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Pilot Age and Accident Rates Report 3: An Analysis of Professional Air Transport 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 third of four studies proposed by the agency.

Accident rate was defined in this study as the ratio of the number of accidents occurring under 14 **CFR** §121 and §135 to annual hours flown by professional pilots holding Class 1 medical and ATP certificates for the period 1988 through 1997. Accident data were provided by the National Transportation Safety Board. 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 with Class 1 medical and ATP certificates (i.e., 60-63, 56-59, …, 21-24). The second analysis examined accident rates by overlapping, four-year age groups declining consistently from age 63 (i.e., 60-63, 59-62, …, 21-24). The third analysis examined accident rates for the 60-63 age group as directed by the Senate and non-overlapping (or independent) five-year age groups (i.e., 55-59, 50-54, …, less than or equal to 29) for comparison to previous studies.

Overall, these analyses support the hypothesis that a "U"-shaped relationship exists between the age of professional pilots holding Class 1 medical and ATP certificates and the accident rate for operations under 14 **CFR** §121 and §135. However, the range of mean differences across age groups was very small and not statistically different when comparing adjacent age groups on either side of the current rule.

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 this study detected a "U"-shaped relationship between accident rates and age when pilots age 60 to 63 were included in the sample.

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, alternative statistical techniques for the investigation of the relationship of pilot age to accidents are recommended. Finally, extending the analysis to pilots holding Class 1 or 2 medical and ATP or commercial certificates is recommended. The results of the latter analysis will be documented in a fourth report in accordance with the research plan proposed by the FAA.

TABLE OF CONTENTS

TABLES

FIGURES

PILOT AGE AND ACCIDENT RATES REPORT 3: AN ANALYSIS OF PROFESSIONAL AIR TRANSPORT PILOT ACCIDENT RATES BY AGE

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 60th 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 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 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 Class 1, 2, or 3 medical certificates and operating under Parts 91, 121, or 135. 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). 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. Involvement in a violation or crash within the previous three years was predictive of involvement in a crash during the study time frame (1983-1988). The authors found that pilot age was not associated significantly with increased risk unless age was adjusted for total and recent flight time. Although this adjustment showed that risk increased with age, the authors reported that their analyses indicated that "…greater experience keeps older pilots from being at excess risk" (p. 984). Finally, Rebok, Grabowski, Baker, Lamb, Willoughby, and Li (1999) examined causal factors in accidents for a historical cohort 3,592 air carrier and air taxi pilots aged 45 to 54 in 1987. 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 with Class 3 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 Class 3 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).

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, & 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; 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)." An operational definition of the relevant population would be pilots holding first-class ("Class 1") airman medical and air transport pilot (ATP) certificates. The fourth study will broaden the operational definition of the relevant population to pilots holding first- or second-class airman medical and ATP or commercial certificates. This represents the broadest definition of the population of pilots most likely to be conducting operations under 14 **CFR** §121 and §135.

This report presents the third study proposed by the FAA. The focus of our study was on accident rates for professional pilots holding Class 1 medical and ATP 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 and Class 1 medical certificate 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. Following this introduction, 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 Class 1 medical and ATP 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, … 21-24), for the period 1988 through 1997. The fourth chapter focuses on the accident rate for ATP/Class 1 pilots by consistently overlapping 4-year age groups, declining from age 63 (e.g., 60-63, 59-62, 58-61, 57-60, 56-59, … 21-24) for the period 1988 through 1997. The fifth chapter examines accident rates by non-overlapping 5-year age groups for pilots in the same period. The sixth and final chapter of the report (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 are 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. One 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 Class 1 medical and air transport pilot (ATP) 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 possible 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 results in a discontinuity at age 60. 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.

However, 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.

In response, 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 29 (as the minimum age for ATP certificate is 23 years), 30 to 34, 35 to 39, 40-44, 45-49, 50-54, 55-59, and 60-63 (required by the Senate). 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

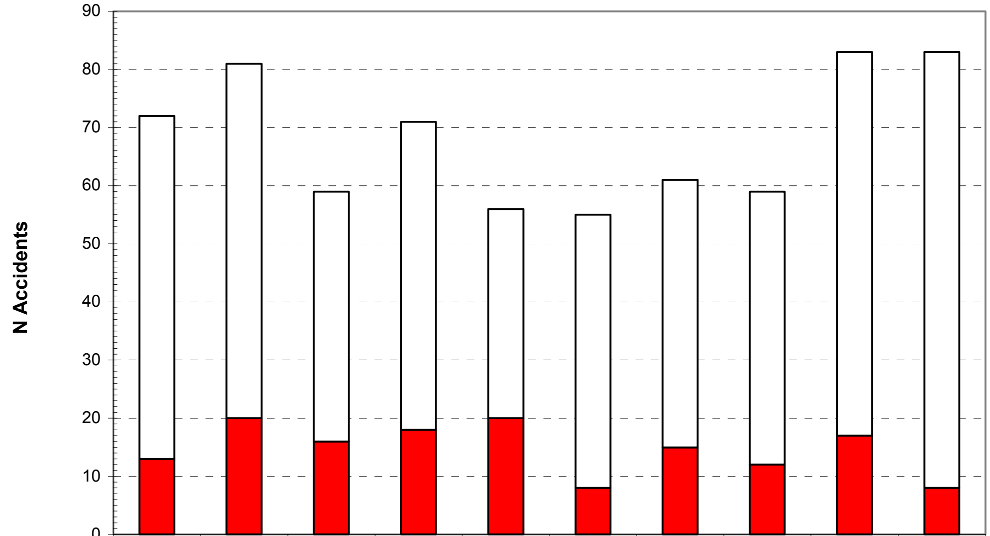
The NTSB maintains the official system of federal records for aviation accidents. An "aircraft accident" is an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and until all such persons have disembarked, 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. Of those usable records, 802 involved a pilot holding an air transport pilot (ATP) certificate at the time of the accident. However, 106 of the accidents involved a pilot holding an ATP and Class 2 medical certificate at the time of the accident. These accident records were excluded from this analysis, leaving a total of 680 accidents involving pilots holding Class 1 medical and ATP certificates. Figure 1 shows that the number of accidents ranged from 55 to 83 per year. There were 147 fatal accidents with 1,533 fatalities between 1988 and 1997 for flights operating under Parts 121 or 135 with a pilot holding a Class 1 medical and ATP certificate at the time of the accident.

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
Non-Fatal Accidents	59	61	43	53	36	47	46	47	66	75
Fatal Accidents	13	20	16	18	20	8	15	12	17	8

Figure 1: Number of non-fatal and fatal accidents involving pilots with an ATP and Class 1 medical certificate, 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 ATP certificate. A Class 1 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 certificate may be issued to a pilot 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 931,743 records of Class 1 examinations between January 1, 1988, and December 31, 1997, were extracted from the CAIS medical certificate data as provided to CAMI by Flight Standards. These records were matched by SSN, name, and date of birth with CAIS certificate data. There were 891,183 records of Class 1 medical examinations for 115,270 individual pilots with ATP certificates between 1988 and 1997. The number of pilots for whom certificate records were available each year ranged from 55,164 to 68,420. The number of pilots for whom certificate records were available are compared in Table 1 to the number of ATP and effective[1] Class 1 medical certificates reported annually by the FAA in the *FAA Aeromedical Certification Statistical Handbook*. Comparison of the available records to the counts of ATP and effective Class 1 certificates suggests that CAIS records were unavailable for some airmen due to a period of changeover of computerized systems. The proportion of active airmen with ATP and effective Class 1 certificates represented by this set of CAIS records ranged from 68% in 1993 to 85% in 1988. However, the available set of CAIS records provided an adequate basis for the estimation of the relationship of age to accident rates for this population.

Table 1

Comparison of number of ATP Certificates, Class 1 medical certificates, and number of CAIS records available for analysis for each year, 1988-1997

Year	ATP Certificates[a]	Class 1 Certificates[b]	N CAIS Records Available
1988	96,968	70,388	59,974
1989	102,087	83,254	61,725
1990	107,732	81,055	65,319
1991	112,167	90,859	68,015
1992	115,855	89,879	68,420
1993	117,070	87,654	59,940
1994	117,434	75,662	55,164
1995	123,877	78,662	64,774
1996	127,486	82,200	66,011
1997	130,858	84,732	63,191

Notes: [a]As reported each year in the annual report, *U.S. Civil Airmen Statistics*
[b]As reported each year in the annual report, *Aeromedical Certification Statistical Handbook*, Table IV.A, for Class 1 certificates that have not lapsed (e.g., are "effective").

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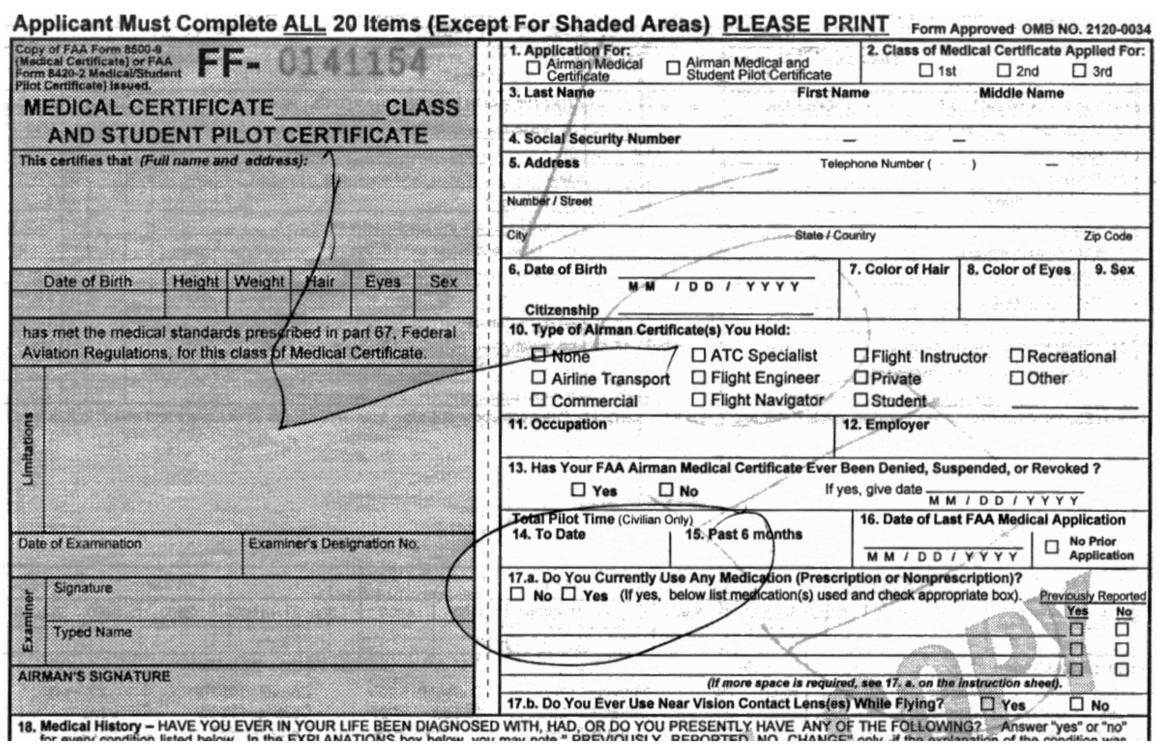
[1] The annual *Aeromedical Certification Statistical Handbook* defines "effective status" for a medical certificate in terms of the time since a required examination. For example, if more than six months have lapsed since the completion of a Class 1 medical examination for an airman, the "effective status" of the airman would be reduced to the next lower level, a Class 2 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 Class 3 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.

The average number of examinations per pilot was about 8 (M = 7.73, SD = 5.57), and ranged from 1 to 21 examinations per pilot. The ages (as of the medical examination) ranged from 23 (the minimum for an ATP certificate) to 83, with an average of 43 years. The average age for ATPs inched upwards from 43.2 in 1988 to 45.3 in 1997 (FAA, 1997). 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).

Pilots reported their recent and total hours without regard to type of operation (e.g., Parts 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 Parts 121 and 135 operations by including hours flown under Part 91 (general aviation). Accident rates that were computed based on these inflated exposure estimates were likely to underestimate the actual Parts 121 and 135 accident rate by some degree. However, pilots also voluntarily indicated their employer (see Figure 2). The employer identification provided a reasonable basis for including or excluding certain pilots from the denominator**.** For example, selecting only



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: Medical examination form

those air transport pilots working for an airline (e.g., Part 121-certificated domestic, flag, or supplemental carrier or Part 135-certificated air taxi or commuter) would more closely reflect the exposure of pilots subject to the Age 60 Rule, assuming the premise that most reported hours would be accumulated in occupational flying, as opposed to recreational flying.

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. 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 compared 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.

However, 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 with Class 1 medical and ATP certificates (i.e., 60-63, 56-59, …, 22-25, 21-24). 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 to previous studies.

CHAPTER 3
ACCIDENT RATES FOR PROFESSIONAL PILOTS WITH CLASS 1 MEDICAL AND ATP CERTIFICATES USING SENATE-DIRECTED AGE GROUPS

Data Preparation

CAIS medical data

The starting points for this analysis were the (a) 680 NTSB accidents occurring for Parts 121 or 135 flights that involved pilots holding an ATP and Class 1 medical certificate at the time of the accident, and (b) 891,183 CAIS Class 1 medical certificate records for pilots with an ATP 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 891,183 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 696 NTSB accidents associated with flights operating under 14 **CFR** §121 and §135 and involving a pilot with an ATP certificate with a Class 1 medical were aggregated by year and pilot identifier. Four pilots had two accidents each. The remaining pilots had only one accident.

Matching CAIS medical and NTSB accident data

The NTSB accident records were then matched with the CAIS medical records for professional pilots with Class 1 medical and ATP certificates for each year, as shown in Figure 3. The resulting file contained 629,439 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 16,839 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.

CAIS Medical				NTSB Accident			
AHRS	DOB	SSN	YEAR	YEAR	SSN	DOB	NACC
600	01/01/53	123456789	1988	1988	123456789	01/01/53	1
340	02/02/47	234567890	1988				
			…	…			
400	01/01/53	123456789	1989				
620	02/02/47	234567890	1989	1989	234567890	02/02/47	1
			…	…			

```
(SPSS Syntax)

MATCH FILES
        FILE = [CAIS Medical]
        /FILE=[NTSB Accident]
        /BY=YEAR SSN DOB
```

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 629,439 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 21-24, 22-25, 23-26, … 54-57, 55-58, 56-59, followed by 60-63. Records for 1,396 pilots age 64 or older were excluded as the Senate report specified 63 as the oldest age to be considered. 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 (21-24, 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

A one-way analysis of variance (ANOVA) was conducted to determine if there was a trend in accident rate across overlapping age groups. The trend analysis was conducted in view of previous studies finding a "U"-shaped function (e.g., quadratic trend) across age groups for aviation (Golaszewski 1993; Kay et al., 1994, p. 5-2) 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

The trend analysis revealed that a quadratic function (i.e., "U" shape) best described the trend in mean accident rate across age group [$F(1) = 18.49$, $p \leq .001$]. The overall *F*-test was not significant [$F(36) = 1.33$, *ns*; see Table 2]. The mean accident rates for each age group, along with their 5/95% confidence intervals, are illustrated in Figure 4. Finally, the planned comparison revealed that the mean accident rate for the 56 group did not differ significantly from that of the 60-63 age group [unequal variances, $t(10.39) = 0.72$, *ns*].

Inspection of the confidence intervals indicated that the mean accident rates for the younger (21-24 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) = 5.51, $p \leq .001$]. 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 834 to 1,981 pilot records per year. Similarly, the accident rates for pilots age 60-63 over the ten years were based on 406 to 1,057 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 7,869 to 10,595 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 2

Results for ANOVA of accident rate by overlapping age group (60-63, and then declining from 59 in 4-year groups) for professional pilots with Class 1 medical and ATP certificate

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	.696	36	.019	1.333	.102
Linear Term	Contrast	.062	1	.062	4.290	.039
	Deviation	.634	35	.018	1.249	.165
Quadratic Term	Contrast	.268	1	.268	18.490	.000
	Deviation	.366	34	.011	.741	.855
Cubic Term	Contrast	.097	1	.097	6.663	.010
	Deviation	.269	33	.008	.562	.977
Within Groups		4.833	333	.015		
	Total	5.530	369			

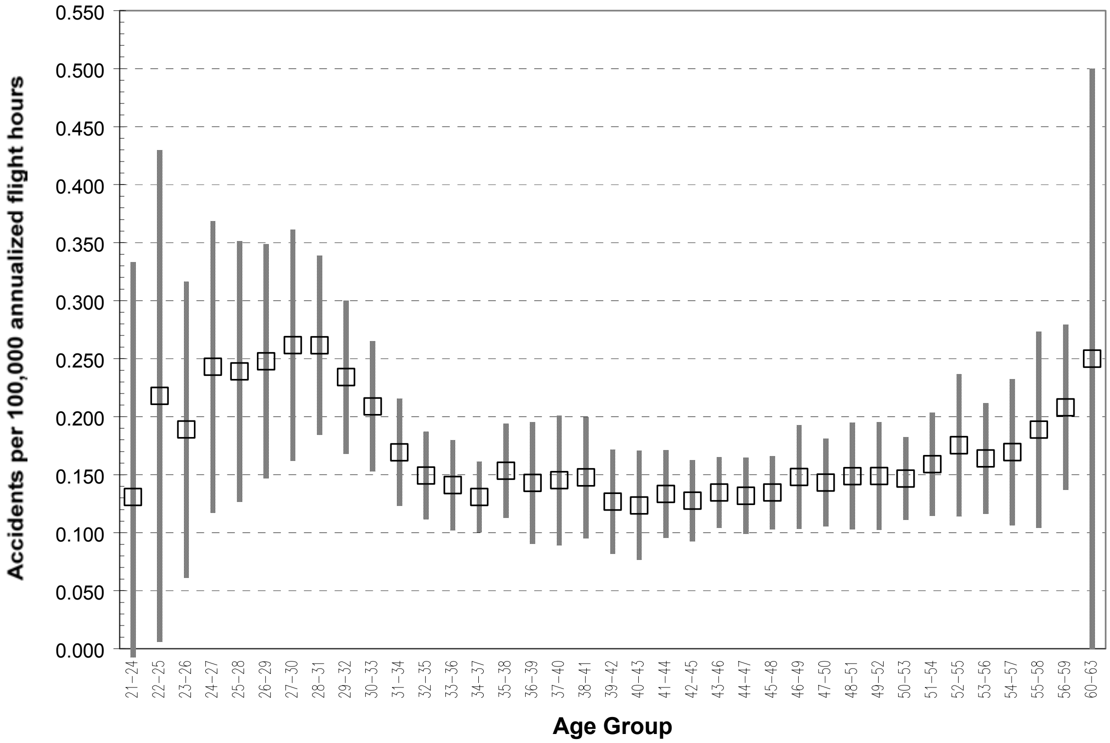


Figure 4: Plot of the mean accident rate and associated 5/95% confidence intervals for age 60-63 and overlapping 4-year age groups declining from age 59 for Part 121/135 accidents for professional pilots holding Class 1 medical and ATP certificates, 1988-1997.

CHAPTER 4
ACCIDENT RATES FOR PROFESSIONAL PILOTS WITH CLASS 1 MEDICAL AND ATP 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 629,439 matched exposure-accident records. First, the 629,439 matched exposure-accident records were all coded into overlapping, 4-year age groups declining from age 63. The age groups for this analysis were 21-24, 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 (21-24, 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

As in the first analysis, a one-way ANOVA was conducted to determine if there was a trend in accident rate 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.

Results

The trend analysis revealed that a quadratic function (i.e., "U" shape) best described the trend in mean accident rate across age group [$F(1) = 33.62, p \leq .001$]. The overall *F*-test also was significant [$F(39) = 1.59, p \leq .05$; see Table 3]. The mean accident rate for each age group, along with their 5/95% confidence intervals, are illustrated in Figure 5.

Finally, the planned comparison revealed that the mean accident rate for the 56-59 age group did not differ significantly from that of the 60-63 age group [unequal variances, $t(10.39) = 0.72$, *ns*]. The latter in fact was somewhat lower but had markedly greater variability.

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 age groups. This observation was supported by rejection of the assumption of equal variances across the age groups [*Levene Statistic*(39, 360) = 5.08, $p \leq .001$]. 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 analysis, 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 3
Results for ANOVA of accident rate by overlapping age group declining from age 63 for professional pilots with Class 1 medical and ATP certificate

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	.914	39	.023	1.592	.016
Linear Term	Contrast	.001	1	.001	.054	.817
	Deviation	.913	38	.024	1.633	.013
Quadratic Term	Contrast	.495	1	.495	33.618	.000
	Deviation	.418	37	.011	.768	.835
Cubic Term	Contrast	.141	1	.141	9.546	.002
	Deviation	.278	36	.008	.524	.990
Within Groups		5.299	360	.015		
	Total	6.212	399			

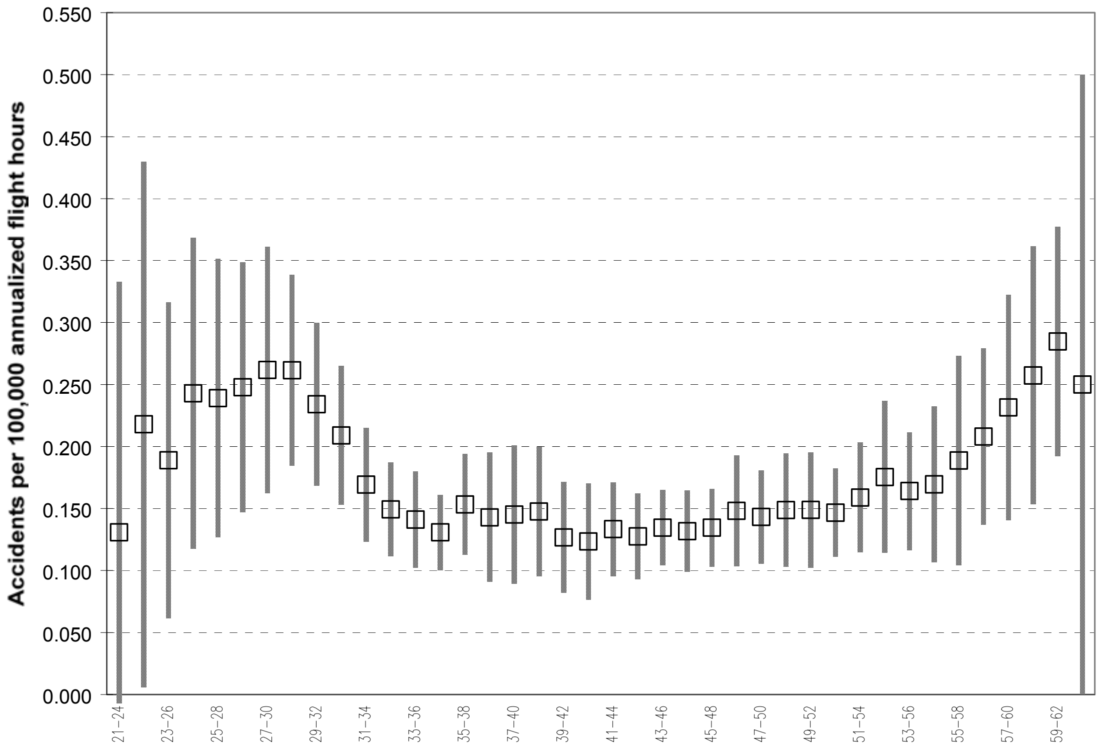


Figure 5: Plot of the mean accident rate and associated 5/95% confidence intervals by overlapping age group (4-year groupings declining from age 63) for Part 121/135 accidents for professional pilots holding Class 1 medical and ATP certificates, 1988-1997. (Only every other age group is labeled on the horizontal axis.)

CHAPTER 5
ACCIDENT RATES FOR PROFESSIONAL PILOTS WITH CLASS 1 MEDICAL AND ATP CERTIFICATES USING INDEPENDENT AGE GROUPS

Method

Procedures for grouping data by age

The starting point for the analysis was again the file containing 629,439 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 629,439 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, a one-way ANOVA was conducted to determine if there was trend in accident rate 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

The trend analysis revealed that a quadratic function (i.e., “U” shape) best described the trend in mean accident rate across age group [$F(1) = 9.36, p \leq .01$]. The overall F-test was not significant [$F(7) = 1.66$, *ns;* see Table 4]. 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 55-59 age group did not differ significantly from that of the 60-63 age group [unequal variances, $t(10.16) = -0.96$, *ns*].

Inspection of the confidence intervals indicated that the mean accident rates for the younger (LE 29) and older (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*(7, 72) = 23.28, $p \leq .001$]. The data presented in Appendix D show that the number of estimates of annualized hours for a pilot aggregated in the denominator of the accident rate varied across age groups as in the previous analyses, with the same effect. Estimates of accident rate based on fewer records were more variable than estimates based on much larger numbers of records.

Table 4
Results for ANOVA of accident rate by independent age group for professional pilots with Class 1 medical and ATP certificate

		Sum of Squares	*Df*	*Mean Square*	*F*	*p*
Between Groups	(Combined)	.298	7	.043	1.659	.133
Linear Term	Contrast	.037	1	.037	1.448	.233
	Deviation	.261	6	.043	1.695	.135
Quadratic Term	Contrast	.240	1	.240	9.356	.003
	Deviation	.021	5	.004	.162	.976
Cubic Term	Contrast	.004	1	.004	.153	.697
	Deviation	.017	4	.004	.165	.956
Within Groups		1.846	72	.026		
	Total	2.144	79			

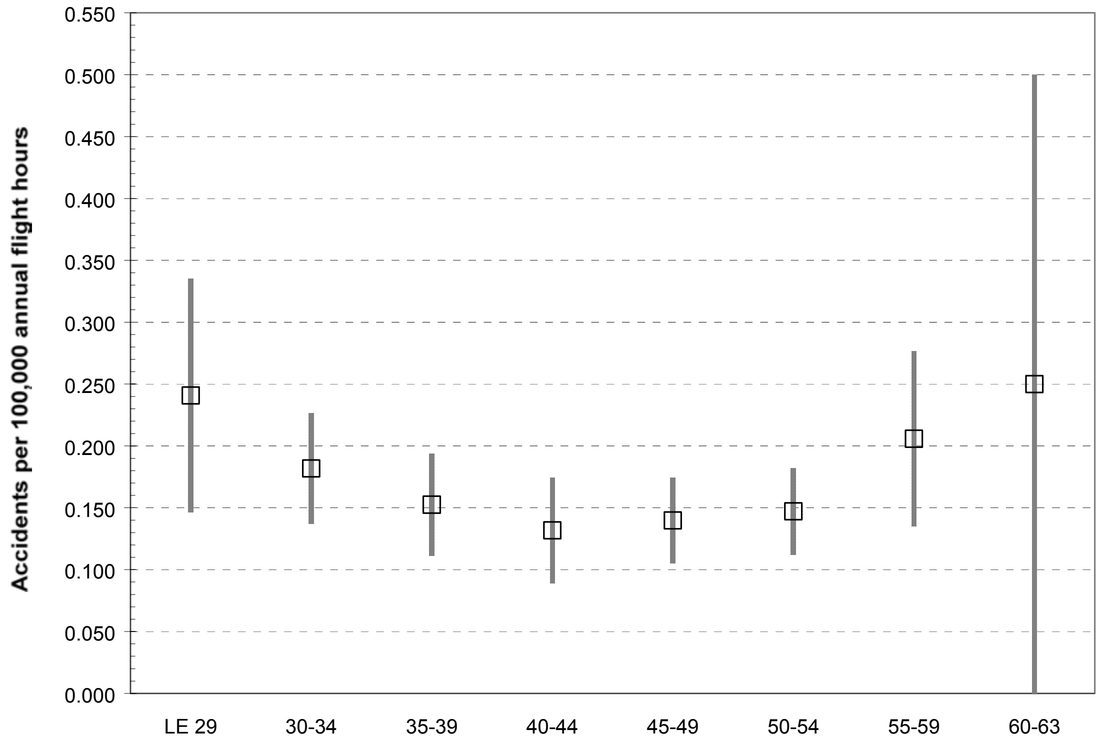


Figure 6: Plot of the mean accident rate and associated 5/95% confidence intervals by independent age group (aged 60-63, then independent 5-year groupings) for Part 121/135 accidents for professional pilots holding Class 1 medical and ATP certificates, 1988-1997.

CHAPTER 6
DISCUSSION

Overview of Key Findings

The results of the three sets of analyses are summarized in Table 5. Overall, for accidents occurring under 14 **CFR** §121 and §135, these analyses support the hypothesis that a "U"-shaped relationship exists between the age of professional pilots holding Class 1 medical and ATP certificates and their accident rate. However, the range of mean differences across age groups was very small and not statistically different when comparing adjacent age groups on either side of the current rule.

The findings are consistent across the three analyses. First, a statistically significant quadratic trend in accident rates across age groups was detected in all analyses. The form of the relationship between age and accident rate took a shallow "U" shape. 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 not statistically different in *a priori* planned comparisons. This finding may be attributable to the very small differences observed, the narrow range for accident rates across the age groups, and the gradual nature of the change across age groups. Third, the overall test in two of three analyses was not significant. While Hays (1988) and others suggests that the overall *F* test not be reported when the focus of an analysis is on trend analysis, we have chosen to report the overall test to provide complete information about the analyses. The overall

Table 5
Summary of results across analyses of accident rates by age group

	Test		
Age grouping	Trend	Comparison	Overall
Senate age groups (21-24, …, 56-59, 60-63)	Yes - Quadratic	No	No
Overlapping age groups (21-24, … , 59-62, 60-63)	Yes - Quadratic	No	Yes
Independent age groups (LE 29, 30-34, … , 55-59, 60-63)	Yes - Quadratic	No	No

Notes: [a]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 there a significant difference in mean accident rate for the 56-59/55-59 year old age groups compared to 60-63 age group? **Overall**: Does $\text{Mean}_{(\text{age group 1})} = \text{Mean}_{(\text{age group 2})} = \ldots$ Overall Mean Across Age Groups?

tests suggest that mean accident rates did not differ statistically by age group. This was expected in view of the very low base rate for accidents, the very small differences observed, and the methodological issues noted in Chapter 2.

Caveats to Findings

The following caveats apply to these conclusions. First, the denominator for pilots under age 60 includes exposure 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 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 confidence intervals 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, the 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 generally 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 Class 3 medical certificates, Golaszewski (1983, p. 14) concluded that "… except for the most and least experienced

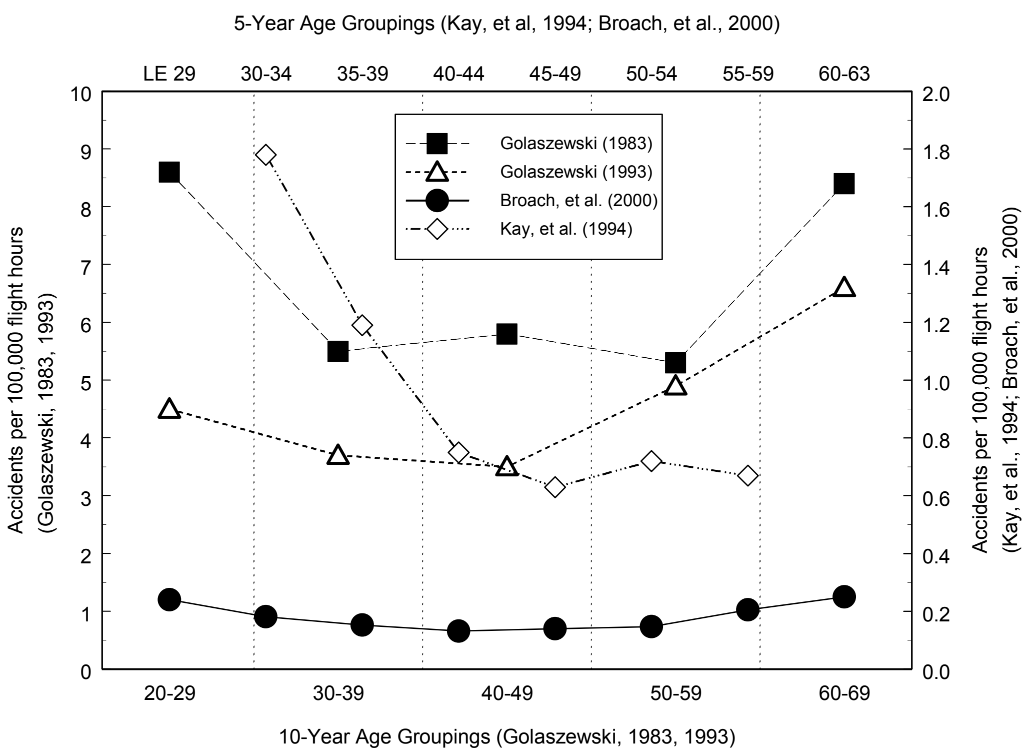


Figure 7: Comparison of accident rates by age 5- and 10-year age groupings from Golaszewski (1983, 1993), Kay et al. (1994) and Broach et al. (2000). Golaszewski (1983) = General aviation accident rate for Class 1, 2, & 3 pilots. Golaszewski (1993) = General aviation accident rate for Class 1 pilots, excluding air transport pilots. Kay et al. (1994) = Accident (all accidents) rate for Class 1 pilots. Broach et al. (2000) = Part 121/135 accident rate for professional Class 1 ATP pilots. Differences in accident rates between studies due to differences in accidents counted in the numerators and differences in the pilot populations included in the denominators of the accident rates.

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 Class 1 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).

On the other hand, our results are both similar to and 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 Class 1 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 Class 1 medical certificates age 60 and above from their analysis. In contrast, our analysis included Class 1 professional ATPs over age 60. The pattern of results in our study was similar to those reported by Kay et al. for younger and middle-aged Class 1 pilots: The accident rate decreased for younger pilots as they aged, and then leveled off in the middle years. Our results for Class 1 pilots differ from those reported by Kay et al. for older pilots. Kay et al. simply did not examine accident rates for Class 1 pilots beyond age 59. But by including Class 1 pilots aged 60-63, our analysis found that the statistical trend for older pilots holding Class 1 medical and ATP 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. There were 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 similar, in that we found no statistically significant differences in the accident rates for 60-63 year old and 56-59 or 55-59 year old professional ATPs holding Class 1 medical certificates. However, while the difference in accident rates between age groups was not statistically significant, the practical significance of any increase should be assessed.

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 Class 1, 2, or 3 medical certificate and had recent and total flight time greater than zero. In their analyses, Kay et al. assumed that all pilots holding Class 1 medical certificates were "Part 121 pilots" or pilots for scheduled airlines. As a result, they did not include Class 1 pilots over age 60 in their analyses. Therefore, Kay et al. were forced to rely on data from pilots holding Class 3 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 pilot had to be at least 23 years of age at the time of the medical examination, as that is the minimum age for holding an ATP certificate. Second, CAIS medical data were matched with CAIS certificate data, and only those pilots holding an ATP certificate and active Class 1 medical were included. Third, the pilot had to report "professional pilot" as his or her occupation for the record to be included in our data set. Kay et al. characterized their results as providing "a hint, and a hint only" of an increase with age; but, their findings were based on pilots with Class 3 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. discuss the difficulties in reconciling pilot identifiers across the different databases, but do 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 Class 1 certificate will take a medical examination twice a year. However, our analysis found that, in fact, the number of Class 1 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 approaches 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 that occurred within a specific period, 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. Consequently, relatively fewer events were counted in the numerator, 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.

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 an unique identifier for each pilot.

Alternative analyses

Our second 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 assess 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.

Analysis of accident rates for pilots holding Class 1 or 2 medical and ATP or Commercial certificates

Finally, we recommend broadening the definition of the population of interest to pilots holding Class 1 or 2 medical and ATP or commercial certificates, in view of the extension of the Age 60 Rule to operations conducted under Part 135. This broader analysis will be completed by the end of September 2000. The results of that analysis will be documented in the fourth report in accordance with the research plan.

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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	21-24	507	402,345	0	0.000
1988	22-25	1,128	905,883	0	0.000
1988	23-26	1,949	1,543,338	3	0.194
1988	24-27	2,930	2,280,336	7	0.307
1988	25-28	3,816	2,897,134	10	0.345
1988	26-29	4,577	3,392,324	11	0.324
1988	27-30	5,424	3,948,187	8	0.203
1988	28-31	6,238	4,434,135	8	0.180
1988	29-32	7,004	4,893,901	7	0.143
1988	30-33	7,614	5,267,573	9	0.171
1988	31-34	7,967	5,448,100	9	0.165
1988	32-35	7,947	5,413,751	11	0.203
1988	33-36	7,908	5,406,122	10	0.185
1988	34-37	7,905	5,378,840	9	0.167
1988	35-38	7,916	5,380,703	9	0.167
1988	36-39	8,255	5,593,698	6	0.107
1988	37-40	8,542	5,752,222	6	0.104
1988	38-41	8,953	6,009,490	6	0.100
1988	39-42	8,974	5,991,051	8	0.134
1988	40-43	8,553	5,679,119	7	0.123
1988	41-44	8,036	5,299,917	7	0.132
1988	42-45	7,613	4,987,353	7	0.140
1988	43-46	7,768	5,069,887	7	0.138
1988	44-47	8,029	5,216,229	5	0.096
1988	45-48	8,420	5,442,038	6	0.110
1988	46-49	8,605	5,557,045	6	0.108
1988	47-50	8,388	5,410,100	5	0.092
1988	48-51	8,086	5,228,694	7	0.134
1988	49-52	7,603	4,943,453	10	0.202
1988	50-53	6,937	4,507,871	10	0.222
1988	51-54	6,385	4,158,280	12	0.289
1988	52-55	5,866	3,822,857	12	0.314
1988	53-56	5,300	3,456,391	8	0.231
1988	54-57	4,593	3,007,491	8	0.266
1988	55-58	3,876	2,554,525	9	0.352
1988	56-59	3,146	2,084,438	9	0.432
1988	60-63	406	249,819	0	0.000
1989	21-24	461	361,594	2	0.553
1989	22-25	1,016	795,274	2	0.251
1989	23-26	1,814	1,411,780	3	0.212

1989	24-27	2,732	2,103,506	6	0.285
1989	25-28	3,649	2,761,557	7	0.253
1989	26-29	4,486	3,305,150	11	0.333
1989	27-30	5,272	3,781,292	14	0.370
1989	28-31	6,186	4,343,134	14	0.322
1989	29-32	7,061	4,857,836	17	0.350
1989	30-33	7,912	5,378,722	16	0.297
1989	31-34	8,519	5,759,971	15	0.260
1989	32-35	8,638	5,807,717	12	0.207
1989	33-36	8,406	5,643,608	11	0.195
1989	34-37	8,195	5,512,600	10	0.181
1989	35-38	7,999	5,353,996	12	0.224
1989	36-39	8,001	5,334,792	13	0.244
1989	37-40	8,308	5,508,808	9	0.163
1989	38-41	8,547	5,626,468	10	0.178
1989	39-42	8,959	5,864,089	5	0.085
1989	40-43	9,064	5,875,191	7	0.119
1989	41-44	8,771	5,614,164	9	0.160
1989	42-45	8,310	5,250,790	9	0.171
1989	43-46	7,938	4,965,087	10	0.201
1989	44-47	7,955	4,941,771	10	0.202
1989	45-48	8,099	5,028,668	9	0.179
1989	46-49	8,432	5,244,004	8	0.153
1989	47-50	8,534	5,333,337	8	0.150
1989	48-51	8,319	5,220,200	5	0.096
1989	49-52	8,007	5,039,775	6	0.119
1989	50-53	7,503	4,736,476	5	0.106
1989	51-54	6,803	4,297,964	5	0.116
1989	52-55	6,219	3,942,352	4	0.101
1989	53-56	5,643	3,585,480	3	0.084
1989	54-57	5,041	3,212,414	4	0.125
1989	55-58	4,351	2,772,293	4	0.144
1989	56-59	3,629	2,335,763	5	0.214
1989	60-63	485	290,027	3	1.034
1990	21-24	529	397,560	3	0.755
1990	22-25	1,152	884,197	4	0.452
1990	23-26	1,981	1,507,015	5	0.332
1990	24-27	2,916	2,196,099	5	0.228
1990	25-28	3,751	2,781,674	2	0.072
1990	26-29	4,608	3,335,599	2	0.060
1990	27-30	5,512	3,903,962	1	0.026
1990	28-31	6,427	4,464,980	3	0.067
1990	29-32	7,405	5,071,367	4	0.079
1990	30-33	8,315	5,624,601	3	0.053
1990	31-34	9,057	6,089,904	6	0.099

1990	32-35	9,398	6,279,839	6	0.096
1990	33-36	9,423	6,289,079	7	0.111
1990	34-37	9,064	6,047,258	10	0.165
1990	35-38	8,684	5,777,599	13	0.225
1990	36-39	8,483	5,627,059	13	0.231
1990	37-40	8,372	5,493,246	15	0.273
1990	38-41	8,663	5,641,067	13	0.230
1990	39-42	8,939	5,771,511	10	0.173
1990	40-43	9,420	6,039,911	10	0.166
1990	41-44	9,613	6,130,930	7	0.114
1990	42-45	9,353	5,933,227	8	0.135
1990	43-46	8,878	5,603,461	7	0.125
1990	44-47	8,330	5,227,614	6	0.115
1990	45-48	8,239	5,144,704	8	0.155
1990	46-49	8,295	5,172,183	8	0.155
1990	47-50	8,533	5,315,155	7	0.132
1990	48-51	8,616	5,378,860	7	0.130
1990	49-52	8,306	5,200,648	5	0.096
1990	50-53	7,902	4,957,814	4	0.081
1990	51-54	7,357	4,626,771	5	0.108
1990	52-55	6,634	4,182,201	4	0.096
1990	53-56	5,996	3,802,218	5	0.132
1990	54-57	5,382	3,411,996	5	0.147
1990	55-58	4,758	3,026,766	3	0.099
1990	56-59	4,030	2,571,128	4	0.156
1990	60-63	601	355,034	0	0.000
1991	21-24	416	304,779	0	0.000
1991	22-25	960	716,919	0	0.000
1991	23-26	1,739	1,288,638	1	0.078
1991	24-27	2,677	1,970,146	3	0.152
1991	25-28	3,608	2,623,704	6	0.229
1991	26-29	4,539	3,235,426	10	0.309
1991	27-30	5,546	3,854,664	11	0.285
1991	28-31	6,672	4,543,984	14	0.308
1991	29-32	7,754	5,204,639	12	0.231
1991	30-33	8,929	5,960,189	10	0.168
1991	31-34	9,833	6,539,154	8	0.122
1991	32-35	10,403	6,901,083	8	0.116
1991	33-36	10,554	6,987,856	8	0.114
1991	34-37	10,294	6,814,350	9	0.132
1991	35-38	9,815	6,476,886	13	0.201
1991	36-39	9,360	6,155,163	15	0.244
1991	37-40	9,044	5,925,316	14	0.236
1991	38-41	8,831	5,707,877	14	0.245
1991	39-42	8,977	5,761,966	10	0.174

1991	40-43	9,146	5,812,811	5	0.086
1991	41-44	9,635	6,085,023	9	0.148
1991	42-45	9,876	6,215,026	7	0.113
1991	43-46	9,542	6,001,971	8	0.133
1991	44-47	8,977	5,648,050	8	0.142
1991	45-48	8,326	5,212,637	8	0.153
1991	46-49	8,074	5,033,328	8	0.159
1991	47-50	8,056	5,009,126	10	0.200
1991	48-51	8,267	5,120,290	10	0.195
1991	49-52	8,310	5,141,116	7	0.136
1991	50-53	7,997	4,951,111	6	0.121
1991	51-54	7,633	4,723,047	5	0.106
1991	52-55	7,049	4,378,326	4	0.091
1991	53-56	6,293	3,915,283	3	0.077
1991	54-57	5,634	3,533,452	4	0.113
1991	55-58	5,010	3,140,621	3	0.096
1991	56-59	4,377	2,754,730	3	0.109
1991	60-63	667	375,092	1	0.267
1992	21-24	337	238,051	0	0.000
1992	22-25	819	594,120	0	0.000
1992	23-26	1,532	1,120,857	2	0.178
1992	24-27	2,398	1,743,139	3	0.172
1992	25-28	3,317	2,379,650	3	0.126
1992	26-29	4,283	3,004,462	6	0.200
1992	27-30	5,331	3,642,650	8	0.220
1992	28-31	6,480	4,321,846	13	0.301
1992	29-32	7,702	5,047,000	14	0.277
1992	30-33	8,817	5,722,794	15	0.262
1992	31-34	9,823	6,386,273	12	0.188
1992	32-35	10,473	6,836,948	9	0.132
1992	33-36	10,846	7,099,589	11	0.155
1992	34-37	10,789	7,068,314	8	0.113
1992	35-38	10,483	6,853,749	7	0.102
1992	36-39	10,000	6,517,982	5	0.077
1992	37-40	9,415	6,119,211	3	0.049
1992	38-41	9,037	5,879,485	5	0.085
1992	39-42	8,765	5,664,181	5	0.088
1992	40-43	8,926	5,716,853	5	0.087
1992	41-44	9,154	5,845,267	9	0.154
1992	42-45	9,678	6,152,508	8	0.130
1992	43-46	9,866	6,277,446	8	0.127
1992	44-47	9,454	6,032,214	9	0.149
1992	45-48	8,835	5,629,772	5	0.089
1992	46-49	8,140	5,141,031	3	0.058
1992	47-50	7,861	4,909,079	3	0.061

1992	48-51	7,793	4,830,778	2	0.041
1992	49-52	7,986	4,922,106	1	0.020
1992	50-53	7,967	4,924,350	5	0.102
1992	51-54	7,660	4,727,265	6	0.127
1992	52-55	7,259	4,494,345	6	0.134
1992	53-56	6,620	4,101,182	6	0.146
1992	54-57	5,862	3,629,284	2	0.055
1992	55-58	5,158	3,218,681	1	0.031
1992	56-59	4,498	2,806,652	3	0.107
1992	60-63	799	473,099	1	0.211
1993	21-24	168	122,962	0	0.000
1993	22-25	445	331,997	3	0.904
1993	23-26	899	667,281	4	0.599
1993	24-27	1,535	1,151,389	8	0.695
1993	25-28	2,268	1,680,773	8	0.476
1993	26-29	3,060	2,223,256	8	0.360
1993	27-30	3,823	2,729,716	11	0.403
1993	28-31	4,616	3,225,348	10	0.310
1993	29-32	5,536	3,780,253	10	0.265
1993	30-33	6,502	4,369,040	8	0.183
1993	31-34	7,520	4,987,595	5	0.100
1993	32-35	8,362	5,520,160	5	0.091
1993	33-36	8,790	5,785,742	6	0.104
1993	34-37	9,069	5,957,903	6	0.101
1993	35-38	8,945	5,884,818	7	0.119
1993	36-39	8,797	5,763,131	4	0.069
1993	37-40	8,546	5,600,672	4	0.071
1993	38-41	8,186	5,351,797	4	0.075
1993	39-42	7,961	5,189,541	3	0.058
1993	40-43	7,790	5,044,329	6	0.119
1993	41-44	8,004	5,156,751	6	0.116
1993	42-45	8,280	5,351,746	6	0.112
1993	43-46	8,793	5,682,837	7	0.123
1993	44-47	8,950	5,823,379	5	0.086
1993	45-48	8,547	5,558,243	5	0.090
1993	46-49	7,951	5,148,845	5	0.097
1993	47-50	7,337	4,706,085	5	0.106
1993	48-51	7,126	4,523,488	4	0.088
1993	49-52	7,106	4,500,188	6	0.133
1993	50-53	7,354	4,638,402	6	0.129
1993	51-54	7,397	4,672,152	5	0.107
1993	52-55	7,093	4,469,122	7	0.157
1993	53-56	6,720	4,232,397	5	0.118
1993	54-57	6,070	3,821,568	4	0.105
1993	55-58	5,297	3,340,977	5	0.150

1993	56-59	4,610	2,933,656	5	0.170
1993	60-63	772	466,342	0	0.000
1994	21-24	182	135,920	0	0.000
1994	22-25	424	319,121	1	0.313
1994	23-26	834	627,610	1	0.159
1994	24-27	1,293	986,049	2	0.203
1994	25-28	1,843	1,401,124	7	0.500
1994	26-29	2,417	1,814,319	9	0.496
1994	27-30	3,012	2,215,146	10	0.451
1994	28-31	3,688	2,655,904	11	0.414
1994	29-32	4,382	3,104,428	8	0.258
1994	30-33	5,174	3,601,699	9	0.250
1994	31-34	6,009	4,125,855	10	0.242
1994	32-35	6,814	4,633,102	11	0.237
1994	33-36	7,486	5,035,873	12	0.238
1994	34-37	7,958	5,314,992	9	0.169
1994	35-38	8,245	5,479,941	9	0.164
1994	36-39	8,230	5,439,590	6	0.110
1994	37-40	8,150	5,369,436	5	0.093
1994	38-41	7,869	5,186,297	5	0.096
1994	39-42	7,554	4,986,203	3	0.060
1994	40-43	7,357	4,849,406	4	0.082
1994	41-44	7,225	4,752,203	3	0.063
1994	42-45	7,458	4,892,236	4	0.082
1994	43-46	7,766	5,086,443	5	0.098
1994	44-47	8,188	5,367,413	4	0.075
1994	45-48	8,351	5,476,955	6	0.110
1994	46-49	7,996	5,241,985	9	0.172
1994	47-50	7,416	4,853,409	8	0.165
1994	48-51	6,889	4,484,921	10	0.223
1994	49-52	6,691	4,329,756	8	0.185
1994	50-53	6,691	4,323,594	7	0.162
1994	51-54	6,886	4,435,480	8	0.180
1994	52-55	6,905	4,449,333	8	0.180
1994	53-56	6,563	4,236,736	7	0.165
1994	54-57	6,146	3,956,825	4	0.101
1994	55-58	5,520	3,546,563	4	0.113
1994	56-59	4,731	3,047,339	5	0.164
1994	60-63	633	383,252	0	0.000
1995	21-24	206	155,750	0	0.000
1995	22-25	570	436,145	0	0.000
1995	23-26	1,094	836,742	0	0.000
1995	24-27	1,744	1,333,346	2	0.150
1995	25-28	2,409	1,836,314	3	0.163
1995	26-29	3,078	2,311,053	4	0.173

1995	27-30	3,758	2,772,472	7	0.252
1995	28-31	4,480	3,222,349	6	0.186
1995	29-32	5,318	3,738,010	7	0.187
1995	30-33	6,223	4,272,046	7	0.164
1995	31-34	7,306	4,919,082	6	0.122
1995	32-35	8,321	5,559,954	7	0.126
1995	33-36	9,072	6,035,204	5	0.083
1995	34-37	9,820	6,535,366	5	0.077
1995	35-38	10,233	6,822,416	4	0.059
1995	36-39	10,536	7,007,150	8	0.114
1995	37-40	10,561	7,010,135	8	0.114
1995	38-41	10,115	6,717,851	8	0.119
1995	39-42	9,503	6,314,631	7	0.111
1995	40-43	8,845	5,884,493	1	0.017
1995	41-44	8,406	5,593,047	3	0.054
1995	42-45	8,239	5,469,039	2	0.037
1995	43-46	8,375	5,544,301	4	0.072
1995	44-47	8,553	5,659,973	6	0.106
1995	45-48	9,021	5,976,299	6	0.100
1995	46-49	9,180	6,074,302	8	0.132
1995	47-50	8,774	5,781,777	7	0.121
1995	48-51	8,184	5,397,117	10	0.185
1995	49-52	7,505	4,919,486	8	0.163
1995	50-53	7,150	4,669,722	8	0.171
1995	51-54	7,036	4,612,894	8	0.173
1995	52-55	7,148	4,658,345	7	0.150
1995	53-56	7,020	4,577,578	10	0.218
1995	54-57	6,598	4,297,563	10	0.233
1995	55-58	6,139	3,987,313	10	0.251
1995	56-59	5,457	3,539,431	8	0.226
1995	60-63	937	573,308	0	0.000
1996	21-24	214	158,538	0	0.000
1996	22-25	542	405,380	0	0.000
1996	23-26	1,081	806,563	0	0.000
1996	24-27	1,730	1,307,880	1	0.076
1996	25-28	2,449	1,840,417	2	0.109
1996	26-29	3,088	2,295,983	3	0.131
1996	27-30	3,756	2,751,670	9	0.327
1996	28-31	4,381	3,122,921	11	0.352
1996	29-32	5,100	3,540,371	13	0.367
1996	30-33	6,000	4,073,056	12	0.295
1996	31-34	6,927	4,637,230	7	0.151
1996	32-35	7,969	5,260,742	7	0.133
1996	33-36	8,836	5,802,432	5	0.086
1996	34-37	9,491	6,225,890	8	0.128

1996	35-38	10,102	6,602,021	9	0.136
1996	36-39	10,450	6,839,787	6	0.088
1996	37-40	10,707	7,023,192	9	0.128
1996	38-41	10,595	6,939,873	7	0.101
1996	39-42	10,087	6,620,191	9	0.136
1996	40-43	9,489	6,239,359	13	0.208
1996	41-44	8,929	5,855,603	10	0.171
1996	42-45	8,605	5,661,355	9	0.159
1996	43-46	8,457	5,564,639	11	0.198
1996	44-47	8,559	5,622,653	10	0.178
1996	45-48	8,701	5,729,171	12	0.209
1996	46-49	9,093	5,988,430	17	0.284
1996	47-50	9,207	6,056,094	13	0.215
1996	48-51	8,785	5,803,652	13	0.224
1996	49-52	8,144	5,392,735	11	0.204
1996	50-53	7,436	4,920,613	8	0.163
1996	51-54	7,084	4,673,644	8	0.171
1996	52-55	6,970	4,583,747	10	0.218
1996	53-56	7,014	4,601,218	12	0.261
1996	54-57	6,841	4,463,421	11	0.246
1996	55-58	6,388	4,174,666	13	0.311
1996	56-59	5,849	3,819,637	8	0.209
1996	60-63	1,057	644,407	4	0.621
1997	21-24	220	167,918	0	0.000
1997	22-25	508	387,363	1	0.258
1997	23-26	966	737,610	1	0.136
1997	24-27	1,630	1,238,915	2	0.161
1997	25-28	2,265	1,701,372	2	0.118
1997	26-29	2,925	2,168,354	2	0.092
1997	27-30	3,491	2,537,116	2	0.079
1997	28-31	4,041	2,874,823	5	0.174
1997	29-32	4,716	3,257,870	6	0.184
1997	30-33	5,408	3,658,415	9	0.246
1997	31-34	6,205	4,119,549	10	0.243
1997	32-35	6,971	4,584,419	7	0.153
1997	33-36	7,698	5,045,463	7	0.139
1997	34-37	8,402	5,490,621	4	0.073
1997	35-38	8,964	5,870,671	8	0.136
1997	36-39	9,507	6,212,078	9	0.145
1997	37-40	9,838	6,409,440	14	0.218
1997	38-41	9,980	6,497,147	16	0.246
1997	39-42	9,898	6,432,181	16	0.249
1997	40-43	9,514	6,177,562	14	0.227
1997	41-44	9,020	5,872,414	13	0.221
1997	42-45	8,626	5,590,475	11	0.197

1997	43-46	8,345	5,416,108	7	0.129
1997	44-47	8,168	5,288,464	9	0.170
1997	45-48	8,272	5,368,133	8	0.149
1997	46-49	8,416	5,503,574	9	0.164
1997	47-50	8,831	5,780,376	11	0.190
1997	48-51	8,957	5,872,112	10	0.170
1997	49-52	8,589	5,628,539	13	0.231
1997	50-53	7,975	5,225,932	11	0.210
1997	51-54	7,233	4,731,505	10	0.211
1997	52-55	6,841	4,474,862	14	0.313
1997	53-56	6,626	4,329,700	9	0.208
1997	54-57	6,559	4,277,081	13	0.304
1997	55-58	6,302	4,114,499	14	0.340
1997	56-59	5,738	3,752,936	11	0.293
1997	60-63	901	545,285	2	0.367

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	21-24	507	402,345	0	0.000
1988	22-25	1,128	905,883	0	0.000
1988	23-26	1,949	1,543,338	3	0.194
1988	24-27	2,930	2,280,336	7	0.307
1988	25-28	3,816	2,897,134	10	0.345
1988	26-29	4,577	3,392,324	11	0.324
1988	27-30	5,424	3,948,187	8	0.203
1988	28-31	6,238	4,434,135	8	0.180
1988	29-32	7,004	4,893,901	7	0.143
1988	30-33	7,614	5,267,573	9	0.171
1988	31-34	7,967	5,448,100	9	0.165
1988	32-35	7,947	5,413,751	11	0.203
1988	33-36	7,908	5,406,122	10	0.185
1988	34-37	7,905	5,378,840	9	0.167
1988	35-38	7,916	5,380,703	9	0.167
1988	36-39	8,255	5,593,698	6	0.107
1988	37-40	8,542	5,752,222	6	0.104
1988	38-41	8,953	6,009,490	6	0.100
1988	39-42	8,974	5,991,051	8	0.134
1988	40-43	8,553	5,679,119	7	0.123
1988	41-44	8,036	5,299,917	7	0.132
1988	42-45	7,613	4,987,353	7	0.140
1988	43-46	7,768	5,069,887	7	0.138
1988	44-47	8,029	5,216,229	5	0.096
1988	45-48	8,420	5,442,038	6	0.110
1988	46-49	8,605	5,557,045	6	0.108
1988	47-50	8,388	5,410,100	5	0.092
1988	48-51	8,086	5,228,694	7	0.134
1988	49-52	7,603	4,943,453	10	0.202
1988	50-53	6,937	4,507,871	10	0.222
1988	51-54	6,385	4,158,280	12	0.289
1988	52-55	5,866	3,822,857	12	0.314
1988	53-56	5,300	3,456,391	8	0.231
1988	54-57	4,593	3,007,491	8	0.266
1988	55-58	3,876	2,554,525	9	0.352
1988	56-59	3,146	2,084,438	9	0.432
1988	57-60	2,316	1,546,564	8	0.517
1988	58-61	1,578	1,050,593	6	0.571
1988	59-62	887	574,842	2	0.348

1988	60-63	406	249,819	0	0.000
1989	21-24	461	361,594	2	0.553
1989	22-25	1,016	795,274	2	0.251
1989	23-26	1,814	1,411,780	3	0.212
1989	24-27	2,732	2,103,506	6	0.285
1989	25-28	3,649	2,761,557	7	0.253
1989	26-29	4,486	3,305,150	11	0.333
1989	27-30	5,272	3,781,292	14	0.370
1989	28-31	6,186	4,343,134	14	0.322
1989	29-32	7,061	4,857,836	17	0.350
1989	30-33	7,912	5,378,722	16	0.297
1989	31-34	8,519	5,759,971	15	0.260
1989	32-35	8,638	5,807,717	12	0.207
1989	33-36	8,406	5,643,608	11	0.195
1989	34-37	8,195	5,512,600	10	0.181
1989	35-38	7,999	5,353,996	12	0.224
1989	36-39	8,001	5,334,792	13	0.244
1989	37-40	8,308	5,508,808	9	0.163
1989	38-41	8,547	5,626,468	10	0.178
1989	39-42	8,959	5,864,089	5	0.085
1989	40-43	9,064	5,875,191	7	0.119
1989	41-44	8,771	5,614,164	9	0.160
1989	42-45	8,310	5,250,790	9	0.171
1989	43-46	7,938	4,965,087	10	0.201
1989	44-47	7,955	4,941,771	10	0.202
1989	45-48	8,099	5,028,668	9	0.179
1989	46-49	8,432	5,244,004	8	0.153
1989	47-50	8,534	5,333,337	8	0.150
1989	48-51	8,319	5,220,200	5	0.096
1989	49-52	8,007	5,039,775	6	0.119
1989	50-53	7,503	4,736,476	5	0.106
1989	51-54	6,803	4,297,964	5	0.116
1989	52-55	6,219	3,942,352	4	0.101
1989	53-56	5,643	3,585,480	3	0.084
1989	54-57	5,041	3,212,414	4	0.125
1989	55-58	4,351	2,772,293	4	0.144
1989	56-59	3,629	2,335,763	5	0.214
1989	57-60	2,803	1,809,206	5	0.276
1989	58-61	1,832	1,182,666	4	0.338
1989	59-62	1,129	727,236	4	0.550
1989	60-63	485	290,027	3	1.034
1990	21-24	529	397,560	3	0.755
1990	22-25	1,152	884,197	4	0.452
1990	23-26	1,981	1,507,015	5	0.332
1990	24-27	2,916	2,196,099	5	0.228

1990	25-28	3,751	2,781,674	2	0.072
1990	26-29	4,608	3,335,599	2	0.060
1990	27-30	5,512	3,903,962	1	0.026
1990	28-31	6,427	4,464,980	3	0.067
1990	29-32	7,405	5,071,367	4	0.079
1990	30-33	8,315	5,624,601	3	0.053
1990	31-34	9,057	6,089,904	6	0.099
1990	32-35	9,398	6,279,839	6	0.096
1990	33-36	9,423	6,289,079	7	0.111
1990	34-37	9,064	6,047,258	10	0.165
1990	35-38	8,684	5,777,599	13	0.225
1990	36-39	8,483	5,627,059	13	0.231
1990	37-40	8,372	5,493,246	15	0.273
1990	38-41	8,663	5,641,067	13	0.230
1990	39-42	8,939	5,771,511	10	0.173
1990	40-43	9,420	6,039,911	10	0.166
1990	41-44	9,613	6,130,930	7	0.114
1990	42-45	9,353	5,933,227	8	0.135
1990	43-46	8,878	5,603,461	7	0.125
1990	44-47	8,330	5,227,614	6	0.115
1990	45-48	8,239	5,144,704	8	0.155
1990	46-49	8,295	5,172,183	8	0.155
1990	47-50	8,533	5,315,155	7	0.132
1990	48-51	8,616	5,378,860	7	0.130
1990	49-52	8,306	5,200,648	5	0.096
1990	50-53	7,902	4,957,814	4	0.081
1990	51-54	7,357	4,626,771	5	0.108
1990	52-55	6,634	4,182,201	4	0.096
1990	53-56	5,996	3,802,218	5	0.132
1990	54-57	5,382	3,411,996	5	0.147
1990	55-58	4,758	3,026,766	3	0.099
1990	56-59	4,030	2,571,128	4	0.156
1990	57-60	3,143	1,997,138	2	0.100
1990	58-61	2,143	1,351,542	1	0.074
1990	59-62	1,226	762,230	1	0.131
1990	60-63	601	355,034	0	0.000
1991	21-24	416	304,779	0	0.000
1991	22-25	960	716,919	0	0.000
1991	23-26	1,739	1,288,638	1	0.078
1991	24-27	2,677	1,970,146	3	0.152
1991	25-28	3,608	2,623,704	6	0.229
1991	26-29	4,539	3,235,426	10	0.309
1991	27-30	5,546	3,854,664	11	0.285
1991	28-31	6,672	4,543,984	14	0.308
1991	29-32	7,754	5,204,639	12	0.231

1991	30-33	8,929	5,960,189	10	0.168
1991	31-34	9,833	6,539,154	8	0.122
1991	32-35	10,403	6,901,083	8	0.116
1991	33-36	10,554	6,987,856	8	0.114
1991	34-37	10,294	6,814,350	9	0.132
1991	35-38	9,815	6,476,886	13	0.201
1991	36-39	9,360	6,155,163	15	0.244
1991	37-40	9,044	5,925,316	14	0.236
1991	38-41	8,831	5,707,877	14	0.245
1991	39-42	8,977	5,761,966	10	0.174
1991	40-43	9,146	5,812,811	5	0.086
1991	41-44	9,635	6,085,023	9	0.148
1991	42-45	9,876	6,215,026	7	0.113
1991	43-46	9,542	6,001,971	8	0.133
1991	44-47	8,977	5,648,050	8	0.142
1991	45-48	8,326	5,212,637	8	0.153
1991	46-49	8,074	5,033,328	8	0.159
1991	47-50	8,056	5,009,126	10	0.200
1991	48-51	8,267	5,120,290	10	0.195
1991	49-52	8,310	5,141,116	7	0.136
1991	50-53	7,997	4,951,111	6	0.121
1991	51-54	7,633	4,723,047	5	0.106
1991	52-55	7,049	4,378,326	4	0.091
1991	53-56	6,293	3,915,283	3	0.077
1991	54-57	5,634	3,533,452	4	0.113
1991	55-58	5,010	3,140,621	3	0.096
1991	56-59	4,377	2,754,730	3	0.109
1991	57-60	3,515	2,220,767	3	0.135
1991	58-61	2,428	1,500,041	2	0.133
1991	59-62	1,488	909,658	2	0.220
1991	60-63	667	375,092	1	0.267
1992	21-24	337	238,051	0	0.000
1992	22-25	819	594,120	0	0.000
1992	23-26	1,532	1,120,857	2	0.178
1992	24-27	2,398	1,743,139	3	0.172
1992	25-28	3,317	2,379,650	3	0.126
1992	26-29	4,283	3,004,462	6	0.200
1992	27-30	5,331	3,642,650	8	0.220
1992	28-31	6,480	4,321,846	13	0.301
1992	29-32	7,702	5,047,000	14	0.277
1992	30-33	8,817	5,722,794	15	0.262
1992	31-34	9,823	6,386,273	12	0.188
1992	32-35	10,473	6,836,948	9	0.132
1992	33-36	10,846	7,099,589	11	0.155
1992	34-37	10,789	7,068,314	8	0.113

1992	35-38	10,483	6,853,749	7	0.102
1992	36-39	10,000	6,517,982	5	0.077
1992	37-40	9,415	6,119,211	3	0.049
1992	38-41	9,037	5,879,485	5	0.085
1992	39-42	8,765	5,664,181	5	0.088
1992	40-43	8,926	5,716,853	5	0.087
1992	41-44	9,154	5,845,267	9	0.154
1992	42-45	9,678	6,152,508	8	0.130
1992	43-46	9,866	6,277,446	8	0.127
1992	44-47	9,454	6,032,214	9	0.149
1992	45-48	8,835	5,629,772	5	0.089
1992	46-49	8,140	5,141,031	3	0.058
1992	47-50	7,861	4,909,079	3	0.061
1992	48-51	7,793	4,830,778	2	0.041
1992	49-52	7,986	4,922,106	1	0.020
1992	50-53	7,967	4,924,350	5	0.102
1992	51-54	7,660	4,727,265	6	0.127
1992	52-55	7,259	4,494,345	6	0.134
1992	53-56	6,620	4,101,182	6	0.146
1992	54-57	5,862	3,629,284	2	0.055
1992	55-58	5,158	3,218,681	1	0.031
1992	56-59	4,498	2,806,652	3	0.107
1992	57-60	3,712	2,322,724	3	0.129
1992	58-61	2,629	1,635,631	3	0.183
1992	59-62	1,620	993,932	4	0.402
1992	60-63	799	473,099	1	0.211
1993	21-24	168	122,962	0	0.000
1993	22-25	445	331,997	3	0.904
1993	23-26	899	667,281	4	0.599
1993	24-27	1,535	1,151,389	8	0.695
1993	25-28	2,268	1,680,773	8	0.476
1993	26-29	3,060	2,223,256	8	0.360
1993	27-30	3,823	2,729,716	11	0.403
1993	28-31	4,616	3,225,348	10	0.310
1993	29-32	5,536	3,780,253	10	0.265
1993	30-33	6,502	4,369,040	8	0.183
1993	31-34	7,520	4,987,595	5	0.100
1993	32-35	8,362	5,520,160	5	0.091
1993	33-36	8,790	5,785,742	6	0.104
1993	34-37	9,069	5,957,903	6	0.101
1993	35-38	8,945	5,884,818	7	0.119
1993	36-39	8,797	5,763,131	4	0.069
1993	37-40	8,546	5,600,672	4	0.071
1993	38-41	8,186	5,351,797	4	0.075
1993	39-42	7,961	5,189,541	3	0.058

1993	40-43	7,790	5,044,329	6	0.119
1993	41-44	8,004	5,156,751	6	0.116
1993	42-45	8,280	5,351,746	6	0.112
1993	43-46	8,793	5,682,837	7	0.123
1993	44-47	8,950	5,823,379	5	0.086
1993	45-48	8,547	5,558,243	5	0.090
1993	46-49	7,951	5,148,845	5	0.097
1993	47-50	7,337	4,706,085	5	0.106
1993	48-51	7,126	4,523,488	4	0.088
1993	49-52	7,106	4,500,188	6	0.133
1993	50-53	7,354	4,638,402	6	0.129
1993	51-54	7,397	4,672,152	5	0.107
1993	52-55	7,093	4,469,122	7	0.157
1993	53-56	6,720	4,232,397	5	0.118
1993	54-57	6,070	3,821,568	4	0.105
1993	55-58	5,297	3,340,977	5	0.150
1993	56-59	4,610	2,933,656	5	0.170
1993	57-60	3,764	2,404,608	4	0.166
1993	58-61	2,658	1,692,690	4	0.236
1993	59-62	1,658	1,053,224	2	0.190
1993	60-63	772	466,342	0	0.000
1994	21-24	182	135,920	0	0.000
1994	22-25	424	319,121	1	0.313
1994	23-26	834	627,610	1	0.159
1994	24-27	1,293	986,049	2	0.203
1994	25-28	1,843	1,401,124	7	0.500
1994	26-29	2,417	1,814,319	9	0.496
1994	27-30	3,012	2,215,146	10	0.451
1994	28-31	3,688	2,655,904	11	0.414
1994	29-32	4,382	3,104,428	8	0.258
1994	30-33	5,174	3,601,699	9	0.250
1994	31-34	6,009	4,125,855	10	0.242
1994	32-35	6,814	4,633,102	11	0.237
1994	33-36	7,486	5,035,873	12	0.238
1994	34-37	7,958	5,314,992	9	0.169
1994	35-38	8,245	5,479,941	9	0.164
1994	36-39	8,230	5,439,590	6	0.110
1994	37-40	8,150	5,369,436	5	0.093
1994	38-41	7,869	5,186,297	5	0.096
1994	39-42	7,554	4,986,203	3	0.060
1994	40-43	7,357	4,849,406	4	0.082
1994	41-44	7,225	4,752,203	3	0.063
1994	42-45	7,458	4,892,236	4	0.082
1994	43-46	7,766	5,086,443	5	0.098
1994	44-47	8,188	5,367,413	4	0.075

1994	45-48	8,351	5,476,955	6	0.110
1994	46-49	7,996	5,241,985	9	0.172
1994	47-50	7,416	4,853,409	8	0.165
1994	48-51	6,889	4,484,921	10	0.223
1994	49-52	6,691	4,329,756	8	0.185
1994	50-53	6,691	4,323,594	7	0.162
1994	51-54	6,886	4,435,480	8	0.180
1994	52-55	6,905	4,449,333	8	0.180
1994	53-56	6,563	4,236,736	7	0.165
1994	54-57	6,146	3,956,825	4	0.101
1994	55-58	5,520	3,546,563	4	0.113
1994	56-59	4,731	3,047,339	5	0.164
1994	57-60	3,682	2,363,837	5	0.212
1994	58-61	2,519	1,607,139	4	0.249
1994	59-62	1,492	950,268	3	0.316
1994	60-63	633	383,252	0	0.000
1995	21-24	206	155,750	0	0.000
1995	22-25	570	436,145	0	0.000
1995	23-26	1,094	836,742	0	0.000
1995	24-27	1,744	1,333,346	2	0.150
1995	25-28	2,409	1,836,314	3	0.163
1995	26-29	3,078	2,311,053	4	0.173
1995	27-30	3,758	2,772,472	7	0.252
1995	28-31	4,480	3,222,349	6	0.186
1995	29-32	5,318	3,738,010	7	0.187
1995	30-33	6,223	4,272,046	7	0.164
1995	31-34	7,306	4,919,082	6	0.122
1995	32-35	8,321	5,559,954	7	0.126
1995	33-36	9,072	6,035,204	5	0.083
1995	34-37	9,820	6,535,366	5	0.077
1995	35-38	10,233	6,822,416	4	0.059
1995	36-39	10,536	7,007,150	8	0.114
1995	37-40	10,561	7,010,135	8	0.114
1995	38-41	10,115	6,717,851	8	0.119
1995	39-42	9,503	6,314,631	7	0.111
1995	40-43	8,845	5,884,493	1	0.017
1995	41-44	8,406	5,593,047	3	0.054
1995	42-45	8,239	5,469,039	2	0.037
1995	43-46	8,375	5,544,301	4	0.072
1995	44-47	8,553	5,659,973	6	0.106
1995	45-48	9,021	5,976,299	6	0.100
1995	46-49	9,180	6,074,302	8	0.132
1995	47-50	8,774	5,781,777	7	0.121
1995	48-51	8,184	5,397,117	10	0.185
1995	49-52	7,505	4,919,486	8	0.163

1995	50-53	7,150	4,669,722	8	0.171
1995	51-54	7,036	4,612,894	8	0.173
1995	52-55	7,148	4,658,345	7	0.150
1995	53-56	7,020	4,577,578	10	0.218
1995	54-57	6,598	4,297,563	10	0.233
1995	55-58	6,139	3,987,313	10	0.251
1995	56-59	5,457	3,539,431	8	0.226
1995	57-60	4,410	2,858,287	5	0.175
1995	58-61	3,119	2,002,539	3	0.150
1995	59-62	1,961	1,239,646	2	0.161
1995	60-63	937	573,308	0	0.000
1996	21-24	214	158,538	0	0.000
1996	22-25	542	405,380	0	0.000
1996	23-26	1,081	806,563	0	0.000
1996	24-27	1,730	1,307,880	1	0.076
1996	25-28	2,449	1,840,417	2	0.109
1996	26-29	3,088	2,295,983	3	0.131
1996	27-30	3,756	2,751,670	9	0.327
1996	28-31	4,381	3,122,921	11	0.352
1996	29-32	5,100	3,540,371	13	0.367
1996	30-33	6,000	4,073,056	12	0.295
1996	31-34	6,927	4,637,230	7	0.151
1996	32-35	7,969	5,260,742	7	0.133
1996	33-36	8,836	5,802,432	5	0.086
1996	34-37	9,491	6,225,890	8	0.128
1996	35-38	10,102	6,602,021	9	0.136
1996	36-39	10,450	6,839,787	6	0.088
1996	37-40	10,707	7,023,192	9	0.128
1996	38-41	10,595	6,939,873	7	0.101
1996	39-42	10,087	6,620,191	9	0.136
1996	40-43	9,489	6,239,359	13	0.208
1996	41-44	8,929	5,855,603	10	0.171
1996	42-45	8,605	5,661,355	9	0.159
1996	43-46	8,457	5,564,639	11	0.198
1996	44-47	8,559	5,622,653	10	0.178
1996	45-48	8,701	5,729,171	12	0.209
1996	46-49	9,093	5,988,430	17	0.284
1996	47-50	9,207	6,056,094	13	0.215
1996	48-51	8,785	5,803,652	13	0.224
1996	49-52	8,144	5,392,735	11	0.204
1996	50-53	7,436	4,920,613	8	0.163
1996	51-54	7,084	4,673,644	8	0.171
1996	52-55	6,970	4,583,747	10	0.218
1996	53-56	7,014	4,601,218	12	0.261
1996	54-57	6,841	4,463,421	11	0.246

1996	55-58	6,388	4,174,666	13	0.311
1996	56-59	5,849	3,819,637	8	0.209
1996	57-60	4,865	3,163,921	9	0.284
1996	58-61	3,417	2,212,110	8	0.362
1996	59-62	2,138	1,364,897	4	0.293
1996	60-63	1,057	644,407	4	0.621
1997	21-24	220	167,918	0	0.000
1997	22-25	508	387,363	1	0.258
1997	23-26	966	737,610	1	0.136
1997	24-27	1,630	1,238,915	2	0.161
1997	25-28	2,265	1,701,372	2	0.118
1997	26-29	2,925	2,168,354	2	0.092
1997	27-30	3,491	2,537,116	2	0.079
1997	28-31	4,041	2,874,823	5	0.174
1997	29-32	4,716	3,257,870	6	0.184
1997	30-33	5,408	3,658,415	9	0.246
1997	31-34	6,205	4,119,549	10	0.243
1997	32-35	6,971	4,584,419	7	0.153
1997	33-36	7,698	5,045,463	7	0.139
1997	34-37	8,402	5,490,621	4	0.073
1997	35-38	8,964	5,870,671	8	0.136
1997	36-39	9,507	6,212,078	9	0.145
1997	37-40	9,838	6,409,440	14	0.218
1997	38-41	9,980	6,497,147	16	0.246
1997	39-42	9,898	6,432,181	16	0.249
1997	40-43	9,514	6,177,562	14	0.227
1997	41-44	9,020	5,872,414	13	0.221
1997	42-45	8,626	5,590,475	11	0.197
1997	43-46	8,345	5,416,108	7	0.129
1997	44-47	8,168	5,288,464	9	0.170
1997	45-48	8,272	5,368,133	8	0.149
1997	46-49	8,416	5,503,574	9	0.164
1997	47-50	8,831	5,780,376	11	0.190
1997	48-51	8,957	5,872,112	10	0.170
1997	49-52	8,589	5,628,539	13	0.231
1997	50-53	7,975	5,225,932	11	0.210
1997	51-54	7,233	4,731,505	10	0.211
1997	52-55	6,841	4,474,862	14	0.313
1997	53-56	6,626	4,329,700	9	0.208
1997	54-57	6,559	4,277,081	13	0.304
1997	55-58	6,302	4,114,499	14	0.340
1997	56-59	5,738	3,752,936	11	0.293
1997	57-60	4,786	3,128,738	10	0.320
1997	58-61	3,346	2,168,140	6	0.277
1997	59-62	1,995	1,271,396	3	0.236

1997	60-63	901	545,285	2	0.367

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	5,705	4,298,207	11	0.256
1988	30-34	9,635	6,641,418	9	0.136
1988	35-39	10,155	6,883,483	12	0.174
1988	40-44	10,318	6,828,533	8	0.117
1988	45-49	10,582	6,846,867	8	0.117
1988	50-54	8,376	5,451,138	13	0.238
1988	55-59	4,404	2,904,799	11	0.379
1988	60-63	406	249,819	0	0.000
1989	LE 29	5,502	4,100,424	13	0.317
1989	30-34	10,103	6,852,619	19	0.277
1989	35-39	10,068	6,721,568	14	0.208
1989	40-44	10,983	7,072,956	9	0.127
1989	45-49	10,242	6,365,441	11	0.173
1989	50-54	8,940	5,654,508	6	0.106
1989	55-59	5,021	3,222,372	5	0.155
1989	60-63	485	290,027	3	1.034
1990	LE 29	5,760	4,219,796	6	0.142
1990	30-34	10,790	7,281,085	6	0.082
1990	35-39	10,783	7,145,700	15	0.210
1990	40-44	11,760	7,517,275	11	0.146
1990	45-49	10,357	6,474,276	10	0.154
1990	50-54	9,491	5,957,246	6	0.101
1990	55-59	5,422	3,450,917	4	0.116
1990	60-63	601	355,034	0	0.000
1991	LE 29	5,499	3,952,345	10	0.253
1991	30-34	11,619	7,730,111	10	0.129
1991	35-39	12,089	7,956,308	20	0.251
1991	40-44	11,804	7,492,553	9	0.120
1991	45-49	10,492	6,551,798	9	0.137
1991	50-54	9,638	5,972,337	8	0.134
1991	55-59	5,882	3,697,519	4	0.108
1991	60-63	667	375,092	1	0.267
1992	LE 29	5,102	3,598,582	6	0.167
1992	30-34	11,584	7,551,198	16	0.212
1992	35-39	12,734	8,315,147	8	0.096
1992	40-44	11,351	7,263,841	10	0.138
1992	45-49	10,792	6,833,946	5	0.073
1992	50-54	9,758	6,018,786	6	0.100
1992	55-59	6,029	3,764,269	4	0.106
1992	60-63	799	473,099	1	0.211

1993	LE 29	3,505	2,555,253	11	0.430
1993	30-34	8,737	5,829,339	9	0.154
1993	35-39	11,096	7,296,866	7	0.096
1993	40-44	9,974	6,445,695	7	0.109
1993	45-49	10,181	6,607,431	6	0.091
1993	50-54	9,182	5,785,441	7	0.121
1993	55-59	6,232	3,955,407	7	0.177
1993	60-63	772	466,342	0	0.000
1994	LE 29	2,841	2,133,440	10	0.469
1994	30-34	7,014	4,835,171	11	0.227
1994	35-39	10,214	6,778,028	9	0.133
1994	40-44	9,199	6,052,345	5	0.083
1994	45-49	10,028	6,571,665	11	0.167
1994	50-54	8,426	5,439,438	8	0.147
1994	55-59	6,417	4,134,964	7	0.169
1994	60-63	633	383,252	0	0.000
1995	LE 29	3,648	2,747,198	4	0.146
1995	30-34	8,510	5,781,098	9	0.156
1995	35-39	12,969	8,628,349	10	0.116
1995	40-44	10,845	7,211,815	3	0.042
1995	45-49	11,253	7,447,342	8	0.107
1995	50-54	8,854	5,788,513	9	0.155
1995	55-59	7,235	4,691,689	12	0.256
1995	60-63	937	573,308	0	0.000
1996	LE 29	3,630	2,701,363	3	0.111
1996	30-34	8,134	5,494,100	13	0.237
1996	35-39	12,827	8,379,457	9	0.107
1996	40-44	11,644	7,645,633	14	0.183
1996	45-49	11,179	7,369,414	17	0.231
1996	50-54	9,287	6,122,085	10	0.163
1996	55-59	7,542	4,931,916	13	0.264
1996	60-63	1,057	644,407	4	0.621
1997	LE 29	3,433	2,555,717	3	0.117
1997	30-34	7,229	4,838,558	10	0.207
1997	35-39	11,532	7,548,676	10	0.132
1997	40-44	11,563	7,511,526	19	0.253
1997	45-49	10,508	6,841,472	10	0.146
1997	50-54	9,668	6,329,167	13	0.205
1997	55-59	7,479	4,883,771	16	0.328
1997	60-63	901	545,285	2	0.367