a range for the size of the estimated target population. The number of pilots represented by the CAIS records extracted for this analysis was then compared to the crude estimate of the target population for each year. The number of pilots for which records were available for this analysis was greater than the estimated population size in five of the ten years, and fell within the range in the other five years. This rough comparison suggests that the set of CAIS records encompassed the airmen likely to be operating aircraft under 14 **CFR** §121 and §135, and therefore, was an adequate sample for the estimation of the relationship of age to accident rates for professional pilots likely to be covered by the Age 60 Rule.

The average number of medical examinations per pilot was about 7 (M = 7.12, SD = 5.57), and ranged from 1 to 21 examinations per pilot. The ages (as of the medical examination) ranged from 18 (the minimum for a Commercial certificate) to 84, with an average of 42 years. Important data fields in the extracted CAIS medical and certificate records included pilot identifiers (i.e., name, SSN, certificate number, and date of birth), the date that the medical certificate was issued, and the class of medical certificate. Recent (i.e., in the last six months) and total (i.e., as of medical) flight hours are both reported by pilots at the time of examination (see Figure 2).

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[1]The annual *Aeromedical Certification Statistical Handbook* defines "effective status" for a medical certificate in terms of the time since a required examination. For example, if more than six months have lapsed since the completion of a first-class ("Class 1") medical examination for an airman, the "effective status" of the airman would be reduced to the next lower level, a second-class ("Class 2") airman medical certificate. If more than 13 months have lapsed since the completion of a Class 1 medical examination for an airman, the "effective status" would be reduced to the third-class ("Class 3") airman medical certificate. If the lapse is greater than 25 months, the medical certificate would no longer be effective, as a medical examination must be completed at least every two years to hold a Class 3 medical certificate.

Table 1

Comparison of number of ATP and commercial certificates, first- and second class medical certificates, estimated target population size, and number of CAIS records available for analysis for each year, 1988-1997

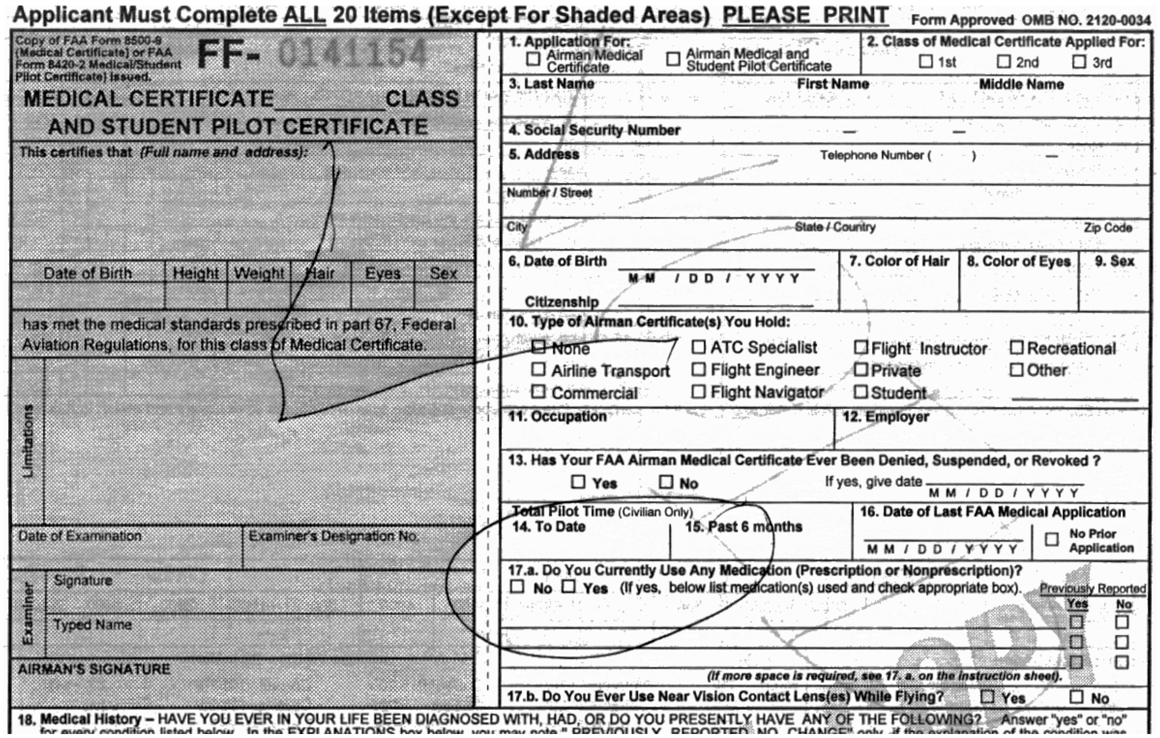
	Pilot Certificate[a]		Medical Certificate[b]				
Year	ATP	Commercial	Class 1	Class 2	% Class 1 Reporting "Professional Pilot"[c]	Estimated Target Population Size[d]	N CAIS Records Available
1988	96,968	143,030	70,388	112,830	47.9	53,830 – 68,511	63,105
1989	102,087	144,450	83,254	119,382	48.2	57,542 – 69,624	64,977
1990	107,732	149,666	81,055	115,757	49.1	56,837 – 73,486	69,455
1991	112,167	148,365	90,859	120,396	46.5	55,984 – 68,990	72,142
1992	115,855	146,385	89,879	118,078	47.1	55,614 – 68,947	72,622
1993	117,070	143,014	87,654	113,164	47.7	53,979 – 68,218	63,474
1994	117,434	138,728	75,662	101,316	46.4	47,011 – 64,370	58,768
1995	123,877	133,980	78,662	99,550	48.6	48,381 – 65,114	70,151
1996	127,486	129,187	82,200	97,107	49.5	48,068 – 63,948	72,037
1997	130,858	125,300	84,732	96,120	50.5	48,541 – 66,083	69,295

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

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

[c]As reported annually in *FAA Aeromedical Certification Statistical Handbook*, Table IV.I, for Class 1 pilots

[d]Computed as proportion reporting professional pilot times number of Commercial and number of effective Class 2 medical certificates



Applicant Must Complete ALL 20 Items (Except For Shaded Areas) PLEASE PRINT Form Approved OMB NO. 2120-0034

Copy of FAA Form 8500-9 (Medical Certificate) or FAA Form 8420-2 Medical/Student Pilot Certificate) issued. FF- 0141154

MEDICAL CERTIFICATE ________ CLASS AND STUDENT PILOT CERTIFICATE

This certifies that (Full name and address):

Date of Birth	Height	Weight	Hair	Eyes	Sex

has met the medical standards prescribed in part 67, Federal Aviation Regulations, for this class of Medical Certificate.

Limitations

Date of Examination | Examiner's Designation No.

Examiner: Signature; Typed Name

AIRMAN'S SIGNATURE

1. Application For: ☐ Airman Medical Certificate ☐ Airman Medical and Student Pilot Certificate
2. Class of Medical Certificate Applied For: ☐ 1st ☐ 2nd ☐ 3rd
3. Last Name — First Name — Middle Name
4. Social Security Number
5. Address — Telephone Number ( )
Number / Street
City — State / Country — Zip Code
6. Date of Birth MM / DD / YYYY — Citizenship
7. Color of Hair
8. Color of Eyes
9. Sex
10. Type of Airman Certificate(s) You Hold: ☐ None ☐ ATC Specialist ☐ Flight Instructor ☐ Recreational ☐ Airline Transport ☐ Flight Engineer ☐ Private ☐ Other ☐ Commercial ☐ Flight Navigator ☐ Student
11. Occupation
12. Employer
13. Has Your FAA Airman Medical Certificate Ever Been Denied, Suspended, or Revoked? ☐ Yes ☐ No If yes, give date MM / DD / YYYY

Total Pilot Time (Civilian Only)
14. To Date
15. Past 6 months
16. Date of Last FAA Medical Application MM / DD / YYYY ☐ No Prior Application
17.a. Do You Currently Use Any Medication (Prescription or Nonprescription)? ☐ No ☐ Yes (If yes, below list medication(s) used and check appropriate box). Previously Reported Yes No
(If more space is required, see 17. a. on the instruction sheet).
17.b. Do You Ever Use Near Vision Contact Lens(es) While Flying? ☐ Yes ☐ No
18. Medical History – HAVE YOU EVER IN YOUR LIFE BEEN DIAGNOSED WITH, HAD, OR DO YOU PRESENTLY HAVE ANY OF THE FOLLOWING? Answer "yes" or "no"

Figure 2: Sample pilot medical examination form.

Pilots reported their recent and total hours without regard to type of operation (e.g., 14 **CFR** §91, 121, 129, or 135). As a consequence, the total and recent flight hours data associated with each medical certificate at the time of issuance reflects the pilot's experience for all types of operations. Therefore, the exposure estimates were likely inflated relative to actual hours flown under 14 **CFR** §121 and §135 operations by including hours flown under Part 91 (general aviation). Accident rates computed from these inflated exposure estimates were likely to underestimate the actual Parts 121 and 135 accident rate by some degree.

Analytic Techniques

In previous analyses of accident rates, hours of recent flying reported at the time of the medical examination were annualized by some set of rules (Golaszewski, 1981; Kay et al., 1994). The next step in those analyses was to group the records by year and age group, summing the number of accidents and annualized hours flown for each combination of year and age group. Descriptive statistics included the sum of annualized flight hours (e.g., recent flight experience), sum of cumulative total flight hours (e.g., total flight experience), and total number of accidents for each age group across the ten years.

Event rates were then calculated for each year and age group combination as the ratio of accidents to total annualized hours flown for that year and age group. The event rates were analyzed using analysis of variance (ANOVA), with age group as the independent variable. ANOVA is a broad class of techniques for identifying and measuring the sources of variation within a collection of data (Kachigan, 1986). For example, Kay et al. (1994) used ANOVA to determine if accident rates changed with age, that is, if there was a trend in accident rates as a function of age. Kay et al. also used ANOVA to compare the accident rates for specific age groups.

We had two working hypotheses or expectations. First, we hypothesized that a "U" shaped trend might describe accident rates across age groups similar to that observed in automobile accident involvement. Second, because of the low base rate for accidents under 14 **CFR** §121 and §135 and the gradual change in accident rates as a function of age associated with the likely trend, we did not expect statistically significant differences between adjacent age groups. Procedurally, we conducted an *a priori* trend analysis with a planned comparison (Hays, 1988; Marascuilo & Serlin, 1988). We compared the accident rate for the 60-63 age group to the accident rate for the next younger, non-overlapping age group. These age groups were selected to contrast ages on either side of the Age 60 Rule in view of discussions about increasing the age limit. Finally, we conducted an overall, or omnibus, test for differences in accident rates by age for the sake of completeness.

Technical considerations in the design of the ANOVA included (a) whether to treat the data as proportions or rates and (b) the definition of the degrees of freedom in the denominator. Kay et al., for example, treated the data as a proportion rather than a rate (Kay, et al., 1994, p. 4-4). By approaching the data as proportions, Kay, et al. assumed the degrees of freedom in the denominator were infinite (p. 4-4). As a result, the critical value of the *F* required for statistical significance was lower (smaller) than would be required if the degrees of freedom for the denominator were not infinite. The consequence was a relatively liberal test of the effect of age on accident rates in the Kay et al. analyses.

However, the treatment of the ratio of accidents to hours flown as a proportion appeared problematic. A proportion is, by definition, constrained to take a value between 0.0 and 1.0; the ratio of accidents to hours flown can exceed 1.0, as shown in Kay et al.'s Table B-1B. Rates, in constrast, can take any value greater than or equal to 0. We therefore chose to treat the data for this study as rates rather than proportions. As a consequence, we could not assume that the degrees of freedom for the denominator in the statistical test were infinite. Rather, the degrees of freedom for the denominator were defined as the number of aggregated records for each year and age group combination. As a result, the statistical tests were more stringent, as the critical value of *F* required for statistical significance would be larger than required in the Kay et al. analyses.

Additional technical considerations included the distribution of accident rate and the purpose of the analysis. ANOVA assumes that the data are normally distributed.

However, the research literature on aviation accidents suggested that the rate was likely to take a Poisson distribution (Boyer, Dionne, & Vanasse, 1990; Dionne, Gagné, & Vanasse, 1992). Similarly, Kay et al. (1994, p. 4-3) argued that the number of accidents for a given pilot group was binomially distributed. Such distributions are characterized by higher degrees of skewness and kurtosis, thus violating the assumption of a normally distributed dependent variable (accident rate). Transformations of the dependent variable have been suggested to normalize the distribution (Levine & Dunlap, 1982). However, the issue is not well settled (Kirk, 1995, p. 103). Games (1983) suggested that the decision to transform the dependent variable should take into account factors such as the purpose of the analysis, nature of the scales used for measurement, and simplicity of interpretation. The present study was a preliminary, descriptive investigation rather than a formal test of theoretically-based predictions with experimental controls. Moreover, the scales used for measurement - age and accidents per 100,000 flight hours - were directly interpretable and meaningful, resulting in straightforward, simple descriptions. Transformations of the accident rate, such as the natural logarithm or base 10 logarithm, would complicate the interpretation. Moreover, research suggests that ANOVA is reasonably robust, even in the presence of violations of statistical assumptions (Budescu & Applebaum, 1981). Therefore, the accident rates were not transformed.

Finally, and related to the purpose of the analysis, the use of ANOVA to analyze accident rates by age group relies upon aggregated data. This technique does not result in a predictive model that would allow decision-makers to estimate the number of additional accidents that might occur over the baseline as a result of changing the current age restriction. Moreover, estimating the influence of potential moderating variables, such as recent flight and total flight time, geographic region, and type of employer is problematic in ANOVA-based analyses of rates. For example, investigation of the effects of total experience requires aggregation of the source data by year, age group, and total experience group. As a result, the degrees of freedom (e.g., the number of lines of data) for the analysis change. This makes comparison and interpretation of results across various analyses somewhat problematic as they are based on different levels of aggregation. However, ANOVA has been the primary analytic technique in previous studies. Therefore, we also used ANOVA to analyze accident rates by age group across the ten year span of the study. Alternative approaches that might be utilized in future studies are considered in Chapter 6 of this report.

Analyses

Three analyses of accident rates are presented in this study. Consistent with the Senate request, the first analysis (Chapter 3) examines accident rates as a function of one unique (60-63) and 36 overlapping, four-year age groups declining from age 59 for pilots holding ATP or commercial and first- or second-class medical certificates (i.e., 60-63, 56-59, …, 22-25, LE 24). The second analysis (Chapter 4) also examines accident rates by overlapping, four-year age groups declining consistently from age 63. As a result, the second analysis includes three additional age groups (viz., 57-60, 58-61, 59-62) that were not specified in the Senate request. The third analysis (Chapter 5) examines accident rates as a function of non-overlapping (or independent) five-year age groups (i.e., 60-63, 55-59, …, 30-34, less than or equal to 29) for direct comparison with previous studies.

CHAPTER 3
ACCIDENT RATES FOR PROFESSIONAL PILOTS HOLDING ATP OR COMMERCIAL AND FIRST- OR SECOND-CLASS MEDICAL CERTIFICATES USING SENATE-DIRECTED AGE GROUPS

Data Preparation

CAIS medical data

The starting points for this analysis were the (a) 1,334 NTSB accidents occurring for Parts 121 or 135 flights that involved pilots holding an ATP or commercial and first- or second-class medical certificate at the time of the accident, and (b) 939,767 CAIS first- or second-class medical certificate records for professional pilots holding an ATP or Commercial certificate. The first step was to annualize the CAIS medical data, creating a single record for each pilot for each year of the study period (1988 through 1997). This was accomplished by aggregating the 939,767 records by year and pilot social security number. The flight hours in the last six months were summed across medical examinations for the year for each pilot. The number of medical examinations conducted for the pilot for that year was counted. The number of medical examinations ranged from one to three per year. Therefore, the sum of the flight hours reported in the last six months across examinations in the year was annualized by using the following rules:

1. If there was just one medical examination for a pilot in a given year, then the annualized flight hours for that pilot in that year were equal to twice the flight hours reported in the last six months.
2. If there were two medical examinations for a pilot in a given year, then the annualized flight hours for that pilot in that year were equal to the sum of the flight hours reported in the last six months for each examination.
3. If there were three medical examinations for a pilot in a given year, then the annualized flight hours for that pilot in that year were equal to twice the average number of flight hours reported in the last six months across the three medical examinations for that year.

Age for the pilot in a given year was computed simply as the difference between that calendar year and year of birth.

NTSB accident data

The 1,334 NTSB accidents were next evaluated. The accidents involved 1,288 individual pilots. Most (1,247) of the pilots had just one accident over the ten year span; the other 41 pilots had two or more accidents in the ten years of the study. There were 11 pilots with two accidents in a single year (e.g., two accidents in 1991), and 25 pilots with two accidents occurring in different years (e.g., one accident in 1988 and the second in 1992). Four pilots had two accidents in one year, and a third accident in a different year (e.g., two accidents in 1995, and a third in 1996). There was one pilot with three accidents in three different years (1988, 1990, 1991). The 1,334 accidents for flights operating under 14 **CFR** §121 and §135 were aggregated by year and pilot identifier for matching to the CAIS medical records.

Matching CAIS medical and NTSB accident data

The NTSB accident records were then matched with the CAIS medical records for professional pilots holding ATP or commercial and first- or second-class medical certificates for each year, as shown in Figure 3. The resulting file contained 673,384 matched exposure-accident records. The number of accidents was set as zero for pilot records without a matching accident record. The data necessary to estimate exposure were missing for 20,512 matched records. Rather than discarding these records, the annualized flight hours were imputed using the SPSS® missing values analysis procedure. The SPSS® procedure uses an iterative maximum likelihood estimation algorithm to estimate the expected value for the missing datum in a given record.

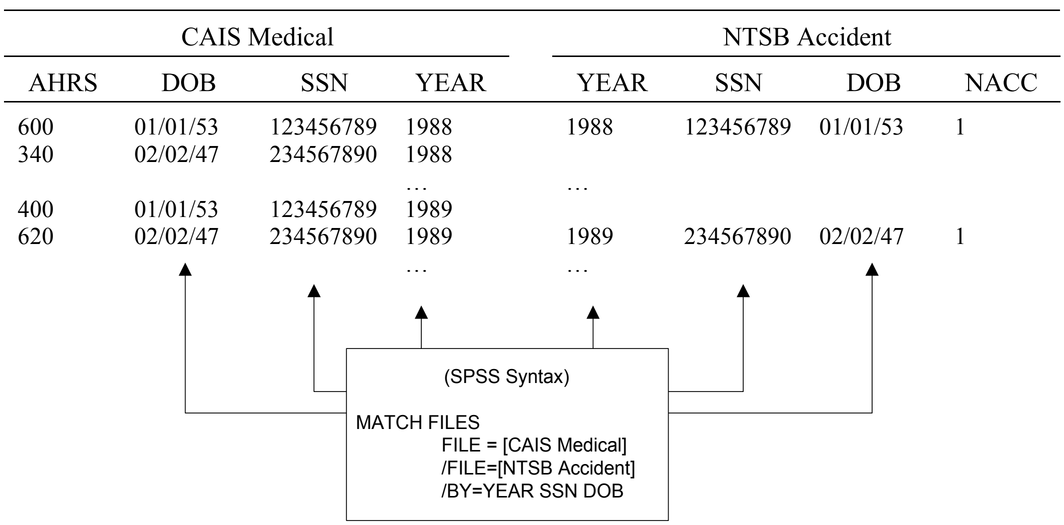


Figure 3: Matching CAIS Medical (exposure) with NTSB Accident data by year and pilot identifiers. (AHRS = Annualized flight hours. DOB = Date of birth. NACC = Number of accidents.)

Method

Procedures for grouping data by age

Next, the 673,384 matched exposure-accident records were coded into age groups as specified by the Senate. For example, records for a pilot age 62 were coded as belonging to the 60-63 age group. The overlapping age groups for this analysis were LE 24, 22-25, 23-26, … 54-57, 55-58, 56-59, followed by 60-63. The following procedure was then used to group and aggregate the data by age as specified by the Senate. First, records for pilots falling in the required age ranges (for example, 45 to 48) were selected from the matched exposure-accident records master file using the SPSS® "SELECT IF" syntax. Next, the records for each age range were aggregated by year. Annual flight hours and accidents were summed across pilots for each year. The aggregated data were then saved under a file name reflecting the age range. There were 37 files reflecting the age groups defined by the Senate (LE 24, 22-25, 23-26, … 55-58, 56-59, and 60-63). Next, the 37 files of aggregated data for each age range were appended, to create the overall file for analysis. The aggregated file, which had 370 records (i.e., 10 years x 37 age groups), is reproduced in Appendix B. The accident rate for each year-age group combination was computed as

$$Accident\_Rate_{Year-Age\ group} = \frac{\text{Count of accidents for year and age group}}{\left(\dfrac{\text{Sum of annualized flight hours for year and age group}}{\text{100,000 flight hours}}\right)}$$

Analysis

Descriptive statistics for each age group, including the sum of annualized flight hours, total cumulative flight hours, and total accidents across the ten year time span were calculated (Table 2). A one-way analysis of variance (ANOVA) of accident rate was conducted to determine if there was a trend across overlapping age groups. The trend analysis was conducted in view of previous studies finding a "U"-shaped function (Golaszewski 1993) or quadratic trend (Kay et al., 1994, p. 5-2) across age groups for aviation and automobile accident rates. A *t*-test was used to compare the mean (average) accident rates of the 56-59 and 60-63 age groups in an *a priori* planned comparison. In view of discussions about increasing the age limit, this comparison was planned to contrast age groups that were immediately adjacent to the current limit of 60.

Results

Descriptive statistics by age group

The sum of annualized and cumulative total flight hours across the ten year span of the study both took an inverted "U"-shaped distribution across age groups, as shown in Figure 4. The raw number of accidents for the ten-year study period also appeared to take the same form, as shown in Figure 5. In particular, the absolute number of accidents appeared to decrease starting at about age 50. There were only 25 accidents involving pilots age 60 to 63 between 1988 and 1997, compared to 81 accidents for pilots age 56 to 59 in the same time period. However, the 25 accidents for pilots age 60 to 63 occurred with 4.75 million annual flight hours, compared to 30. 97 million annual flight hours for pilots age 56 to 59 across the ten years. Inspection of the figures suggested that the accident rate for older pilots might differ from the accident rate for middle-aged pilots, in view of the differing exposure.

Table 2
Total annual flight hours, cumulative hours, and accidents by overlapping age group (60-63, and then declining from 59 in overlapping 4-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates

Age Group	Total Annual Hours	Total Cumulative Hours	Fatal Accidents	Nonfatal Accidents	Total Accidents
21-24	3,975,788	12,668,119	9	30	39
22-25	7,477,663	24,882,759	16	48	64
23-26	12,333,154	44,894,035	24	64	88
24-27	18,178,070	73,551,115	32	95	127
25-28	24,159,649	109,515,576	35	107	142
26-29	29,649,836	150,758,635	39	129	168
27-30	34,981,036	196,972,999	41	140	181
28-31	40,278,436	247,174,930	42	142	184
29-32	45,748,494	300,517,230	40	144	184
30-33	51,359,734	357,881,734	39	130	169
31-34	56,573,579	417,176,042	38	128	166
32-35	60,485,264	473,588,385	37	124	161
33-36	62,922,903	525,188,958	44	120	164
34-37	64,157,604	571,728,505	41	121	162
35-38	64,270,297	611,972,535	46	127	173
36-39	64,074,860	650,930,992	43	116	159
37-40	63,573,168	685,390,255	38	120	158
38-41	62,678,686	714,824,882	43	122	165
39-42	61,500,747	740,569,553	39	108	147
40-43	60,090,884	761,639,637	35	112	147
41-44	58,840,150	782,157,402	40	109	149
42-45	58,092,175	806,888,448	39	99	138
43-46	57,767,902	836,090,715	38	105	143
44-47	57,413,520	866,117,861	38	103	141
45-48	57,193,533	902,411,891	34	109	143
46-49	56,749,232	937,935,065	35	119	154
47-50	55,821,839	968,230,351	31	119	150
48-51	54,453,096	991,076,235	38	114	152
49-52	52,537,934	1,004,329,486	36	107	143
50-53	50,258,199	1,009,405,605	36	94	130
51-54	47,925,012	1,009,440,393	35	85	120
52-55	45,555,146	1,002,565,250	25	89	114
53-56	42,740,548	978,708,450	20	77	97
54-57	39,316,417	936,403,539	15	73	88
55-58	35,384,533	875,397,541	16	73	89
56-59	30,974,619	795,969,904	20	61	81
60-63	4,750,670	143,531,638	5	20	25

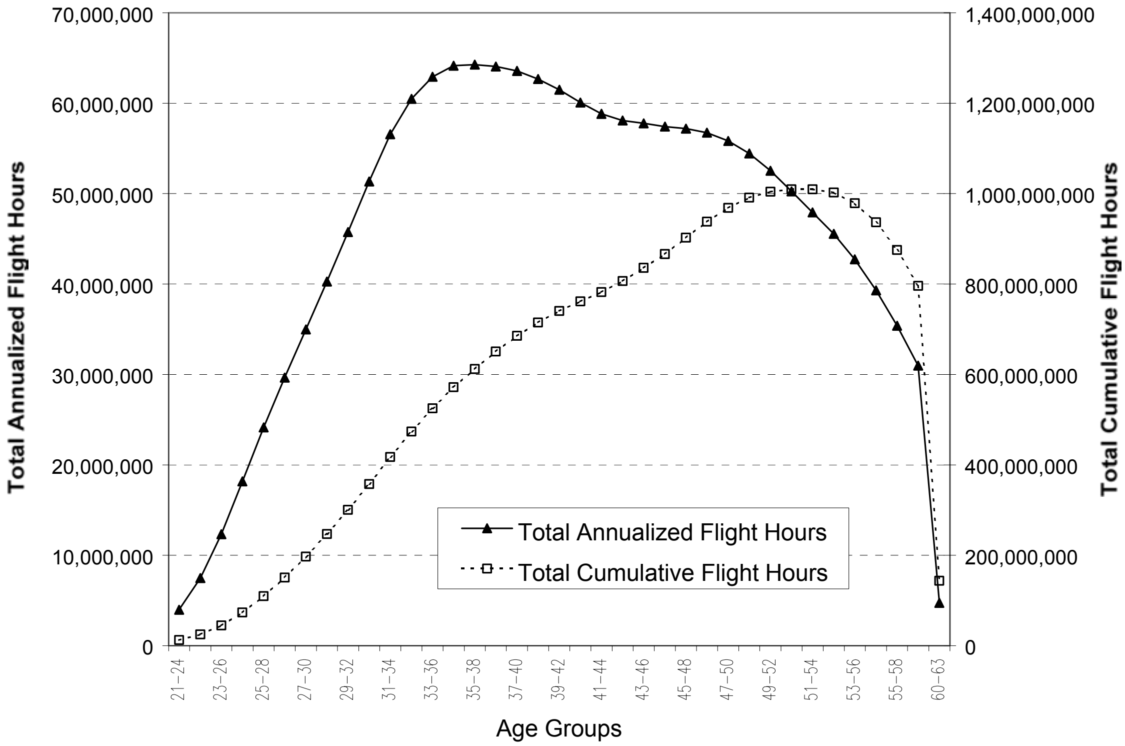


Figure 4: Total annualized and total cumulative flight hours by age group, 1988-1997 by overlapping age group (60-63 and then declining from age 59 in overlapping 4-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates. (Only every other age group is labeled on the horizontal axis.)

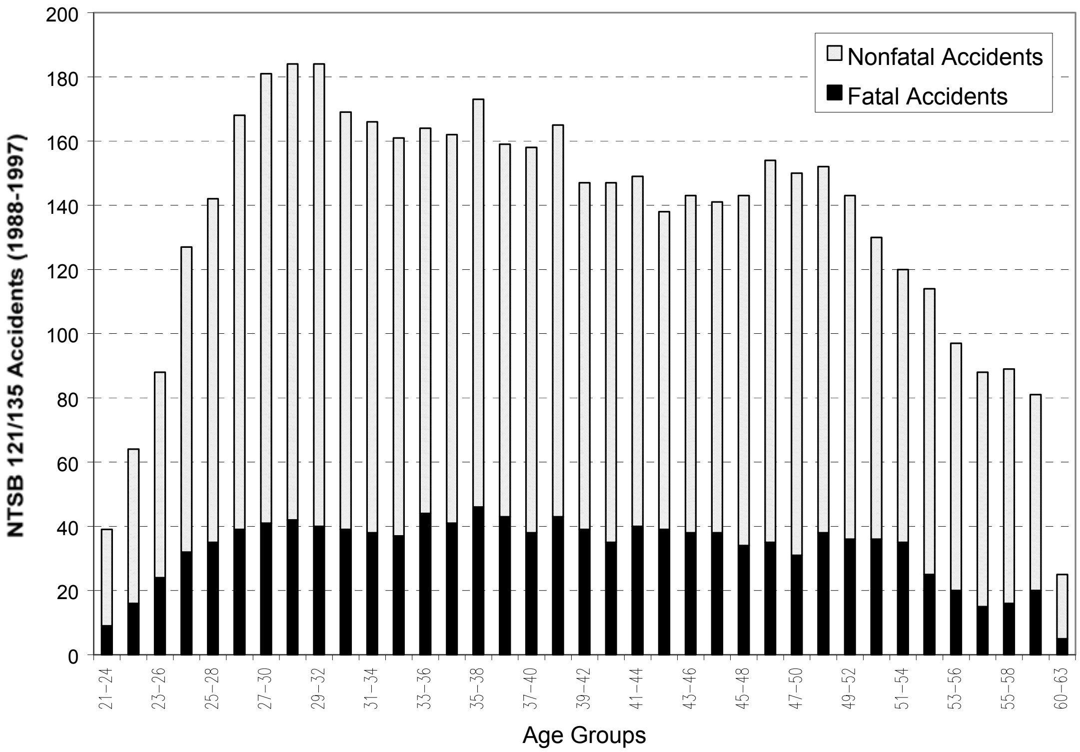


Figure 5: Fatal and nonfatal accidents for flights operating under 14 CFR §121 or §135, 1988-1997 by overlapping age group (60-63 and then declining from age 59 in overlapping 4-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates. (Only every other age group is labeled on the horizontal axis.)

ANOVA of accident rate

The trend analysis revealed that a quadratic function (i.e., "U" shape) best described the trend in mean accident rate across age group [$F(1) = 261.32$, $p \leq .001$; see Table 3]. The overall F-test also was significant [$F(36) = 15.488$, $p \leq .001$]. The mean accident rate for each age group, along with their 5/95% confidence intervals, are illustrated in Figure 6. Finally, the planned comparison revealed that the mean accident rate for the 56-59 age group was significantly different from that of the 60-63 age group [unequal variances, $t(11.985) = 2.27$, $p \leq .05$]. The accident rate for the 60-63 age group was statistically greater than the accident rate for the 56-59 age group.

Inspection of the confidence intervals indicated that the mean accident rates for the younger (LE 24 through about 28-31) and the 60-63 age groups were more variable than the accident rates for the other age groups. This observation was supported by rejection of the assumption of equal variances across the age groups [*Levene Statistic*(36, 333) = 6.02, $p \leq .001$]. The data presented in Appendix B show that the number of estimates of annualized hours for a pilot aggregated in the denominator of the accident rate varied across age groups by as much as a factor of ten. For example, accident rates for the 23-26 age group were based on just 1,036 to 2,361 pilot records per year. Similarly, the accident rates for pilots age 60-63 over the ten years were based on 442 to 1,219 estimates of annualized flight hours per year. In contrast, the accident rates for the 38-41 age group across the ten years were computed on 8,337 to 11,474 records per year. As noted by Golaszewski (1991), accident rates may be sensitive to the relatively small number of pilots that contribute flight hours to the denominator for the very young and old age groups. When the number of records being aggregated decreases, the relative influence of records with very low or high flight hours increases for a given year. The greater influence of extreme values is reflected in the larger confidence intervals for age ranges based on fewer records. Conversely, the impact of extreme values is diminished when large numbers of records are aggregated for a given year in the middle age groups, and the confidence intervals are smaller.

Table 3

Results for ANOVA of accident rate by overlapping age group (age 60-63, and then declining from 59 in overlapping 4-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	14.200	36	.394	15.488	.000
Linear Term	Contrast	6.153	1	6.153	241.597	.000
	Deviation	8.047	35	.230	9.027	.000
Quadratic Term	Contrast	6.655	1	6.655	261.320	.000
	Deviation	1.391	34	.041	1.607	.020
Cubic Term	Contrast	.569	1	.569	22.324	.000
	Deviation	.823	33	.025	.979	.504
Within Groups		8.481	333	.026		
	Total	22.681	369			

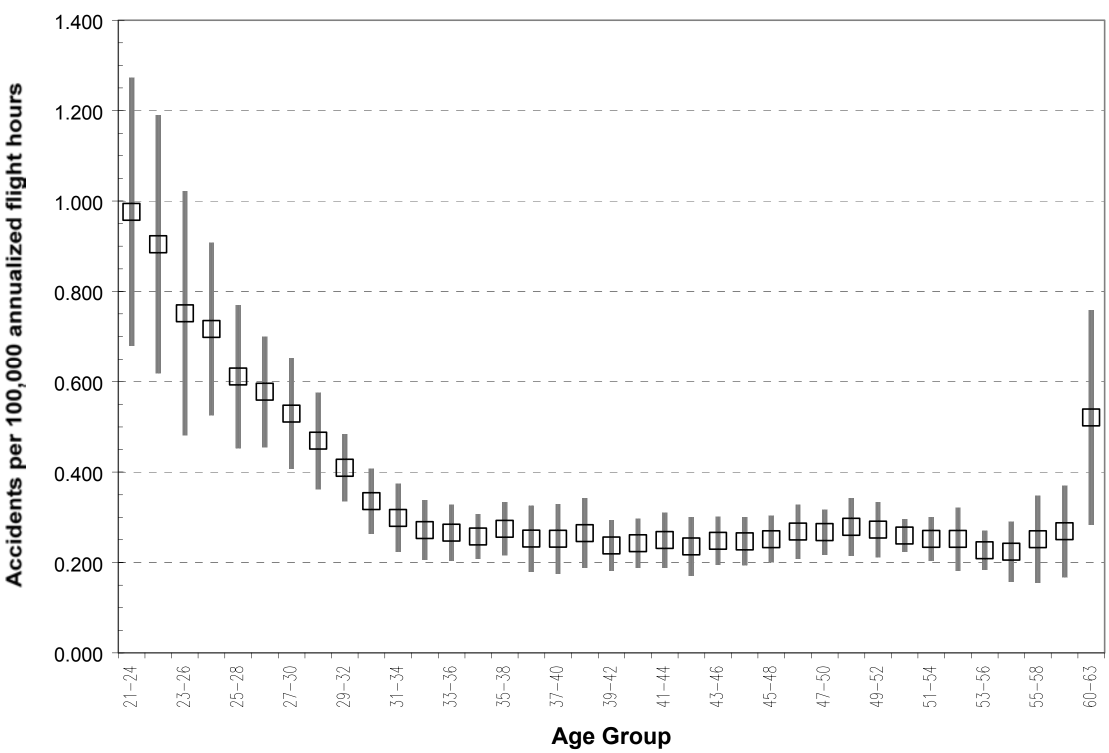


Figure 6: Mean accident rate and associated 5/95% confidence intervals for age 60-63 and overlapping 4-year age groups declining from age 59 for §121 and §135 accidents for professional pilots holding ATP or commercial and first- or second-class medical certificates, 1988-1997. (Only every other age group is labeled on the horizontal axis.)

CHAPTER 4
ACCIDENT RATES FOR PROFESSIONAL PILOTS HOLDING ATP OR COMMERCIAL AND FIRST- OR SECOND-CLASS MEDICAL CERTIFICATES USING OVERLAPPING AGE GROUPS DECLINING FROM AGE 63

Method

Procedures for grouping data by age

The starting point for the analysis was the file containing 673,384 matched exposure-accident records. First, the matched exposure-accident records were all coded into overlapping, 4-year age groups declining from age 63. The age groups for this analysis were LE 24, 22-25, 23-26, …, 56-59, 57-60, 58-61, 59-62, and 60-63. For example, records for pilots age 59 were coded as belonging to the 56-59, 57-60, 58-61, and 59-62 age groups. The following procedure was used to group and aggregate the data by 4-year age groups declining from age 63. First, records for pilots falling in the required age ranges (for example, 45 to 48) were selected from the matched exposure-accident records master file using the SPSS® "SELECT IF" syntax. Next, the records for each age range were aggregated by year. Annual flight hours and accidents were summed across pilots for each year. The aggregated data were then saved under a file name reflecting the age range. There were 40 files (LE 24, 22-25, 23-26, … 56-59, 57-60, 58-61, 59-62, and 60-63). Next, the 40 files of aggregated data for each age range were appended, to create the overall file for analysis. The aggregated file, which had 400 records (i.e., 10 years x 40 age groups), is reproduced in Appendix C. The accident rate for each year-age group combination was computed as

$$Accident\_Rate_{Year-Age\ group} = \frac{\text{Count of accidents for year and age group}}{\left(\dfrac{\text{Sum of annualized flight hours for year and age group}}{\text{100,000 flight hours}}\right)}$$

Analysis

Descriptive statistics for each age group, including the sum of annualized flight hours, total cumulative flight hours, and total accidents across the ten year time span were calculated (Table 4). As in the first analysis, a one-way ANOVA was conducted to determine if there was a trend in accident rates across age groups. An *a priori* planned comparison used a *t*-test to compare the mean (average) accident rates of the 56-59 and 60-63 age groups. In view of discussions about increasing the age limit, this comparison was planned to contrast age groups that were immediately adjacent to the current limit of 60.

Table 4
Total annual flight hours, cumulative hours, and accidents by overlapping age group (declining from 63 in consecutive 4-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates

Age Group	Total Annualized Hours	Total Cumulative Hours	Total Fatal Accidents	Total Nonfatal Accidents	Total Accidents
LE 24	3,975,788	12,668,119	9	30	39
22-25	7,477,663	24,882,759	16	48	64
23-26	12,333,154	44,894,035	24	64	88
24-27	18,178,070	73,551,115	32	95	127
25-28	24,159,649	110,000,000	35	107	142
26-29	29,649,836	151,000,000	39	129	168
27-30	34,981,036	197,000,000	41	140	181
28-31	40,278,436	247,000,000	42	142	184
29-32	45,748,494	301,000,000	40	144	184
30-33	51,359,734	358,000,000	39	130	169
31-34	56,573,579	417,000,000	38	128	166
32-35	60,485,264	474,000,000	37	124	161
33-36	62,922,903	525,000,000	44	120	164
34-37	64,157,604	572,000,000	41	121	162
35-38	64,270,297	612,000,000	46	127	173
36-39	64,074,860	651,000,000	43	116	159
37-40	63,573,168	685,000,000	38	120	158
38-41	62,678,686	715,000,000	43	122	165
39-42	61,500,747	741,000,000	39	108	147
40-43	60,090,884	762,000,000	35	112	147
41-44	58,840,150	782,000,000	40	109	149
42-45	58,092,175	807,000,000	39	99	138
43-46	57,767,902	836,000,000	38	105	143
44-47	57,413,520	866,000,000	38	103	141
45-48	57,193,533	902,000,000	34	109	143
46-49	56,749,232	938,000,000	35	119	154
47-50	55,821,839	968,000,000	31	119	150
48-51	54,453,096	991,000,000	38	114	152
49-52	52,537,934	1,000,000,000	36	107	143
50-53	50,258,199	1,010,000,000	36	94	130
51-54	47,925,012	1,010,000,000	35	85	120
52-55	45,555,146	1,000,000,000	25	89	114
53-56	42,740,548	979,000,000	20	77	97
54-57	39,316,417	936,000,000	15	73	88
55-58	35,384,533	875,000,000	16	73	89

(Table 4 continues)

(Table 4 continued)

Age Group	Total Annualized Hours	Total Cumulative Hours	Total Fatal Accidents	Total Nonfatal Accidents	Total Accidents
56-59	30,974,619	796,000,000	20	61	81
57-60	24,932,530	663,000,000	20	56	76
58-61	17,275,750	474,000,000	15	44	59
59-62	10,465,007	297,000,000	9	33	42
60-63	4,750,670	144,000,000	5	20	25

Results

Descriptive statistics by age group

As in the previous analysis, the sum of annualized and cumulative total flight hours across the ten year span of the study both took an inverted "U"-shaped distribution across age groups, as shown in Figure 7. The raw number of accidents for the ten-year study period also appeared to take the same form, as shown in Figure 8. In particular, the absolute number of accidents appeared to decrease starting at about age 50. For example, there were 130 accidents under 14 **CFR** §121 or §135 for pilots age 50 to 53, compared to 120 for pilots age 51 to 54. The decline in the absolute number of accidents was relatively smooth as age increased down to the 25 accidents for pilots age 60 to 63. However, annual flight hours followed much the same course of declining with age. For example, pilots age 50 to 53 had a total of 50.26 million annual flight hours over the ten-year study period, compared to just 4.75 million annual flight hours for pilots age 60 to 63. Inspection of the figures suggested that the accident rate for older pilots might differ from the accident rate for middle-aged pilots, in view of the differing exposure.

ANOVA of accident rate

The trend analysis revealed that a quadratic function (i.e., “U” shape) best described the trend in mean accident rates across age group [$F(1) = 307.349$, $p \leq .001$; see Table 5]. The overall *F*-test also was significant [$F(39) = 14.417$, $p \leq .001$]. The mean accident rate for each age group, along with their 5/95% confidence intervals, are illustrated in Figure 9. Finally, the planned comparison revealed that the mean accident rate for the 56-59 age group was significantly different from that of the 60-63 age group [unequal variances, $t(11.985) = 2.27$, $p \leq .05$]. The accident rate for the 60-63 age group was statistically greater than the accident rate for the 56-59 age group.

Inspection of the confidence intervals indicated that the mean accident rates for the younger and older age groups were more variable than the accident rates for the other, middle age groups. This observation was supported by rejection of the assumption of equal variances across the age groups [*Levene Statistic*(39, 360) = 5.48, $p \leq .001$]. The data presented in Appendix C show that the number of estimates of annualized hours for a pilot 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 more variable than estimates based on much larger numbers of records.

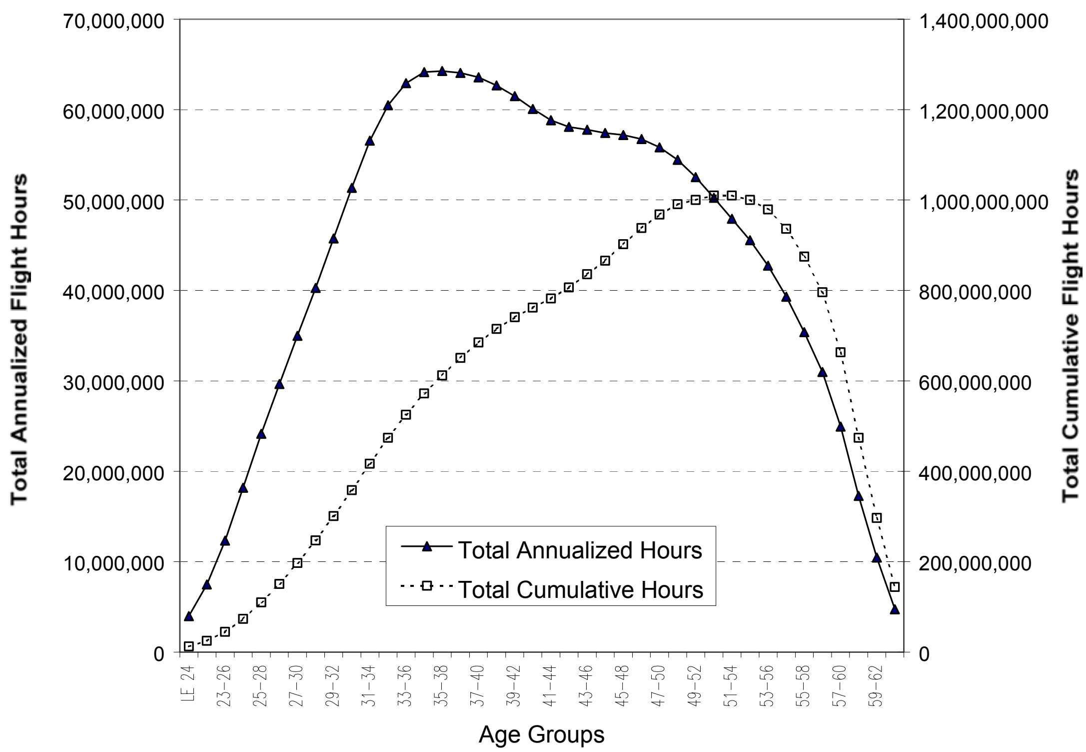


Figure 7: Total annualized and total cumulative flight hours by age group, 1988-1997 by overlapping age group (declining from age 63 in consecutive 4-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates. (Only every other age group is labeled on the horizontal axis.)

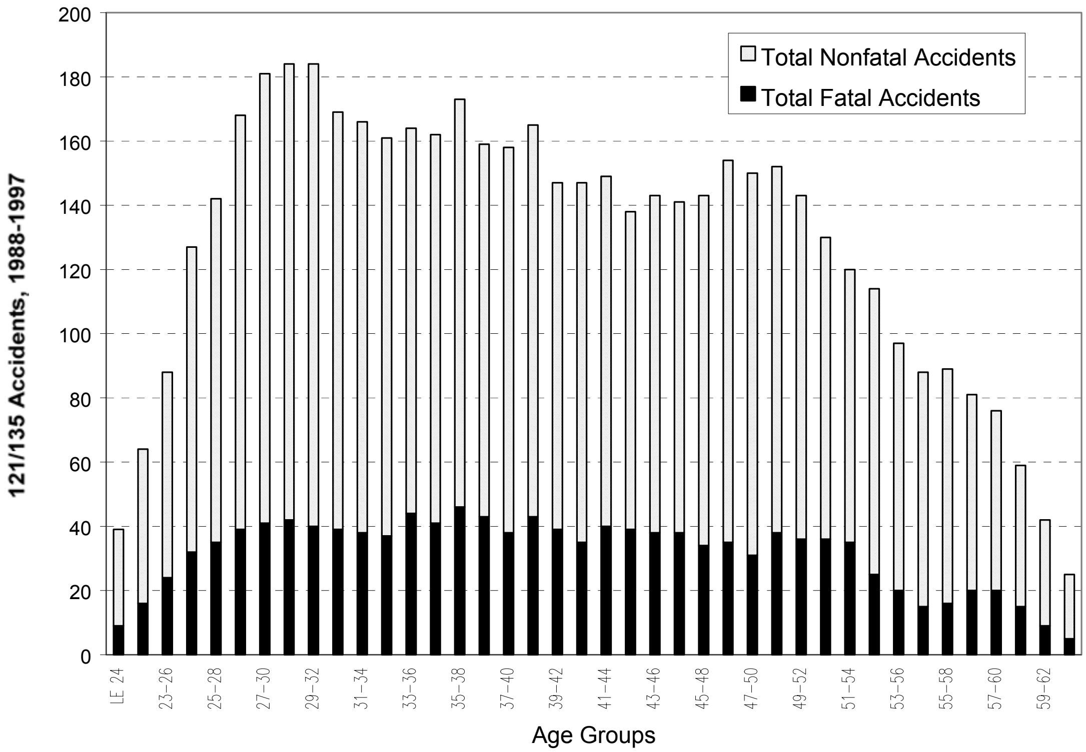


Figure 8: Fatal and nonfatal accidents for flights operating under 14 **CFR** §121 or §135, 1988-1997, by overlapping age group (declining from age 63 in consecutive 4-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates. (Only every other age group is labeled on the horizontal axis.)

Table 5

Results for ANOVA of accident rate by overlapping age groups (declining from age 63 in consecutive 4-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	14.247	39	.365	14.417	.000
Linear Term	Contrast	5.000	1	5.000	197.339	.000
	Deviation	9.247	38	.243	9.604	.000
Quadratic Term	Contrast	7.787	1	7.787	307.349	.000
	Deviation	1.459	37	.039	1.556	.024
Cubic Term	Contrast	.603	1	.603	23.807	.000
	Deviation	.856	36	.024	.938	.574
Within Groups		9.121	360	.025		
	Total	23.368	399			

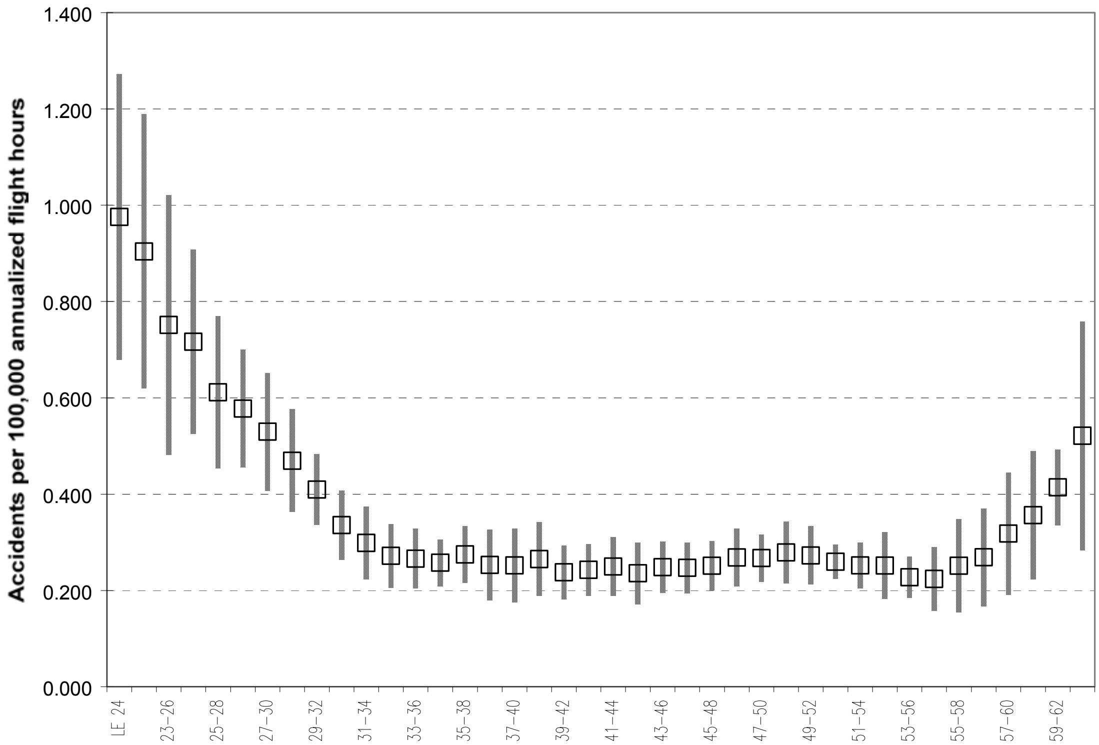


Figure 9: Mean accident rate and associated 5/95% confidence intervals by overlapping age group (declining from age 63 in consecutive 4-year groups) for §121 and §135 accidents for professional pilots holding ATP or commercial and first- or second-class medical certificates, 1988-1997. (Only every other age group is labeled on the horizontal axis.)

CHAPTER 5
ACCIDENT RATES FOR PROFESSIONAL PILOTS HOLDING ATP OR COMMERCIAL AND FIRST- OR SECOND-CLASS MEDICAL CERTIFICATES USING INDEPENDENT AGE GROUPS

Method

Procedures for grouping data by age

The starting point for the analysis was again the file containing 673,384 matched exposure-accident records. Age was categorized into the following eight independent groups: less than or equal to (LE) 29; 30-34; 35-39; 40-44; 45-49; 50-54; 55-59; and 60-63. The 60-63 age group was specifically requested by the Senate. The matched records were then aggregated by year and independent age group. Annual flight hours and accidents were summed across pilots for each year and age group combination. The aggregated file, which had 80 records (i.e., 10 years x 8 age groups), is included in Appendix D. The accident rate for each year-age group combination was computed as

$$Accident\_Rate_{Year-Age\ group} = \frac{\text{Count of accidents for year and age group}}{\left(\dfrac{\text{Sum of annualized flight hours for year and age group}}{\text{100,000 flight hours}}\right)}$$

Analysis

As in the first and second analyses, descriptive statistics for each age group, including the sum of annualized flight hours, total cumulative flight hours, and total accidents across the ten year time span were calculated (Table 6). A one-way ANOVA was then conducted to determine if there was trend in accident rates across the independent age groups. A *t*-test was also used to compare the mean (average) accident rates of the 55-59 and 60-63 age groups in an *a priori* planned comparison. As in the previous analyses, this comparison was planned to contrast age groups that were immediately adjacent to the current limit of 60.

Results

Descriptive statistics by age group

As in the previous analysis, the sum of annualized and cumulative total flight hours across the ten year span of the study both took an inverted "U"-shaped distribution across age groups, as shown in Figure 10. The raw number of accidents for the ten-year study period also appeared to take the same form, as shown in Figure 11. In particular, the absolute number of accidents appeared to decrease starting at about age 50. For example, there were 153 accidents under 14 **CFR** §121 or §135 for pilots age 50 to 54, 110

Table 6
Total annual flight hours, cumulative hours, and accidents by independent age group (age 60-63, and then declining from 59 in independent 5-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates

Age Group	Total Annualized Hours	Total Cumulative Hours	Total Fatal Accidents	Total Nonfatal Accidents	Total Accidents
LE 29	37,387,370	176,646,199	55	179	234
30-34	67,186,665	484,843,810	49	159	208
35-39	80,208,825	789,311,326	54	154	208
40-44	74,437,292	964,636,205	48	138	186
45-49	71,204,649	1,150,467,293	46	140	186
50-54	61,435,031	1,261,888,723	41	112	153
55-59	41,410,293	1,040,376,666	21	89	110
60-63	4,750,670	143,531,638	5	20	25

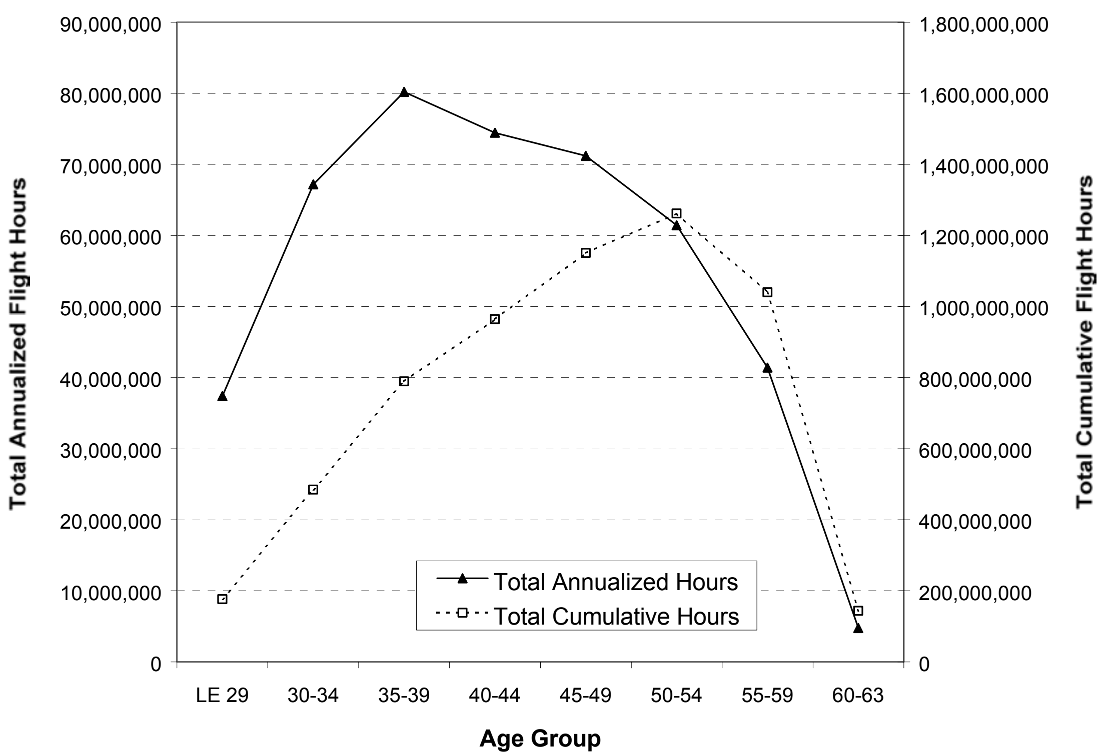


Figure 10: Total annualized and total cumulative flight hours by independent age group (age 60-63, and then declining from 59 in independent 5-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates.

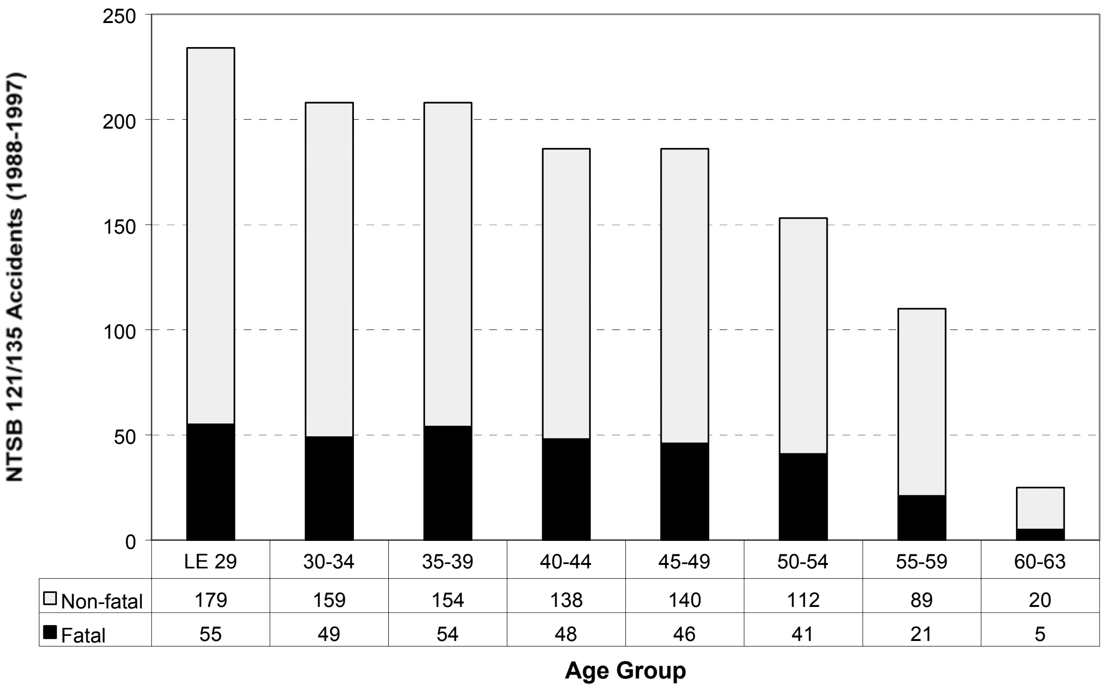


Figure 11: Fatal and nonfatal accidents for flights operating under 14 **CFR** §121 or §135, 1988-1997, by independent age group (age 60-63, and then declining from 59 in independent 5-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates.

accidents for pilots age 55 to 59, and 25 accidents for pilots age 60 to 63. However, annual flight hours followed much the same course of declining with age. For example, pilots age 50 to 54 had a total of 61.44 million annual flight hours over the ten-year study period, compared to just 4.75 million annual flight hours for pilots age 60 to 63. Inspection of the figures suggested that the accident rate for older pilots might differ from the accident rate for middle-aged pilots, in view of the differing exposure.

<u>ANOVA of accident rate</u>

The trend analysis revealed that a quadratic function (i.e., "U" shape) best described the trend in mean accident rates across age group [$F(1) = 59.588$, $p \leq .001$; see Table 7]. The overall F-test also was significant [$F(7) = 10.503$, $p \leq .001$]. The mean accident rate for each age group, along with their 5/95% confidence intervals, are illustrated in Figure 12. Finally, the planned comparison revealed that the mean accident rate for the 55-59 age group was significantly different from that of the 60-63 age group [unequal variances, $t(11.181) = 2.34$, $p \leq .05$]. The accident rate for the 60-63 age group was statistically greater than the accident rate for the 55-59 age group.

Inspection of the confidence intervals indicated that the mean accident rates for the younger and older age groups were more variable than the accident rates for the other, middle age groups. This observation was supported by rejection of the assumption of equal variances across the age groups [*Levene Statistic*(7, 72) = 9.526, $p \leq .001$]. The data presented in Appendix D show that 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 more variable than estimates based on much larger numbers of records.

Table 7

Results for ANOVA of accident rate by independent age group (age 60-63, and then declining from 59 in independent 5-year groups) for professional pilots holding ATP or commercial and first- or second-class medical certificates

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	1.575	7	.225	10.503	.000
Linear Term	Contrast	.073	1	.073	3.420	.069
	Deviation	1.502	6	.250	11.683	.000
Quadratic Term	Contrast	1.277	1	1.277	59.588	.000
	Deviation	.225	5	.045	2.102	.075
Cubic Term	Contrast	.011	1	.011	.504	.480
	Deviation	.214	4	.054	2.501	.050
Within Groups		1.543	72	.021		
	Total	3.118	79			

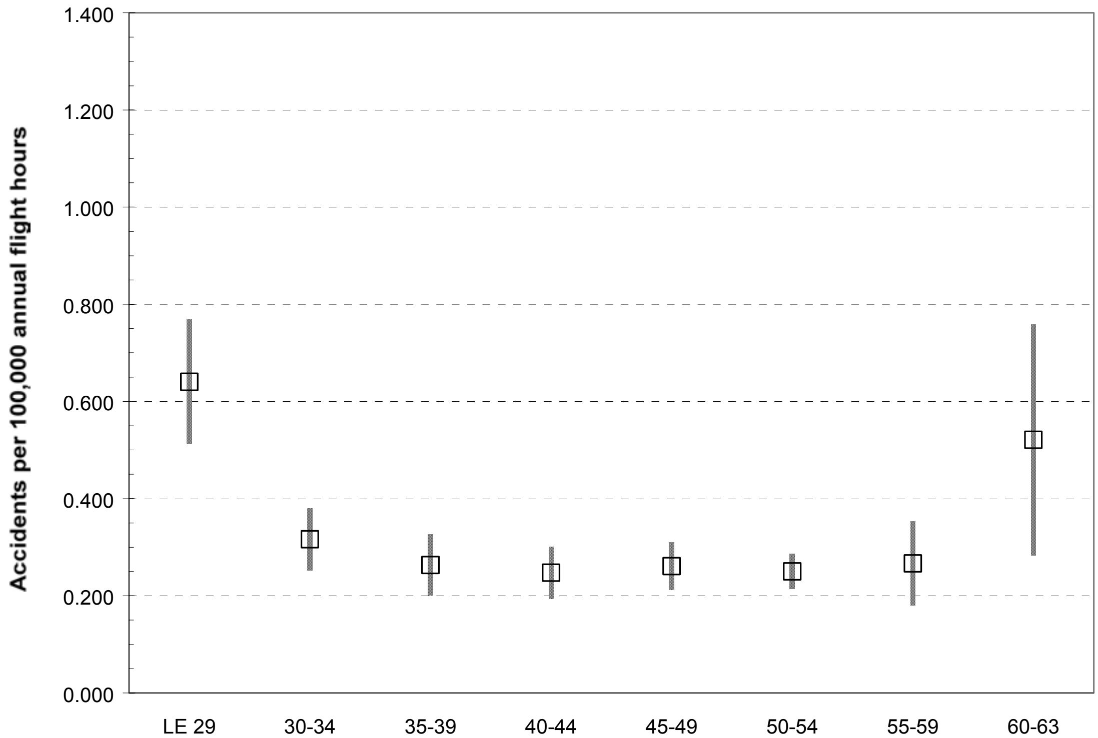


Figure 12: Mean accident rate and associated 5/95% confidence intervals by independent age group (age 60-63, then declining from 59 in independent 5-year groups) for §121 and §135 accidents for professional pilots holding ATP or commercial and first- or second-class medical certificates, 1988-1997.

CHAPTER 6
DISCUSSION

Overview of Key Findings

The summary of results presented in Table 8 highlights the consistent findings across the three analyses. First, for accidents occurring under 14 **CFR** §121 and §135, these analyses support the hypothesis that a "U"-shaped relationship exists between the ages of professional pilots holding ATP or commercial and first- or second-class medical certificates and their accident rates. This finding suggests that the probability of an aviation accident under Parts 121 and 135, as a function of pilot annual flight hours, is related to pilot age. Second, the accident rates for the age groups on either side of 60 (e.g., 56 or 55 to 59 and 60-63) were statistically different in *a priori* planned comparisons. Third, the main effect for age was statistically significant in all analyses. While Hays (1988) and others suggest that the overall *F* test not be reported when the focus of an analysis is on a trend analysis, we have chosen to report the overall test to provide complete information about the analyses. The overall tests suggest that mean accident rates differed statistically by age group. *Post-hoc* comparisons revealed that, in general, the accident rates for the younger (LE 24 to about 27-30) and older (56-59 to 60-63) age groups were significantly higher than the accident rates in the middle years (mid-30s to mid-50s).

Table 8
Summary of results across analyses of accident rates by age group

	Test		
Age grouping	Trend	Comparison	Overall
Senate age groups (LE 24, …, 56-59, 60-63)	Yes - Quadratic	Yes	Yes
Overlapping age groups (LE 24, … , 59-62, 60-63)	Yes - Quadratic	Yes	Yes
Independent age groups (LE 29, 30-34, … , 55-59, 60-63)	Yes - Quadratic	Yes	Yes

Notes: Definition of tests performed. **Trend**: Is there a trend across age groups, described by linear (straight line), quadratic (parabola or U-shape), or cubic (sideways S-shape) relationship ?. **Comparison**: Is the accident rate for the 60-63 age group greater than the accident rate for the 56-59/55-59 year old age group(s)? **Overall**: Is there a main effect of age, such that the accident rate for one or more age groups is different than the overall average accident rate across groups?

Caveats to Findings

The following caveats apply to these conclusions. First, the denominator for pilots under age 60 includes expsoure to the hazards of flight under all flight regulations, including the statistically safer hours accumulated under Part 121. However, at age 60, due to the effect of the rule, the denominator includes only hours accumulated under historically less safe Part 91, 135 and other flight regulations. The numerator also qualitatively changes at age 60. Below age 60, the numerator includes accidents occurring under both Part 121 and 135; over age 60, the numerator includes only accidents occurring under Part 135. It might be argued, therefore, that the upward trend in accident rate for older pilots, and the apparent difference in rate for pilots age 55-59 and 60-63, may be a result of the qualitative changes in the numerator and denominator rather than a quantitative change in accident risk as a function of age.

Second, accident rates for the youngest and oldest age groups were affected by the number of cases contributing exposure data to the denominator, as evidenced by the relatively large confidenceintervals about the mean estimate of accident rates for the 21-24, 22-25, and 60-63 age groups.

Landy (1992) and Tsang (1997) have suggested that individual variability in functioning appears to increase with age. That is, differences in performance between individuals within an age cohort may increase as the cohort ages. Also, it may be the case that the individual's performance becomes increasingly variable with age. However, their suppositions cannot be assessed in a cross-sectional design based on aggregated data. Longitudinal analyses at the individual level of analysis would be required to formally evaluate these hypotheses.

Third, this study is based solely on the age of the pilot in command. Therefore, the study design may inappropriately attribute greater risk to the pilot with more seniority. Given the interdependent nature of the pilot and co-pilot roles in modern aircraft, future analyses should examine the age profile of the cockpit team, rather than focusing solely on the pilot in command.

Fourth, although accidents associated with Part 91 flights (i.e., general aviation) were excluded from the numerator, the hours of exposure in the denominator represented exposure to the hazards of flight under all Parts (e.g., 91, 121, 135). Consequently, the accident rate for Parts 121 and 135 operations may be underestimated. Future analyses should examine all accidents or survey data on hours flown under different parts of the regulations to develop a correction factor.

Comparison with Previous Research

Similarities and differences in results

On one hand, the results of the three analyses reported in this study are consistent with the conclusions reported by Golaszewski (1983; 1991; 1993; see Figure 7) although the methodologies differed significantly: Accident rates appear to be higher in younger and older groups than in the middle age groups. For example, in his analysis of general aviation accident rates for pilots with third-class medical certificates, Golaszewski (1983, p. 14) concluded that "… except for the most and least experienced Class III pilots, accident rates generally decline as age increases except for pilots of age 60 and over …". In 1993, Golaszewski analyzed general aviation accident rates for pilots holding first-class medical certificates, indicating professional employment as a pilot, but excluding air transport pilots. He concluded that accident rates for this group "… decrease gradually with age up to the 40 to 49 age category and then increase" (Golaszewski, 1993, p. 6-7).

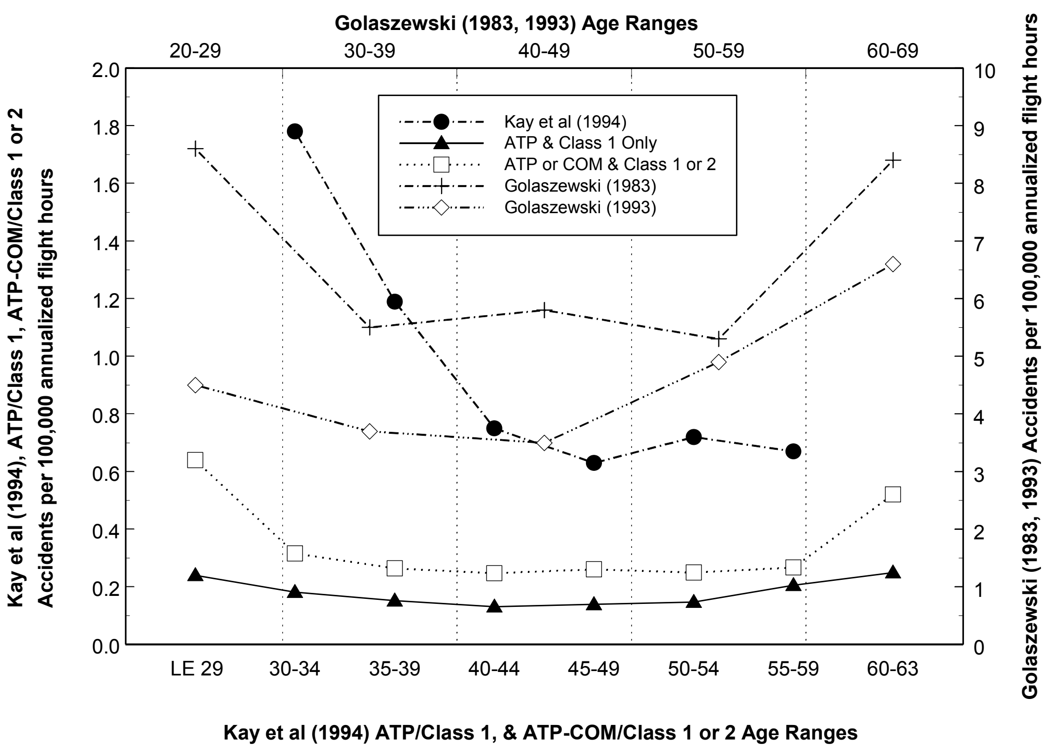


Figure 13: Comparison of accident rates by age for 5-year age groupings (Class 1 pilots (Kay et al., 1994), ATP/Class 1 pilots (Study 3; Broach, et al., 2000), and ATP-COM/Class 1 or 2 (Study 4; this report)) and 10-year age groupings (Golaszewski (1983, 1993)). Golaszewski (1983) = General aviation accident rate for Class 1, 2, & 3 pilots. Golaszewski (1993) = General aviation accident rate for Class 1 pilots, excluding air transport pilots. Kay et al. (1994) = Accident (all accidents) rate for Class 1 pilots. ATP/Class 1 (Study 3; Broach et al., 2000) = 14 CFR §121 & §135 accident rate for

professional pilots holding Class 1 Medical and ATP certificates. ATP-COM/Class 1 or 2 (Study 4; this report) = 14 CFR §121 & §135 accident rate for professional pilots holding ATP or commercial and first- or second-class medical Pilot certificates. Differences in accident rates between studies are due to differences in accidents counted in the numerators and differences in the pilot populations included in the denominators of the accident rates.

The results of this study show the same pattern of higher accident rates for younger pilots, declining with age to a relatively stable rate in the middle years, followed by an increase for older pilots over age 60.

On the other hand, our results are both similar and very different from the results reported in the Hilton Systems, Incorporated (Kay et al., 1994; see Figure 7) study of age and aviation accident rates. First, in their analysis of accident rates for pilots holding first-class medical certificates, Kay et al. found that "… accident rate decreased with increased age for the younger pilots leveling off for the older pilots … " (p. 5-2). They went on to conclude 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). However, Kay et al. truncated the data at age 59, and excluded pilots with first-class medical certificates age 60 and above from their analysis.

Our analysis included professional pilots holding ATP or commercial and first- or second-class medical certificates over age 60. The pattern of results in our study was similar to those reported by Kay et al. for younger and middle-aged pilots holding first-class medical certificates: The accident rate decreased for younger pilots as they aged, and then leveled off in the middle years in both analyses. However, Kay et al. simply did not examine accident rates for pilots with first-class medical certificates beyond age 59. By including pilots aged 60-63, our analysis found that the statistical trend for older pilots holding ATP or commercial and first- or second-class medical certificates was toward higher accident rates.

Second, Kay et al. compared the accident rate for 60-64 year old Class 3 pilots with that of 55-59 year old Class 3 pilots. Kay et al. found no statistically significant differences in the accident rates for the two age groups, for either all Class 3 pilots, or for Class 3 pilots with at least 500 total and 50 recent flight hours. The results of our analysis were very different for pilots holding ATP or commercial and first- or second-class medical certificates: the accident rate for 60-63 year old pilots was statistically greater than the accident rate for 55 or 56 to 59 year olds, for the period 1988 to 1997.

Methodological differences from previous research

The similarities and differences of our results with previous research, as illustrated in Figure 7, should be considered in light of important differences in methodologies used by the studies. These methodological differences include (a) definition of the pilot sample, (b) treatment of missing data, (c) method for annualizing flight hours, (d) definition of the criterion events (accidents), and (e) analytic strategy.

Sample differences. Kay et al. 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. In their analyses, Kay et al. assumed that all pilots holding first-class medical certificates were "Part 121 pilots" or pilots for scheduled airlines. As a result, they did not include pilots with first-class medical certificates over age 60 in their analyses. Therefore, Kay et al. were forced to rely on data from pilots holding third-class medical certificates to evaluate the relationship of age to accident rates. The generalizability of the findings derived from the sample used by Kay et al. to the working population of pilots covered by the Age 60 Rule has not been determined.

In contrast, the sample used in this analysis more closely approximated the class of pilots covered by the Age 60 Rule. First, the pilots held ATP or commercial and first- or second-class medical certificates, the credentials required to pilot aircraft under 14 **CFR** §121 or §135. Second, the pilot had to report "professional pilot" as his or her occupation for the record to be included in our data set. Third, CAIS medical data were matched with CAIS certificate data, and only those pilots holding an ATP or commercial and active first- or second class medical certificates were included. These differences resulted in a study population much more similar to and representative of the population of pilots covered by the Age 60 Rule than in previous studies. For example, Kay et al. characterized their results as providing "a hint, and a hint only" of an increase with age, based on pilots holding third-class medical certificates. The analyses reported in this study are based on a sample that is very similar to the working population of airline pilots subject to the Age 60 Rule. Therefore, the differences in results between the studies might be explained, at least in part, by differences in the samples.

Missing data. In previous studies, little mention had been made of missing data, either in flight hours reported in the CAIS medical record or in the matching of accident records to exposure records. Kay et al. excluded CAIS medical examination records with invalid or zero flight hours reported. These records were retained in the present study, and missing values for annualized flight hours were imputed by using an accepted maximum-likelihood estimation technique. These differences in the handling of missing exposure data would likely have relatively little influence on the accident rates, given the magnitude of the aggregated exposure for most age groups. However, additional research is recommended to assess the sensitivity of accident rates to the number of cases contributing hours to the rate denominator and different methods for handling the missing data.

Previous studies also have provided minimal explanation of problems in matching accident and exposure records for a pilot in a given year. For example, the Golaszewski reports do not clearly describe if exposure and accident records were matched at the pilot level (e.g., the annualized flight hours for a given year matched with any accident occurring for the pilot in that given year). Kay et al. discussed the difficulties in reconciling pilot identifiers across the different databases, but did not report the number of records excluded by failures to match. Procedures for matching exposure and accident records should be explained more fully, including "hit" (match) and "miss" (no match) rates.

Annualizing flight hours. Previous studies have annualized recent flight hours for pilots by multiplying the self-reported hours in the last six months by two. This rule is based on the assumption that, on average, pilots holding a first-class medical certificate will take a medical examination twice a year. However, our analysis found that, in fact, the number of first-class medical certificates varies, with 59% of the pilots holding an ATP having just one medical examination in any given year. At first, this seemed improbable. However, pilots can revert to the next lower class of medical certificate. Another possible explanation might be movement between employers with different certificate requirements, as well as movement in and out of the workforce.

Doubling the self-reported recent flight hours for pilots with just one 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 two examinations in a year would likely result in an overestimate. Therefore, as described in the report, this study 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.

Criterion events. Another possible explanation for differences in results relative to Kay et al. may be in the selection of NTSB accidents. The study by Kay et al. used all NTSB accidents in a specific time period that involved pilots holding first-class medical certificates without regard to the regulation under which the flight was operated. In contrast, the present study focused specifically on those accidents that occurred between 1988 and 1997 for flights operating under 14 **CFR** §121 or §135. Golaszewski's 1983 study focused on general aviation accidents (e.g., §91) for Class 1, 2, and 3 pilots. His 1993 study also examined general aviation accidents involving Class 1 pilots, excluding air transport pilots. There are significantly fewer accidents for flights operating under §121 and §135 than under the general aviation regulation. For example, there were 19,884 general aviation accidents between 1988 and 1997, compared to the 1,334 examined in the present study. Consequently, relatively fewer events were counted in the numerator in the present study of age and accidents than in previous studies, resulting in lower estimated accident rates, as shown in Figure 7.

Analytic strategy. Finally, in contrast with previous studies, this study did not attempt to analyze the joint effects of age, recent experience, and total experience on accident rates. As previously discussed, incorporating recent and total experience into the analyses would require aggregation of the matched accident-exposure records in different ways. Consequently, the degrees of freedom would vary from analysis to analysis, complicating comparison and interpretation of the results of these analyses. This study, as directed by the Senate request, used a simpler analytic strategy, analyzing accident rates by overlapping and independent age groups. Moreover, the design did not result in the development of a model by which the number of accidents might be predicted as a function of pilot age, experience, employer, and other factors. Alternative techniques should be considered in future analyses, as discussed below, that maximize statistical power to detect potential age-related effects and enable stronger inferences about the relationship of age to aviation safety.

The analytic strategy for this study also differed from the work of Kay et al. in technical details of conducting the ANOVA of rates. Specifically, the ANOVA design used by Kay et al. treated the data as proportions. In their analysis, the value of the degrees of freedom for the denominator were assumed to be infinite, as the estimate of the variance was exact (Kay et al., 1994, p. 4-4). The ANOVA strategy used in our analysis took a more conservative approach. The degrees of freedom associated with the denominator were defined in terms of the number of aggregated observations available. For example, there were 370 observations available (37 age groups x 10 years) in the first analysis, resulting in 369 degrees of freedom in the denominator of the overall test for a main effect of age. However, conducting the statistical tests with the assumption of infinite degrees of freedom for the denominator would not change the pattern of results obtained in this study. The critical value of F to achieve statistical significance would be smaller under the assumption of an infinite degrees of freedom than the actual critical values based on the actual degrees of freedom.

Finally, no transformations of accident rate were made to normalize the distribution. As with the assumption about the degrees of freedom associated with the denominator, transforming the accident rate would not change the pattern of results obtained in this study, but would unnecessarily complicate the description and interpretation. For example, the overall F-test for the main effect of age on raw accident rate for independent groups was 10.50 ($p \leq .001$). The overall F for the effect of age on the base 10 logarithm of the accident rate was 12.76 ($p \leq .001$). Similarly, the overall F using the natural logarithm of accident rate was also 12.76. Statistically significant quadratic trends, significant main effects, and significant contrasts between accident rates for pilots age 60 to 63 and pilots age 55 or 56 to 59 are obtained with untransformed and transformed accident rates (see Appendix E).

Recommendations for Further Research

Databases and data matching

The first recommendation is to develop and implement a unique identifier for each pilot that can be used consistently across all aviation safety and regulatory databases. Such an identifier will make future research on pilot safety less onerous. Efforts are currently underway at CAMI to develop and implement a unique identifier for each pilot.

Data collected from pilots

The second recommendation is to consider collecting additional information on a voluntary basis from pilots during the medical examination. For example, pilot flight hours may not be the most appropriate measure of exposure to the risks of flight; alternative measures such as the number of take-offs and landings might provide better estimates (Stuck, van Gorp, Josephson, Morgenstern, & Beck, 1992). A self-report of cycles (take-offs and landings) might be added to the self-report of recent and cumulative flight time. Similarly, an estimate of the proportions of flight time under the major flight rules (e.g., §121, §135, §91, and other) would provide a basis for developing correction factors. The third datum that would be useful in epidemiological analyses of aviation accidents would be estimates from each pilot of the proportions of flight time in Alaska, Hawaii, the continental United States, and over-water. These data could be used to develop more realistic estimates of exposure to various risks in future analyses of accident rates.

Alternative analyses

Our third recommendation is to investigate the use of alternative statistical techniques for the analysis of aviation safety data. For example, the class of statistical techniques based on regression models may be useful for development of a predictive model to support policy decision making. These techniques can be used to predict the number of accidents as a function of explanatory variables such as age, experience, geographic region, and employer type. These techniques have been used, for example, in highway safety analyses to model the influence of highway geometry and truck company characteristics on truck accidents (Joshua, & Garber, 1990; Miaou, Hu, Wright, Rathi, & Davis, 1992; Moses & Savage, 1994, 1996). This analytic technique assessed the degree to which accidents are predicted by pilot and employer characteristics at a consistent level of analysis - the individual pilot.

Finally, the case-control technique used in epidemiology offers another alternative. For example, Li and Baker (1994) conducted a case control analysis to investigate the relationships between pilot demographics and accidents. In the context of the Age 60 Rule, pilots with accidents might be matched with accident-free controls on the basis of annual hours flown, cumulative hours flown, geographic region (for example, Alaska versus the other continental states), and employer type. The average age for each group would then be compared statistically. This third analytic approach determines if there is a difference in the age for pilots with and without accidents, after controlling for employer, recent exposure, total exposure, and perhaps other factors.

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APPENDIX A
VERBATIM EXCERPT FROM THE UNITED STATES SENATE REPORT 106-55 (1999)

Human Factors & Aviation Medicine.—During hearings for fiscal year 2000 FAA appropriations, the Committee submitted a question related to whether there was any scientific or medical reason why the United States should not ‘‘cautiously increase the retirement age to age 63’’ like other countries have for commercial aviation. The text of the question follows:

The Age 60 Rule was instituted in 1959 without the benefit of medical or scientific studies and without public comment. The EEOC has essentially eliminated age discrimination rules in all facets of commercial aviation with the exception of Part 121 and Part 135 carriers. Other countries—Great Britain, Germany, Australia, etc.—have modified their age 60 restrictions. Japan began a study on the age sixty issue and discontinued it after finding no safety or operational reasons to maintain age 60 as a mandatory retirement age. The most recent pilot aging study was the Hilton Systems Technical Report 8025 (known generally as the Hilton Study) undertaken by Lehigh University and Hilton Systems, Inc to "conduct statistical analysis on historical data to investigate the relationship between pilot age and accident rates." The report concluded: "we saw no hint of an increase in accident rate for pilots of scheduled air carriers as they neared their 60th birthday." In spite of this study, the Age 60 Rule not only remains in effect, it was expanded in 1995 to include Part 135 pilots in spite of no record of any age-related accidents or incidents in the affected pilot group. Clearly, the United States seems to be moving against the international aviation community and contrary to our own national trends on age discrimination rules. Can you provide any medical or scientific reason why the United States should not follow the findings of the Hilton Study and "cautiously increase the retirement age to age 63?"

The answer from the FAA indicated that, "While science does not dictate the age of 60, that age is within the age range during which sharp increases in disease mortality and morbidity occur" and

" * * * In late 1990, FAA initiated its most recent study of the issue, aimed at consolidating available accident data and correlating it with the amount of flying by pilots as a function of age. This resulted in the March 1993 Hilton study report, ‘Age 60 Project, Consolidated Database Experiments, Final Report’, which found ‘no hint of an increase in accident rate for pilots of scheduled air carriers as they neared their 60th birthday’’ but noted that there were no data available on scheduled air carrier pilots beyond age 60." 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. The Committee directs the FAA to deliver this report no later than January 1, 2000. No more than half the funds appropriated in the Human Factors and Aviation Medicine program may be obligated for other than this initiative until delivery of the report."

APPENDIX B
EXPOSURE-ACCIDENT DATA AGGREGATED BY YEAR AND SENATE-DEFINED AGE GROUP (60-63, 56-59, 55-58, …, 21-24)

Year	Age Group	N Pilots	Sum Annual Hours	N Accidents	Accident Rate
1988	LE 24	788	588,534	5	0.850
1988	22-25	1,434	1,113,139	8	0.719
1988	23-26	2,229	1,725,904	13	0.753
1988	24-27	3,198	2,439,197	17	0.697
1988	25-28	4,129	3,088,049	20	0.648
1988	26-29	4,920	3,597,622	19	0.528
1988	27-30	5,801	4,171,495	13	0.312
1988	28-31	6,633	4,670,563	16	0.343
1988	29-32	7,413	5,135,756	14	0.273
1988	30-33	8,032	5,513,943	15	0.272
1988	31-34	8,379	5,694,582	20	0.351
1988	32-35	8,346	5,653,320	18	0.318
1988	33-36	8,300	5,645,311	18	0.319
1988	34-37	8,266	5,606,494	20	0.357
1988	35-38	8,252	5,592,316	19	0.340
1988	36-39	8,602	5,812,910	18	0.310
1988	37-40	8,872	5,958,593	20	0.336
1988	38-41	9,304	6,219,742	17	0.273
1988	39-42	9,355	6,219,057	16	0.257
1988	40-43	8,919	5,896,882	14	0.237
1988	41-44	8,419	5,529,335	12	0.217
1988	42-45	8,027	5,239,306	16	0.305
1988	43-46	8,199	5,334,162	18	0.337
1988	44-47	8,481	5,493,689	16	0.291
1988	45-48	8,887	5,731,584	17	0.297
1988	46-49	9,054	5,836,630	15	0.257
1988	47-50	8,797	5,667,999	13	0.229
1988	48-51	8,456	5,464,472	13	0.238
1988	49-52	7,967	5,176,584	16	0.309
1988	50-53	7,278	4,728,966	16	0.338
1988	51-54	6,720	4,374,731	17	0.389
1988	52-55	6,186	4,032,838	18	0.446
1988	53-56	5,573	3,635,191	12	0.330
1988	54-57	4,822	3,157,811	11	0.348
1988	55-58	4,074	2,686,151	14	0.521
1988	56-59	3,305	2,185,836	13	0.595
1988	60-63	442	266,831	1	0.375
1989	LE 24	774	556,082	8	1.439
1989	22-25	1,337	998,205	12	1.202
1989	23-26	2,155	1,621,137	13	0.802

1989	24-27	3,043	2,281,994	21	0.920
1989	25-28	4,006	2,967,581	21	0.708
1989	26-29	4,870	3,530,361	26	0.736
1989	27-30	5,677	4,024,167	31	0.770
1989	28-31	6,625	4,601,067	25	0.543
1989	29-32	7,505	5,117,411	29	0.567
1989	30-33	8,386	5,654,885	25	0.442
1989	31-34	8,995	6,035,180	23	0.381
1989	32-35	9,112	6,082,792	21	0.345
1989	33-36	8,872	5,922,882	19	0.321
1989	34-37	8,633	5,776,943	18	0.312
1989	35-38	8,399	5,599,286	21	0.375
1989	36-39	8,364	5,556,614	21	0.378
1989	37-40	8,665	5,722,562	16	0.280
1989	38-41	8,882	5,821,138	19	0.326
1989	39-42	9,313	6,061,357	16	0.264
1989	40-43	9,445	6,092,223	18	0.295
1989	41-44	9,149	5,826,747	20	0.343
1989	42-45	8,697	5,472,170	17	0.311
1989	43-46	8,330	5,192,894	17	0.327
1989	44-47	8,344	5,170,016	16	0.309
1989	45-48	8,494	5,264,140	16	0.304
1989	46-49	8,841	5,486,229	15	0.273
1989	47-50	8,938	5,580,133	13	0.233
1989	48-51	8,698	5,452,952	11	0.202
1989	49-52	8,359	5,255,423	11	0.209
1989	50-53	7,841	4,945,251	12	0.243
1989	51-54	7,126	4,497,186	12	0.267
1989	52-55	6,529	4,133,400	9	0.218
1989	53-56	5,937	3,772,923	7	0.186
1989	54-57	5,297	3,382,168	5	0.148
1989	55-58	4,560	2,913,988	5	0.172
1989	56-59	3,804	2,454,460	6	0.244
1989	60-63	504	300,812	3	0.997
1990	LE 24	973	649,868	6	0.923
1990	22-25	1,581	1,135,802	9	0.792
1990	23-26	2,361	1,715,692	12	0.699
1990	24-27	3,288	2,398,188	14	0.584
1990	25-28	4,170	3,018,712	12	0.398
1990	26-29	5,077	3,608,644	15	0.416
1990	27-30	6,036	4,210,236	14	0.333
1990	28-31	6,976	4,781,812	15	0.314
1990	29-32	7,996	5,416,017	16	0.295
1990	30-33	8,930	5,974,972	12	0.201
1990	31-34	9,670	6,446,436	13	0.202

1990	32-35	10,008	6,637,731	12	0.181
1990	33-36	10,013	6,630,585	14	0.211
1990	34-37	9,602	6,365,824	18	0.283
1990	35-38	9,183	6,068,680	22	0.363
1990	36-39	8,929	5,889,178	22	0.374
1990	37-40	8,775	5,729,737	24	0.419
1990	38-41	9,038	5,857,926	23	0.393
1990	39-42	9,304	5,981,189	20	0.334
1990	40-43	9,817	6,261,000	21	0.335
1990	41-44	10,019	6,360,199	19	0.299
1990	42-45	9,779	6,179,041	19	0.307
1990	43-46	9,308	5,858,405	16	0.273
1990	44-47	8,753	5,487,430	17	0.310
1990	45-48	8,661	5,402,481	18	0.333
1990	46-49	8,713	5,423,313	17	0.313
1990	47-50	8,967	5,574,831	20	0.359
1990	48-51	9,038	5,628,212	20	0.355
1990	49-52	8,702	5,437,105	16	0.294
1990	50-53	8,283	5,184,252	13	0.251
1990	51-54	7,718	4,840,556	11	0.227
1990	52-55	6,981	4,387,523	7	0.160
1990	53-56	6,319	3,997,903	8	0.200
1990	54-57	5,679	3,597,121	11	0.306
1990	55-58	5,008	3,187,152	8	0.251
1990	56-59	4,224	2,700,844	9	0.333
1990	60-63	645	378,472	2	0.528
1991	LE 24	762	500,705	3	0.599
1991	22-25	1,319	929,431	4	0.430
1991	23-26	2,111	1,505,632	5	0.332
1991	24-27	3,055	2,184,813	11	0.503
1991	25-28	4,056	2,878,972	14	0.486
1991	26-29	5,020	3,506,111	21	0.599
1991	27-30	6,078	4,151,930	22	0.530
1991	28-31	7,267	4,875,951	23	0.472
1991	29-32	8,399	5,558,318	20	0.360
1991	30-33	9,630	6,348,101	15	0.236
1991	31-34	10,568	6,959,492	14	0.201
1991	32-35	11,132	7,323,434	13	0.178
1991	33-36	11,241	7,398,170	13	0.176
1991	34-37	10,930	7,196,520	15	0.208
1991	35-38	10,382	6,815,050	21	0.308
1991	36-39	9,850	6,445,095	24	0.372
1991	37-40	9,464	6,172,528	24	0.389
1991	38-41	9,212	5,931,355	26	0.438
1991	39-42	9,326	5,963,011	19	0.319

1991	40-43	9,484	6,005,368	14	0.233
1991	41-44	10,020	6,300,767	19	0.302
1991	42-45	10,286	6,446,389	18	0.279
1991	43-46	9,951	6,238,674	18	0.289
1991	44-47	9,382	5,908,475	18	0.305
1991	45-48	8,706	5,458,172	15	0.275
1991	46-49	8,429	5,265,068	12	0.228
1991	47-50	8,404	5,236,046	14	0.267
1991	48-51	8,625	5,333,146	15	0.281
1991	49-52	8,661	5,354,433	12	0.224
1991	50-53	8,333	5,156,646	12	0.233
1991	51-54	7,973	4,925,894	12	0.244
1991	52-55	7,387	4,578,607	10	0.218
1991	53-56	6,609	4,105,096	10	0.244
1991	54-57	5,923	3,707,659	8	0.216
1991	55-58	5,263	3,298,010	6	0.182
1991	56-59	4,576	2,881,549	4	0.139
1991	60-63	707	399,907	3	0.750
1992	LE 24	622	401,661	6	1.494
1992	22-25	1,140	779,262	7	0.898
1992	23-26	1,918	1,337,391	10	0.748
1992	24-27	2,842	1,981,228	13	0.656
1992	25-28	3,836	2,665,723	11	0.413
1992	26-29	4,871	3,331,294	16	0.480
1992	27-30	5,922	3,972,727	18	0.453
1992	28-31	7,096	4,675,426	20	0.428
1992	29-32	8,358	5,421,452	21	0.387
1992	30-33	9,517	6,132,299	24	0.391
1992	31-34	10,569	6,831,150	23	0.337
1992	32-35	11,237	7,295,612	20	0.274
1992	33-36	11,586	7,547,815	20	0.265
1992	34-37	11,481	7,487,415	13	0.174
1992	35-38	11,132	7,243,847	12	0.166
1992	36-39	10,570	6,858,215	10	0.146
1992	37-40	9,905	6,409,146	8	0.125
1992	38-41	9,442	6,113,835	11	0.180
1992	39-42	9,112	5,862,142	12	0.205
1992	40-43	9,267	5,906,154	12	0.203
1992	41-44	9,501	6,033,878	18	0.298
1992	42-45	10,069	6,369,971	17	0.267
1992	43-46	10,272	6,509,014	14	0.215
1992	44-47	9,851	6,259,901	16	0.256
1992	45-48	9,219	5,853,097	10	0.171
1992	46-49	8,508	5,353,704	6	0.112
1992	47-50	8,218	5,115,997	8	0.156

1992	48-51	8,131	5,028,508	6	0.119
1992	49-52	8,338	5,127,972	5	0.098
1992	50-53	8,302	5,122,245	9	0.176
1992	51-54	7,971	4,913,121	8	0.163
1992	52-55	7,561	4,678,053	9	0.192
1992	53-56	6,895	4,271,718	8	0.187
1992	54-57	6,118	3,789,809	5	0.132
1992	55-58	5,398	3,368,329	3	0.089
1992	56-59	4,711	2,941,421	4	0.136
1992	60-63	839	496,051	2	0.403
1993	LE 24	326	199,167	2	1.004
1993	22-25	624	424,041	7	1.651
1993	23-26	1,111	782,606	12	1.533
1993	24-27	1,786	1,280,277	17	1.328
1993	25-28	2,604	1,858,279	15	0.807
1993	26-29	3,462	2,432,371	16	0.658
1993	27-30	4,277	2,965,812	16	0.539
1993	28-31	5,093	3,475,853	14	0.403
1993	29-32	6,019	4,038,276	16	0.396
1993	30-33	7,036	4,660,451	11	0.236
1993	31-34	8,088	5,300,256	9	0.170
1993	32-35	8,989	5,877,253	10	0.170
1993	33-36	9,433	6,157,871	11	0.179
1993	34-37	9,674	6,323,169	13	0.206
1993	35-38	9,516	6,230,926	12	0.193
1993	36-39	9,305	6,073,603	9	0.148
1993	37-40	9,015	5,884,329	10	0.170
1993	38-41	8,618	5,600,683	9	0.161
1993	39-42	8,338	5,411,713	10	0.185
1993	40-43	8,130	5,240,960	15	0.286
1993	41-44	8,319	5,340,998	13	0.243
1993	42-45	8,594	5,540,198	12	0.217
1993	43-46	9,144	5,887,951	14	0.238
1993	44-47	9,325	6,046,264	9	0.149
1993	45-48	8,932	5,785,775	9	0.156
1993	46-49	8,328	5,369,693	12	0.223
1993	47-50	7,692	4,915,386	12	0.244
1993	48-51	7,462	4,721,099	15	0.318
1993	49-52	7,422	4,688,463	16	0.341
1993	50-53	7,661	4,824,722	14	0.290
1993	51-54	7,692	4,852,534	10	0.206
1993	52-55	7,350	4,629,437	9	0.194
1993	53-56	6,979	4,393,329	7	0.159
1993	54-57	6,303	3,965,963	5	0.126
1993	55-58	5,514	3,478,880	7	0.201

1993	56-59	4,820	3,065,153	6	0.196
1993	60-63	828	496,407	1	0.201
1994	LE 24	341	220,428	2	0.907
1994	22-25	602	414,315	5	1.207
1994	23-26	1,036	734,607	8	1.089
1994	24-27	1,536	1,112,307	9	0.809
1994	25-28	2,158	1,565,808	17	1.086
1994	26-29	2,795	2,015,139	19	0.943
1994	27-30	3,440	2,442,988	18	0.737
1994	28-31	4,147	2,905,899	22	0.757
1994	29-32	4,819	3,351,142	17	0.507
1994	30-33	5,613	3,861,697	17	0.440
1994	31-34	6,485	4,412,104	20	0.453
1994	32-35	7,328	4,948,459	21	0.424
1994	33-36	8,059	5,387,697	22	0.408
1994	34-37	8,549	5,676,431	19	0.335
1994	35-38	8,822	5,835,279	17	0.291
1994	36-39	8,774	5,774,128	11	0.191
1994	37-40	8,663	5,685,574	10	0.176
1994	38-41	8,337	5,471,810	10	0.183
1994	39-42	7,977	5,239,167	7	0.134
1994	40-43	7,749	5,074,994	7	0.138
1994	41-44	7,576	4,950,769	5	0.101
1994	42-45	7,802	5,085,313	5	0.098
1994	43-46	8,108	5,278,988	7	0.133
1994	44-47	8,552	5,573,750	7	0.126
1994	45-48	8,738	5,695,283	11	0.193
1994	46-49	8,391	5,467,272	16	0.293
1994	47-50	7,799	5,069,718	16	0.316
1994	48-51	7,268	4,705,089	18	0.383
1994	49-52	7,049	4,535,303	16	0.353
1994	50-53	7,030	4,516,859	13	0.288
1994	51-54	7,212	4,625,325	12	0.259
1994	52-55	7,194	4,615,425	11	0.238
1994	53-56	6,820	4,389,410	8	0.182
1994	54-57	6,381	4,100,679	6	0.146
1994	55-58	5,740	3,685,077	5	0.136
1994	56-59	4,942	3,184,374	6	0.188
1994	60-63	705	415,711	0	0.000
1995	LE 24	419	257,198	4	1.555
1995	22-25	821	556,831	4	0.718
1995	23-26	1,377	971,722	4	0.412
1995	24-27	2,088	1,502,984	9	0.599
1995	25-28	2,806	2,034,036	9	0.442
1995	26-29	3,564	2,556,969	11	0.430

1995	27-30	4,348	3,087,153	14	0.453
1995	28-31	5,109	3,556,380	11	0.309
1995	29-32	6,017	4,119,741	15	0.364
1995	30-33	6,899	4,654,032	15	0.322
1995	31-34	7,969	5,296,943	17	0.321
1995	32-35	9,025	5,978,026	19	0.318
1995	33-36	9,815	6,484,450	18	0.278
1995	34-37	10,658	7,048,192	16	0.227
1995	35-38	11,129	7,371,538	14	0.190
1995	36-39	11,419	7,543,675	16	0.212
1995	37-40	11,397	7,513,935	14	0.186
1995	38-41	10,907	7,182,730	16	0.223
1995	39-42	10,198	6,714,240	12	0.179
1995	40-43	9,495	6,249,705	9	0.144
1995	41-44	8,999	5,920,099	9	0.152
1995	42-45	8,753	5,753,234	5	0.087
1995	43-46	8,896	5,834,556	10	0.171
1995	44-47	9,074	5,952,010	12	0.202
1995	45-48	9,587	6,294,446	13	0.207
1995	46-49	9,789	6,416,098	18	0.281
1995	47-50	9,370	6,116,293	14	0.229
1995	48-51	8,755	5,719,252	15	0.262
1995	49-52	8,045	5,231,825	14	0.268
1995	50-53	7,646	4,960,282	13	0.262
1995	51-54	7,488	4,877,964	13	0.267
1995	52-55	7,558	4,898,094	11	0.225
1995	53-56	7,363	4,774,370	12	0.251
1995	54-57	6,887	4,462,941	10	0.224
1995	55-58	6,411	4,141,968	11	0.266
1995	56-59	5,703	3,683,188	10	0.272
1995	60-63	1,073	644,718	2	0.310
1996	LE 24	476	289,862	1	0.345
1996	22-25	869	565,991	2	0.353
1996	23-26	1,438	987,002	3	0.304
1996	24-27	2,124	1,502,930	6	0.399
1996	25-28	2,932	2,087,286	11	0.527
1996	26-29	3,616	2,566,693	12	0.468
1996	27-30	4,369	3,064,927	22	0.718
1996	28-31	5,081	3,484,464	21	0.603
1996	29-32	5,826	3,921,773	20	0.510
1996	30-33	6,761	4,484,141	19	0.424
1996	31-34	7,649	5,040,172	10	0.198
1996	32-35	8,682	5,670,898	12	0.212
1996	33-36	9,602	6,252,944	11	0.176
1996	34-37	10,306	6,714,220	16	0.238

1996	35-38	11,002	7,146,612	17	0.238
1996	36-39	11,359	7,394,894	14	0.189
1996	37-40	11,606	7,573,157	16	0.211
1996	38-41	11,474	7,471,165	12	0.161
1996	39-42	10,940	7,128,513	13	0.182
1996	40-43	10,290	6,709,679	16	0.238
1996	41-44	9,664	6,273,478	14	0.223
1996	42-45	9,253	6,024,349	13	0.216
1996	43-46	9,013	5,872,817	17	0.289
1996	44-47	9,108	5,928,679	15	0.253
1996	45-48	9,259	6,039,730	19	0.315
1996	46-49	9,686	6,323,957	26	0.411
1996	47-50	9,861	6,433,196	22	0.342
1996	48-51	9,439	6,180,604	23	0.372
1996	49-52	8,761	5,755,610	18	0.313
1996	50-53	8,022	5,266,440	13	0.247
1996	51-54	7,603	4,977,844	11	0.221
1996	52-55	7,431	4,844,672	12	0.248
1996	53-56	7,437	4,834,345	13	0.269
1996	54-57	7,197	4,658,123	12	0.258
1996	55-58	6,694	4,337,887	14	0.323
1996	56-59	6,143	3,981,735	10	0.251
1996	60-63	1,219	721,896	5	0.693
1997	LE 24	521	312,283	2	0.640
1997	22-25	857	560,646	6	1.070
1997	23-26	1,381	951,461	8	0.841
1997	24-27	2,114	1,494,152	10	0.669
1997	25-28	2,808	1,995,203	12	0.601
1997	26-29	3,542	2,504,632	13	0.519
1997	27-30	4,139	2,889,601	13	0.450
1997	28-31	4,715	3,251,021	17	0.523
1997	29-32	5,438	3,668,608	16	0.436
1997	30-33	6,129	4,075,213	16	0.393
1997	31-34	6,949	4,557,264	17	0.373
1997	32-35	7,715	5,017,739	15	0.299
1997	33-36	8,464	5,495,178	18	0.328
1997	34-37	9,207	5,962,396	14	0.235
1997	35-38	9,801	6,366,763	18	0.283
1997	36-39	10,354	6,726,548	14	0.208
1997	37-40	10,682	6,923,607	16	0.231
1997	38-41	10,817	7,008,302	22	0.314
1997	39-42	10,702	6,920,358	22	0.318
1997	40-43	10,314	6,653,919	21	0.316
1997	41-44	9,770	6,303,880	20	0.317
1997	42-45	9,315	5,982,204	16	0.267

1997	43-46	8,967	5,760,441	12	0.208
1997	44-47	8,726	5,593,306	15	0.268
1997	45-48	8,799	5,668,825	15	0.265
1997	46-49	8,958	5,807,268	17	0.293
1997	47-50	9,425	6,112,240	18	0.294
1997	48-51	9,580	6,219,762	16	0.257
1997	49-52	9,213	5,975,216	19	0.318
1997	50-53	8,559	5,552,536	15	0.270
1997	51-54	7,775	5,039,857	14	0.278
1997	52-55	7,335	4,757,097	18	0.378
1997	53-56	7,057	4,566,263	12	0.263
1997	54-57	6,948	4,494,143	15	0.334
1997	55-58	6,619	4,287,091	16	0.373
1997	56-59	6,011	3,896,059	13	0.334
1997	60-63	1,084	629,865	6	0.953

APPENDIX C
EXPOSURE-ACCIDENT DATA AGGREGATED BY YEAR AND CONSISTENTLY OVERLAPPING 4-YEAR AGE GROUPS DECLINING FROM AGE 63 (21-24, …, 58-61, 59-62, 60-63)

Year	Age Group	N Pilots	Sum Annual Hours	N Accidents	Accident Rate
1988	LE 24	788	588,534	5	0.850
1988	22-25	1,434	1,113,139	8	0.719
1988	23-26	2,229	1,725,904	13	0.753
1988	24-27	3,198	2,439,197	17	0.697
1988	25-28	4,129	3,088,049	20	0.648
1988	26-29	4,920	3,597,622	19	0.528
1988	27-30	5,801	4,171,495	13	0.312
1988	28-31	6,633	4,670,563	16	0.343
1988	29-32	7,413	5,135,756	14	0.273
1988	30-33	8,032	5,513,943	15	0.272
1988	31-34	8,379	5,694,582	20	0.351
1988	32-35	8,346	5,653,320	18	0.318
1988	33-36	8,300	5,645,311	18	0.319
1988	34-37	8,266	5,606,494	20	0.357
1988	35-38	8,252	5,592,316	19	0.340
1988	36-39	8,602	5,812,910	18	0.310
1988	37-40	8,872	5,958,593	20	0.336
1988	38-41	9,304	6,219,742	17	0.273
1988	39-42	9,355	6,219,057	16	0.257
1988	40-43	8,919	5,896,882	14	0.237
1988	41-44	8,419	5,529,335	12	0.217
1988	42-45	8,027	5,239,306	16	0.305
1988	43-46	8,199	5,334,162	18	0.337
1988	44-47	8,481	5,493,689	16	0.291
1988	45-48	8,887	5,731,584	17	0.297
1988	46-49	9,054	5,836,630	15	0.257
1988	47-50	8,797	5,667,999	13	0.229
1988	48-51	8,456	5,464,472	13	0.238
1988	49-52	7,967	5,176,584	16	0.309
1988	50-53	7,278	4,728,966	16	0.338
1988	51-54	6,720	4,374,731	17	0.389
1988	52-55	6,186	4,032,838	18	0.446
1988	53-56	5,573	3,635,191	12	0.330
1988	54-57	4,822	3,157,811	11	0.348
1988	55-58	4,074	2,686,151	14	0.521
1988	56-59	3,305	2,185,836	13	0.595
1988	57-60	2,434	1,620,260	12	0.741
1988	58-61	1,662	1,099,007	9	0.819
1988	59-62	938	600,248	3	0.500

1988	60-63	442	266,831	1	0.375
1989	LE 24	774	556,082	8	1.439
1989	22-25	1,337	998,205	12	1.202
1989	23-26	2,155	1,621,137	13	0.802
1989	24-27	3,043	2,281,994	21	0.920
1989	25-28	4,006	2,967,581	21	0.708
1989	26-29	4,870	3,530,361	26	0.736
1989	27-30	5,677	4,024,167	31	0.770
1989	28-31	6,625	4,601,067	25	0.543
1989	29-32	7,505	5,117,411	29	0.567
1989	30-33	8,386	5,654,885	25	0.442
1989	31-34	8,995	6,035,180	23	0.381
1989	32-35	9,112	6,082,792	21	0.345
1989	33-36	8,872	5,922,882	19	0.321
1989	34-37	8,633	5,776,943	18	0.312
1989	35-38	8,399	5,599,286	21	0.375
1989	36-39	8,364	5,556,614	21	0.378
1989	37-40	8,665	5,722,562	16	0.280
1989	38-41	8,882	5,821,138	19	0.326
1989	39-42	9,313	6,061,357	16	0.264
1989	40-43	9,445	6,092,223	18	0.295
1989	41-44	9,149	5,826,747	20	0.343
1989	42-45	8,697	5,472,170	17	0.311
1989	43-46	8,330	5,192,894	17	0.327
1989	44-47	8,344	5,170,016	16	0.309
1989	45-48	8,494	5,264,140	16	0.304
1989	46-49	8,841	5,486,229	15	0.273
1989	47-50	8,938	5,580,133	13	0.233
1989	48-51	8,698	5,452,952	11	0.202
1989	49-52	8,359	5,255,423	11	0.209
1989	50-53	7,841	4,945,251	12	0.243
1989	51-54	7,126	4,497,186	12	0.267
1989	52-55	6,529	4,133,400	9	0.218
1989	53-56	5,937	3,772,923	7	0.186
1989	54-57	5,297	3,382,168	5	0.148
1989	55-58	4,560	2,913,988	5	0.172
1989	56-59	3,804	2,454,460	6	0.244
1989	57-60	2,930	1,893,706	6	0.317
1989	58-61	1,912	1,233,070	5	0.405
1989	59-62	1,176	753,598	4	0.531
1989	60-63	504	300,812	3	0.997
1990	LE 24	973	649,868	6	0.923
1990	22-25	1,581	1,135,802	9	0.792
1990	23-26	2,361	1,715,692	12	0.699
1990	24-27	3,288	2,398,188	14	0.584

1990	25-28	4,170	3,018,712	12	0.398
1990	26-29	5,077	3,608,644	15	0.416
1990	27-30	6,036	4,210,236	14	0.333
1990	28-31	6,976	4,781,812	15	0.314
1990	29-32	7,996	5,416,017	16	0.295
1990	30-33	8,930	5,974,972	12	0.201
1990	31-34	9,670	6,446,436	13	0.202
1990	32-35	10,008	6,637,731	12	0.181
1990	33-36	10,013	6,630,585	14	0.211
1990	34-37	9,602	6,365,824	18	0.283
1990	35-38	9,183	6,068,680	22	0.363
1990	36-39	8,929	5,889,178	22	0.374
1990	37-40	8,775	5,729,737	24	0.419
1990	38-41	9,038	5,857,926	23	0.393
1990	39-42	9,304	5,981,189	20	0.334
1990	40-43	9,817	6,261,000	21	0.335
1990	41-44	10,019	6,360,199	19	0.299
1990	42-45	9,779	6,179,041	19	0.307
1990	43-46	9,308	5,858,405	16	0.273
1990	44-47	8,753	5,487,430	17	0.310
1990	45-48	8,661	5,402,481	18	0.333
1990	46-49	8,713	5,423,313	17	0.313
1990	47-50	8,967	5,574,831	20	0.359
1990	48-51	9,038	5,628,212	20	0.355
1990	49-52	8,702	5,437,105	16	0.294
1990	50-53	8,283	5,184,252	13	0.251
1990	51-54	7,718	4,840,556	11	0.227
1990	52-55	6,981	4,387,523	7	0.160
1990	53-56	6,319	3,997,903	8	0.200
1990	54-57	5,679	3,597,121	11	0.306
1990	55-58	5,008	3,187,152	8	0.251
1990	56-59	4,224	2,700,844	9	0.333
1990	57-60	3,302	2,101,047	8	0.381
1990	58-61	2,251	1,420,527	4	0.282
1990	59-62	1,294	802,714	4	0.498
1990	60-63	645	378,472	2	0.528
1991	LE 24	762	500,705	3	0.599
1991	22-25	1,319	929,431	4	0.430
1991	23-26	2,111	1,505,632	5	0.332
1991	24-27	3,055	2,184,813	11	0.503
1991	25-28	4,056	2,878,972	14	0.486
1991	26-29	5,020	3,506,111	21	0.599
1991	27-30	6,078	4,151,930	22	0.530
1991	28-31	7,267	4,875,951	23	0.472
1991	29-32	8,399	5,558,318	20	0.360

1991	30-33	9,630	6,348,101	15	0.236
1991	31-34	10,568	6,959,492	14	0.201
1991	32-35	11,132	7,323,434	13	0.178
1991	33-36	11,241	7,398,170	13	0.176
1991	34-37	10,930	7,196,520	15	0.208
1991	35-38	10,382	6,815,050	21	0.308
1991	36-39	9,850	6,445,095	24	0.372
1991	37-40	9,464	6,172,528	24	0.389
1991	38-41	9,212	5,931,355	26	0.438
1991	39-42	9,326	5,963,011	19	0.319
1991	40-43	9,484	6,005,368	14	0.233
1991	41-44	10,020	6,300,767	19	0.302
1991	42-45	10,286	6,446,389	18	0.279
1991	43-46	9,951	6,238,674	18	0.289
1991	44-47	9,382	5,908,475	18	0.305
1991	45-48	8,706	5,458,172	15	0.275
1991	46-49	8,429	5,265,068	12	0.228
1991	47-50	8,404	5,236,046	14	0.267
1991	48-51	8,625	5,333,146	15	0.281
1991	49-52	8,661	5,354,433	12	0.224
1991	50-53	8,333	5,156,646	12	0.233
1991	51-54	7,973	4,925,894	12	0.244
1991	52-55	7,387	4,578,607	10	0.218
1991	53-56	6,609	4,105,096	10	0.244
1991	54-57	5,923	3,707,659	8	0.216
1991	55-58	5,263	3,298,010	6	0.182
1991	56-59	4,576	2,881,549	4	0.139
1991	57-60	3,670	2,318,589	3	0.129
1991	58-61	2,549	1,576,083	3	0.190
1991	59-62	1,561	955,749	4	0.419
1991	60-63	707	399,907	3	0.750
1992	LE 24	622	401,661	6	1.494
1992	22-25	1,140	779,262	7	0.898
1992	23-26	1,918	1,337,391	10	0.748
1992	24-27	2,842	1,981,228	13	0.656
1992	25-28	3,836	2,665,723	11	0.413
1992	26-29	4,871	3,331,294	16	0.480
1992	27-30	5,922	3,972,727	18	0.453
1992	28-31	7,096	4,675,426	20	0.428
1992	29-32	8,358	5,421,452	21	0.387
1992	30-33	9,517	6,132,299	24	0.391
1992	31-34	10,569	6,831,150	23	0.337
1992	32-35	11,237	7,295,612	20	0.274
1992	33-36	11,586	7,547,815	20	0.265
1992	34-37	11,481	7,487,415	13	0.174

1992	35-38	11,132	7,243,847	12	0.166
1992	36-39	10,570	6,858,215	10	0.146
1992	37-40	9,905	6,409,146	8	0.125
1992	38-41	9,442	6,113,835	11	0.180
1992	39-42	9,112	5,862,142	12	0.205
1992	40-43	9,267	5,906,154	12	0.203
1992	41-44	9,501	6,033,878	18	0.298
1992	42-45	10,069	6,369,971	17	0.267
1992	43-46	10,272	6,509,014	14	0.215
1992	44-47	9,851	6,259,901	16	0.256
1992	45-48	9,219	5,853,097	10	0.171
1992	46-49	8,508	5,353,704	6	0.112
1992	47-50	8,218	5,115,997	8	0.156
1992	48-51	8,131	5,028,508	6	0.119
1992	49-52	8,338	5,127,972	5	0.098
1992	50-53	8,302	5,122,245	9	0.176
1992	51-54	7,971	4,913,121	8	0.163
1992	52-55	7,561	4,678,053	9	0.192
1992	53-56	6,895	4,271,718	8	0.187
1992	54-57	6,118	3,789,809	5	0.132
1992	55-58	5,398	3,368,329	3	0.089
1992	56-59	4,711	2,941,421	4	0.136
1992	57-60	3,884	2,431,000	4	0.165
1992	58-61	2,751	1,713,270	4	0.233
1992	59-62	1,698	1,042,884	5	0.479
1992	60-63	839	496,051	2	0.403
1993	LE 24	326	199,167	2	1.004
1993	22-25	624	424,041	7	1.651
1993	23-26	1,111	782,606	12	1.533
1993	24-27	1,786	1,280,277	17	1.328
1993	25-28	2,604	1,858,279	15	0.807
1993	26-29	3,462	2,432,371	16	0.658
1993	27-30	4,277	2,965,812	16	0.539
1993	28-31	5,093	3,475,853	14	0.403
1993	29-32	6,019	4,038,276	16	0.396
1993	30-33	7,036	4,660,451	11	0.236
1993	31-34	8,088	5,300,256	9	0.170
1993	32-35	8,989	5,877,253	10	0.170
1993	33-36	9,433	6,157,871	11	0.179
1993	34-37	9,674	6,323,169	13	0.206
1993	35-38	9,516	6,230,926	12	0.193
1993	36-39	9,305	6,073,603	9	0.148
1993	37-40	9,015	5,884,329	10	0.170
1993	38-41	8,618	5,600,683	9	0.161
1993	39-42	8,338	5,411,713	10	0.185

1993	40-43	8,130	5,240,960	15	0.286
1993	41-44	8,319	5,340,998	13	0.243
1993	42-45	8,594	5,540,198	12	0.217
1993	43-46	9,144	5,887,951	14	0.238
1993	44-47	9,325	6,046,264	9	0.149
1993	45-48	8,932	5,785,775	9	0.156
1993	46-49	8,328	5,369,693	12	0.223
1993	47-50	7,692	4,915,386	12	0.244
1993	48-51	7,462	4,721,099	15	0.318
1993	49-52	7,422	4,688,463	16	0.341
1993	50-53	7,661	4,824,722	14	0.290
1993	51-54	7,692	4,852,534	10	0.206
1993	52-55	7,350	4,629,437	9	0.194
1993	53-56	6,979	4,393,329	7	0.159
1993	54-57	6,303	3,965,963	5	0.126
1993	55-58	5,514	3,478,880	7	0.201
1993	56-59	4,820	3,065,153	6	0.196
1993	57-60	3,929	2,510,188	6	0.239
1993	58-61	2,792	1,776,120	6	0.338
1993	59-62	1,745	1,102,998	3	0.272
1993	60-63	828	496,407	1	0.201
1994	LE 24	341	220,428	2	0.907
1994	22-25	602	414,315	5	1.207
1994	23-26	1,036	734,607	8	1.089
1994	24-27	1,536	1,112,307	9	0.809
1994	25-28	2,158	1,565,808	17	1.086
1994	26-29	2,795	2,015,139	19	0.943
1994	27-30	3,440	2,442,988	18	0.737
1994	28-31	4,147	2,905,899	22	0.757
1994	29-32	4,819	3,351,142	17	0.507
1994	30-33	5,613	3,861,697	17	0.440
1994	31-34	6,485	4,412,104	20	0.453
1994	32-35	7,328	4,948,459	21	0.424
1994	33-36	8,059	5,387,697	22	0.408
1994	34-37	8,549	5,676,431	19	0.335
1994	35-38	8,822	5,835,279	17	0.291
1994	36-39	8,774	5,774,128	11	0.191
1994	37-40	8,663	5,685,574	10	0.176
1994	38-41	8,337	5,471,810	10	0.183
1994	39-42	7,977	5,239,167	7	0.134
1994	40-43	7,749	5,074,994	7	0.138
1994	41-44	7,576	4,950,769	5	0.101
1994	42-45	7,802	5,085,313	5	0.098
1994	43-46	8,108	5,278,988	7	0.133
1994	44-47	8,552	5,573,750	7	0.126

1994	45-48	8,738	5,695,283	11	0.193
1994	46-49	8,391	5,467,272	16	0.293
1994	47-50	7,799	5,069,718	16	0.316
1994	48-51	7,268	4,705,089	18	0.383
1994	49-52	7,049	4,535,303	16	0.353
1994	50-53	7,030	4,516,859	13	0.288
1994	51-54	7,212	4,625,325	12	0.259
1994	52-55	7,194	4,615,425	11	0.238
1994	53-56	6,820	4,389,410	8	0.182
1994	54-57	6,381	4,100,679	6	0.146
1994	55-58	5,740	3,685,077	5	0.136
1994	56-59	4,942	3,184,374	6	0.188
1994	57-60	3,871	2,483,261	6	0.242
1994	58-61	2,678	1,703,034	4	0.235
1994	59-62	1,615	1,017,550	3	0.295
1994	60-63	705	415,711	0	0.000
1995	LE 24	419	257,198	4	1.555
1995	22-25	821	556,831	4	0.718
1995	23-26	1,377	971,722	4	0.412
1995	24-27	2,088	1,502,984	9	0.599
1995	25-28	2,806	2,034,036	9	0.442
1995	26-29	3,564	2,556,969	11	0.430
1995	27-30	4,348	3,087,153	14	0.453
1995	28-31	5,109	3,556,380	11	0.309
1995	29-32	6,017	4,119,741	15	0.364
1995	30-33	6,899	4,654,032	15	0.322
1995	31-34	7,969	5,296,943	17	0.321
1995	32-35	9,025	5,978,026	19	0.318
1995	33-36	9,815	6,484,450	18	0.278
1995	34-37	10,658	7,048,192	16	0.227
1995	35-38	11,129	7,371,538	14	0.190
1995	36-39	11,419	7,543,675	16	0.212
1995	37-40	11,397	7,513,935	14	0.186
1995	38-41	10,907	7,182,730	16	0.223
1995	39-42	10,198	6,714,240	12	0.179
1995	40-43	9,495	6,249,705	9	0.144
1995	41-44	8,999	5,920,099	9	0.152
1995	42-45	8,753	5,753,234	5	0.087
1995	43-46	8,896	5,834,556	10	0.171
1995	44-47	9,074	5,952,010	12	0.202
1995	45-48	9,587	6,294,446	13	0.207
1995	46-49	9,789	6,416,098	18	0.281
1995	47-50	9,370	6,116,293	14	0.229
1995	48-51	8,755	5,719,252	15	0.262
1995	49-52	8,045	5,231,825	14	0.268

1995	50-53	7,646	4,960,282	13	0.262
1995	51-54	7,488	4,877,964	13	0.267
1995	52-55	7,558	4,898,094	11	0.225
1995	53-56	7,363	4,774,370	12	0.251
1995	54-57	6,887	4,462,941	10	0.224
1995	55-58	6,411	4,141,968	11	0.266
1995	56-59	5,703	3,683,188	10	0.272
1995	57-60	4,641	2,995,584	8	0.267
1995	58-61	3,328	2,123,512	6	0.283
1995	59-62	2,133	1,336,409	4	0.299
1995	60-63	1,073	644,718	2	0.310
1996	LE 24	476	289,862	1	0.345
1996	22-25	869	565,991	2	0.353
1996	23-26	1,438	987,002	3	0.304
1996	24-27	2,124	1,502,930	6	0.399
1996	25-28	2,932	2,087,286	11	0.527
1996	26-29	3,616	2,566,693	12	0.468
1996	27-30	4,369	3,064,927	22	0.718
1996	28-31	5,081	3,484,464	21	0.603
1996	29-32	5,826	3,921,773	20	0.510
1996	30-33	6,761	4,484,141	19	0.424
1996	31-34	7,649	5,040,172	10	0.198
1996	32-35	8,682	5,670,898	12	0.212
1996	33-36	9,602	6,252,944	11	0.176
1996	34-37	10,306	6,714,220	16	0.238
1996	35-38	11,002	7,146,612	17	0.238
1996	36-39	11,359	7,394,894	14	0.189
1996	37-40	11,606	7,573,157	16	0.211
1996	38-41	11,474	7,471,165	12	0.161
1996	39-42	10,940	7,128,513	13	0.182
1996	40-43	10,290	6,709,679	16	0.238
1996	41-44	9,664	6,273,478	14	0.223
1996	42-45	9,253	6,024,349	13	0.216
1996	43-46	9,013	5,872,817	17	0.289
1996	44-47	9,108	5,928,679	15	0.253
1996	45-48	9,259	6,039,730	19	0.315
1996	46-49	9,686	6,323,957	26	0.411
1996	47-50	9,861	6,433,196	22	0.342
1996	48-51	9,439	6,180,604	23	0.372
1996	49-52	8,761	5,755,610	18	0.313
1996	50-53	8,022	5,266,440	13	0.247
1996	51-54	7,603	4,977,844	11	0.221
1996	52-55	7,431	4,844,672	12	0.248
1996	53-56	7,437	4,834,345	13	0.269
1996	54-57	7,197	4,658,123	12	0.258

1996	55-58	6,694	4,337,887	14	0.323
1996	56-59	6,143	3,981,735	10	0.251
1996	57-60	5,116	3,308,569	11	0.332
1996	58-61	3,648	2,341,190	9	0.384
1996	59-62	2,345	1,474,232	5	0.339
1996	60-63	1,219	721,896	5	0.693
1997	LE 24	521	312,283	2	0.640
1997	22-25	857	560,646	6	1.070
1997	23-26	1,381	951,461	8	0.841
1997	24-27	2,114	1,494,152	10	0.669
1997	25-28	2,808	1,995,203	12	0.601
1997	26-29	3,542	2,504,632	13	0.519
1997	27-30	4,139	2,889,601	13	0.450
1997	28-31	4,715	3,251,021	17	0.523
1997	29-32	5,438	3,668,608	16	0.436
1997	30-33	6,129	4,075,213	16	0.393
1997	31-34	6,949	4,557,264	17	0.373
1997	32-35	7,715	5,017,739	15	0.299
1997	33-36	8,464	5,495,178	18	0.328
1997	34-37	9,207	5,962,396	14	0.235
1997	35-38	9,801	6,366,763	18	0.283
1997	36-39	10,354	6,726,548	14	0.208
1997	37-40	10,682	6,923,607	16	0.231
1997	38-41	10,817	7,008,302	22	0.314
1997	39-42	10,702	6,920,358	22	0.318
1997	40-43	10,314	6,653,919	21	0.316
1997	41-44	9,770	6,303,880	20	0.317
1997	42-45	9,315	5,982,204	16	0.267
1997	43-46	8,967	5,760,441	12	0.208
1997	44-47	8,726	5,593,306	15	0.268
1997	45-48	8,799	5,668,825	15	0.265
1997	46-49	8,958	5,807,268	17	0.293
1997	47-50	9,425	6,112,240	18	0.294
1997	48-51	9,580	6,219,762	16	0.257
1997	49-52	9,213	5,975,216	19	0.318
1997	50-53	8,559	5,552,536	15	0.270
1997	51-54	7,775	5,039,857	14	0.278
1997	52-55	7,335	4,757,097	18	0.378
1997	53-56	7,057	4,566,263	12	0.263
1997	54-57	6,948	4,494,143	15	0.334
1997	55-58	6,619	4,287,091	16	0.373
1997	56-59	6,011	3,896,059	13	0.334
1997	57-60	5,049	3,270,326	12	0.367
1997	58-61	3,589	2,289,937	9	0.393
1997	59-62	2,220	1,378,625	7	0.508

1997	60-63	1,084	629,865	6	0.953

APPENDIX D
EXPOSURE-ACCIDENT DATA AGGREGATED BY YEAR AND INDEPENDENT 5-YEAR AGE GROUP (LE 29, 30-34, …, 55-59, 60-63)

Year	Age Group	N Pilots	Sum Annual Hours	N Accidents	Accident Rate
1988	LE 29	6,398	4,735,709	27	0.570
1988	30-34	10,146	6,944,142	20	0.288
1988	35-39	10,599	7,161,537	25	0.349
1988	40-44	10,778	7,104,190	17	0.239
1988	45-49	11,160	7,206,246	21	0.291
1988	50-54	8,786	5,716,292	20	0.350
1988	55-59	4,623	3,046,989	16	0.525
1988	60-63	442	266,831	1	0.375
1989	LE 29	6,270	4,562,223	38	0.833
1989	30-34	10,694	7,197,627	29	0.403
1989	35-39	10,547	7,009,476	25	0.357
1989	40-44	11,460	7,343,939	21	0.286
1989	45-49	10,738	6,660,323	19	0.285
1989	50-54	9,361	5,917,118	14	0.237
1989	55-59	5,261	3,381,671	6	0.177
1989	60-63	504	300,812	3	0.997
1990	LE 29	6,766	4,796,515	24	0.500
1990	30-34	11,546	7,717,198	16	0.207
1990	35-39	11,369	7,489,859	25	0.334
1990	40-44	12,265	7,801,546	26	0.333
1990	45-49	10,882	6,792,473	22	0.324
1990	50-54	9,964	6,239,783	16	0.256
1990	55-59	5,702	3,631,207	10	0.275
1990	60-63	645	378,472	2	0.528
1991	LE 29	6,414	4,471,170	25	0.559
1991	30-34	12,513	8,236,231	17	0.206
1991	35-39	12,752	8,348,823	30	0.359
1991	40-44	12,263	7,753,236	21	0.271
1991	45-49	10,959	6,849,143	18	0.263
1991	50-54	10,062	6,227,473	15	0.241
1991	55-59	6,170	3,877,293	7	0.181
1991	60-63	707	399,907	3	0.750
1992	LE 29	6,061	4,133,409	23	0.556
1992	30-34	12,467	8,070,318	28	0.347
1992	35-39	13,495	8,770,893	13	0.148
1992	40-44	11,785	7,505,055	20	0.266
1992	45-49	11,270	7,110,958	10	0.141
1992	50-54	10,155	6,257,215	11	0.176
1992	55-59	6,311	3,940,809	6	0.152
1992	60-63	839	496,051	2	0.403

1993	LE 29	4,115	2,869,096	23	0.802
1993	30-34	9,427	6,210,007	14	0.225
1993	35-39	11,781	7,711,119	13	0.169
1993	40-44	10,393	6,688,698	17	0.254
1993	45-49	10,649	6,884,370	13	0.189
1993	50-54	9,559	6,014,323	15	0.249
1993	55-59	6,486	4,115,522	9	0.219
1993	60-63	828	496,407	1	0.201
1994	LE 29	3,430	2,443,471	24	0.982
1994	30-34	7,608	5,187,098	23	0.443
1994	35-39	10,908	7,206,123	18	0.250
1994	40-44	9,670	6,324,726	8	0.126
1994	45-49	10,506	6,844,576	18	0.263
1994	50-54	8,834	5,673,052	15	0.264
1994	55-59	6,695	4,311,278	8	0.186
1994	60-63	705	415,711	0	0.000
1995	LE 29	4,425	3,129,629	17	0.543
1995	30-34	9,355	6,265,320	21	0.335
1995	35-39	14,057	9,290,719	20	0.215
1995	40-44	11,616	7,643,791	11	0.144
1995	45-49	11,978	7,854,456	18	0.229
1995	50-54	9,430	6,125,625	14	0.229
1995	55-59	7,561	4,878,377	14	0.287
1995	60-63	1,073	644,718	2	0.310
1996	LE 29	4,524	3,153,757	14	0.444
1996	30-34	9,048	5,993,124	21	0.350
1996	35-39	13,930	9,050,951	19	0.210
1996	40-44	12,604	8,200,668	19	0.232
1996	45-49	11,898	7,773,089	27	0.347
1996	50-54	9,987	6,534,274	15	0.230
1996	55-59	7,922	5,137,338	15	0.292
1996	60-63	1,219	721,896	5	0.693
1997	LE 29	4,455	3,092,391	19	0.614
1997	30-34	8,138	5,365,600	19	0.354
1997	35-39	12,565	8,169,325	20	0.245
1997	40-44	12,525	8,071,443	26	0.322
1997	45-49	11,198	7,229,015	20	0.277
1997	50-54	10,382	6,729,876	18	0.267
1997	55-59	7,861	5,089,809	19	0.373
1997	60-63	1,084	629,865	6	0.953

APPENDIX E
ANOVA RESULTS FOR BASE 10 (LOG_{10}) AND NATURAL LOGARITHM (LOG_e)TRANSFORMATIONS OF ACCIDENT RATES

Table E-1

ANOVA results for $\log_{10}$ of accident rate by overlapping age groups (60-63, and then 4-year age groups declining from 59)

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	11.942	36	.332	14.142	.000
	Linear Term Unweighted	5.610	1	5.610	239.174	.000
	Deviation	6.332	35	.181	7.713	.000
	Quadratic Term Unweighted	5.220	1	5.220	222.557	.000
	Deviation	1.111	34	.032	1.394	.076
	Cubic Term Unweighted	.089	1	.089	3.363	.068
	Deviation	1.033	33	.031	1.334	.109
Within Groups		7.787	332	.023		
	Total	19.729	368			

Table E-2

ANOVA results for $\log_e$ of accident rate by overlapping age groups (60-63, and then 4-year age groups declining from 59)

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	63.313	36	1.759	14.142	.000
	Linear Term Unweighted	29.743	1	29.743	239.174	.000
	Deviation	33.570	35	.959	7.713	.000
	Quadratic Term Unweighted	27.677	1	27.677	222.557	.000
	Deviation	5.893	34	.173	1.394	.076
	Cubic Term Unweighted	.418	1	.418	3.363	.068
	Deviation	5.475	33	.166	1.334	.109
Within Groups		41.287	332	.124		
	Total	104.600	368			

Table E-3
ANOVA results for $\log_{10}$ of accident rate by overlapping age groups (declining from age 63 in 4-year age groups)

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	12.081	39	.310	12.958	.000
Linear Term	Unweighted	4.085	1	4.085	170.886	.000
	Deviation	7.859	38	.207	8.651	.000
Quadratic Term	Unweighted	6.760	1	6.760	282.790	.000
	Deviation	1.155	37	.031	1.305	.116
Cubic Term	Unweighted	.053	1	.053	2.197	.139
	Deviation	1.094	36	.030	1.272	.142
Within Groups		8.582	359	.024		
	Total	20.663	398			

Table E-4
ANOVA results for $\log_e$ of accident rate by overlapping age groups (declining from age 63 in 4-year age groups)

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	64.051	39	1.642	12.958	.000
Linear Term	Unweighted	21.659	1	21.659	170.886	.000
	Deviation	41.668	38	1.097	8.651	.000
Quadratic Term	Unweighted	35.842	1	35.842	282.790	.000
	Deviation	6.122	37	.165	1.305	.116
Cubic Term	Unweighted	.278	1	2.78	2.197	.139
	Deviation	5.802	36	.127	1.272	.142
Within Groups		45.502	359	.127		
	Total	109.552	398			

Table E-5
ANOVA results for log_{10} of accident rate by independent age groups (60-63, and then 5-year age groups declining from 59)

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	1.828	7	.261	12.760	.000
Linear Term	Unweighted	.062	1	.062	3.019	.087
	Deviation	1.741	6	.290	14.182	.000
Quadratic Term	Unweighted	1.518	1	1.518	74.176	.000
	Deviation	.242	5	.048	2.364	.048
Cubic Term	Unweighted	.001	1	.001	.042	.839
	Deviation	.241	4	.060	2.939	.026
Within Groups		1.453	71	.020		
	Total	3.281	78			

Table E-6
ANOVA results for log_e of accident rate by independent age groups (60-63, and then 5-year age groups declining from 59)

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	9.692	7	1.385	12.760	.000
Linear Term	Unweighted	.328	1	.328	3.019	.087
	Deviation	9.233	6	1.539	14.182	.000
Quadratic Term	Unweighted	8.048	1	8.048	74.176	.000
	Deviation	1.282	5	.256	2.364	.048
Cubic Term	Unweighted	.004	1	.004	.042	.839
	Deviation	1.275	4	.319	2.939	.026
Within Groups		7.704	71	.109		
	Total	17.396	78			