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An Analysis of the U.S. Pilot Population From 1983-2005: Evaluating the Effects of Regulatory Change

Paul B. Rogers
Stephen J.H. Véronneau
Connie L. Peterman
James E. Whinnery
Estrella M. Forster

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

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16. Abstract

Introduction. The size of the U.S. civil aviator community has been of interest to researchers, policy makers, and special interest groups. A strict definition for membership in the U.S. pilot population was used that was based on Scientific Information System principles. This approach provides methods for scientists to describe, quantify, and predict changes in this population over the 23-year study period. The Bioinformatics Research Team at the Civil Aerospace Medical Institute (CAMI) analyzed and modeled the counts of the U.S. pilot population using a segmented linear regression model.
Methods. A dataset was constructed, based upon the methods prescribed by Scientific Information System principles of data construction, from 1983 to 2005. This methodology was selected since the data represent the entire population of pilots, rather than just a sample. Thus, the statistical results are population parameters, rather than estimates, and are not subject to sampling error. The airmen population was constructed and examined for each year of the study period. The criterion for membership of the U.S. civil pilot population is based on the medical examination that each airman must pass to hold a pilot certificate. A segmented linear regression model was chosen because of its flexibility in accounting for any policy changes that occurred over the 23-year study period.
Discussion. The CAMI Scientific Information System provided the foundation to build a segmented linear regression model pertaining to the counts of the U.S. civil pilot population; from these results it was possible for the first time to explain the changing frequencies over time and make fact-based predictions concerning future population numbers. The capability now exists to categorize the population by gender, medical class, age, and experience over a two-decade time period, which may provide hints at some of the changes taking place within the aviation community as a whole.
Conclusion. The model constructed clearly shows a decline in the overall U.S. civil aviator community. This decline is most evident in second-and third-class medical certificate holders. The percentage of women in the largely male-dominated population remained relatively stable over the study years. The age composition of both men and women changed substantially from the beginning of the study in 1983 to the end in 2005. Both segments of this population have grown significantly older. As a group, men were older than women over the study period. Therefore, when average flight time was calculated and categorized by medical class and gender, men were shown to have more flight experience.

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CONTENTS

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Scientific data are not taken for museum purposes; they are taken as a basis for doing something. If nothing is to be done with the data, then there is no use in collecting any. The ultimate purpose of taking data is to provide a basis for action or a recommendation for action. The step intermediate between the collection of data and the action is prediction.

— William Edwards Deming (1)

INTRODUCTION

The demographics of the U.S. general population, of which the U.S. civil pilot population is a subset, have changed considerably over the last several decades. Are the changes observed in the U.S. general population reflected in the nation's civil aviator community? This question interests researchers, regulators, safety policy makers, and special-interest groups. To better examine changes over time, a longitudinal view of the aviator population is needed to analyze the long range effects of regulations, policies, and changing demographics.

Estimates of the U.S. civil pilot population's numbers have suggested that it has been in an overall decline in recent decades (2). Quantifying and modeling changes in the U.S. civil pilot population was conducted to improve the analysis of this decline. A good statistical model will permit researchers to describe the changes in this population and make predictions relative to its future characteristics. The development of this model was based on the data available for the U.S. civil pilot population from 1983 through 2005. A model covering such a large span of time requires flexibility to accommodate any policy changes that have occurred that may affect the length of time an airman could be considered a member of the population. For this reason, a segmented linear regression model was developed to describe the changes in the overall counts of the U.S. civil airman population.

In addition to modeling the size of the U.S. pilot population, this study examined the trends for factors such as gender, age, experience, and differences in the numbers of medical certificates by class. The reasons for changes in these characteristics within the U.S. civil pilot population were also analyzed and discussed at length.

The data for the study period were constructed on Scientific Information System (SIS) principles, as described in *Development of an Aeromedical Scientific Information System for Aviation Safety* (3). The primary purpose of this system was to enhance the feasibility of aviation epidemiological studies by increasing the accuracy of calculating specific disease prevalence over time. Studying the epidemiology of specific diseases or conditions within the U.S. civil pilot population and the corresponding accident/incident outcomes can determine if segments of the population with these conditions are at greater risk of an accident or incident.

BACKGROUND

Aviators who hold a valid medical certificate in a given year are referred to as *active airmen*. A medical certificate, without limitations, allowed an airman to be classified an active airman for as long as two years prior to 1996 and up to three years after 1996. The change in the duration of medical class is based on an FAA policy amendment enacted in 1996 that increased the length of the certificate's validity based upon the airman's age.

The distribution of the U.S. civil aviator community by age, medical class, experience, and gender can further describe the demographic changes occurring over time. In this study, the U.S. civil pilot population was categorized using these variables to define how they have changed over a 23-year period (1983 – 2005). Many researchers have extensively studied age and measures of experience, seeking a correlation between these variables and adverse outcomes such as accidents and incidents.

This study was not the first attempt to examine the active airmen population using existing electronic aviation records. An effort to observe the U.S. civil pilot population using the accessible electronic aviation records of the day was done as early as 1968 by Booze (4). His attempt to merge the existing datasets into a usable, coherent whole was not possible given the technologies of the time. Regarding these restrictions, Booze stated "Both the airman certification and medical certification systems are automated and the obvious solution, which would involve matching the two tape files and categorizing the airman by rating and medical certification status, would greatly simplify the problem. However, this solution is not feasible due to lead/lag considerations, workload considerations and backlogs, incompatibility of input control data under the separate systems, differences in the degree of automation, and further magnification of discrepancies between the two tape systems due to input errors." These limitations required Booze to restrict his study period to examining the U.S. civil pilot population over a single year from October 1, 1966 to October 1, 1967. In 1977, Booze achieved the construction of an epidemiological database by restricting his data to a sampling of the U.S. pilot population for aviation studies but covered a limited time frame (5). Improved computer and database technologies have allowed the successful linking of the numerous existing datasets into a single, coherent database structure. The SIS, with its 23 years of integrated longitudinal data, permitted us to examine the active airman population year by year and construct a segmented linear regression model describing changes in overall numbers. The SIS liberated us from having to use any sampling techniques or generating point estimates, since the entire population is available for analysis.

Age has been a controversial topic in aviation medicine for many years and has been the focus of numerous studies. Li and Baker, in their retrospective cohort study of professional pilots (air taxi/air carriers), reported that aviation accident rates did not significantly change as commercial pilots aged from their late forties to their late fifties (6). They concluded that the medical certification process effectively screened out pilots that experienced the most age-related declines in health and cognitive ability. In essence, the absence of association between age and accident rates was described as a result of the "healthy worker effect;" those pilots not meeting minimum standards of health are forced out of the system. They argued that the amount of experience, in terms of number of flight hours an individual attains (5,000 – 9,999 hours), is a more likely determinant of an incident than age. They found that pilots with less than 5,000 hours of total flight time were twice as likely to experience an accident and that an additional increase in cumulative flight time beyond 10,000 hours was not associated with any decrease in crash risk.

Booze also conducted a study of 4,491 general aviation accidents from 1974 and reported that age appears to be a factor in accidents and that the common trend for general aviation is increased risk of accident with increasing age (5). Booze pointed out that greater cumulative experience must reduce accidents, but at some point any special benefit gained from cumulative experience is lost and becomes a risk factor as increasing time in the air is measured as increased exposure to the hazards of the environment. He demonstrated this finding by showing that more than half of all airmen with 200 hours or less only accounted for a third of all accidents. He did note that the one exception to this observation was for airline pilots, who had the highest cumulative experience of any group and maintained a very low accident rate. He concluded that "Risk analysis based on high age alone or in any combination not also associated with high exposure are somewhat inconclusive." He then went on to say, "The frequently observed relationships of greater risk of accident at higher ages is seen to result from a dilution of younger age rates by a large number in this age group with little or no exposure." He also adds a gender component to the age argument, noting that the data seem to indicate that women experience significantly fewer accidents proportionately than their male counterparts. This observation on gender has been supported more recently by Baker et al. (7). One of the issues acknowledged by Booze in his research is, "A recognized difficulty in all the studies cited has been the availability of appropriate and accurate denominator data for rate computation." This is one of the primary purposes of the SIS: to provide accurate and consistent denominator and numerator data for any aviation epidemiological study.

A study by Bruckart examined a selection of demographics concerning the U.S. pilot population over a 20-year period (8). He evaluated the U.S. pilot population by categorizing pilots into age ranges and found the mean pilot population age increased from 35 to 40 years and that the number of pilots over the age of 60 increased five-fold over the years spanning 1968 to 1987. Since 1980, he noted, there has been a steady decline in new pilots under the age of 35.

Age continues to be a controversial topic in aviation medicine, as age determines how long an airman's medical certificate is valid and also plays a key factor in the roles an airman can perform. The "Age 60 Rule" (Title 14 of the Code of Federal Regulations (CFR) §121.383), in place since 1960, determined that an airman cannot perform the duties as a pilot or copilot of a commercial passenger or cargo aircraft with ten or more passenger seats or 7,500 payload-pounds of capacity after turning 60 years of age. The purpose of the rule was to diminish the risk of an in-flight incapacitating medical condition such as heart attack or stroke, which are associated with advancing age. The primary effect of this rule was seen in the commercial airline industry, where pilots were forced into retirement or different jobs once they reached 60 years of age.

Since 1994, the FAA has sponsored studies that examined the question of age and pilot performance, particularly in regard to age 60. Both a database consolidation study (9) and an experimental evaluation of pilot performance (10) yielded no conclusive evidence that pilots aged 60 or over caused a greater proportion of accidents or incidents.

In a speech by then-FAA administrator Marion Blakey at the National Press Club in January 2007, it was announced that the age limit of 60 would be raised to 65 (11), meaning that reaching age 60 would no longer signal the end of a commercial aviator's career. Some considered the Age 60 rule obsolete, as foreign pilots older than 60 were allowed to fly in U.S. airspace. Upon reaching 60, many American pilots simply changed employers from a domestic carrier to a foreign-based airline and continued flying. Raising the limit from 60 to 65 years of age puts the FAA in compliance with International Civil Aviation Organization (ICAO) standards. As of December 13, 2007, commercial aviators were allowed to fly beyond the age of 60. That is the date when the Fair Treatment for Experienced Pilots Act was passed, which amended the age standard of Title 14 of the Code of Federal Regulations (CFR) §121.383(c) from 60 to 65, to be the same as the ICAO standard (12).

METHODS

A population database was constructed based upon the methods described by Peterman et al. (3) in *Development of an Aeromedical Scientific Information System for Aviation Safety*, covering the time frame from 1983 through 2005. The electronic medical records, collected on all airmen, are hosted at the Civil Aerospace Medical Institute (CAMI) and served as the foundation for this unique data construct. The primary purpose of using Scientific Information System principles to construct study datasets was to enhance aviation epidemiological research; this is what makes the subject database distinct from a typical management information system (MIS). The database consisted of a table for each year under study, populated with the records of each individual who qualified as an active airman for that year in the U.S. civil pilot population. The criterion for membership in the U.S. civil pilot population is based on the medical examination that each airman must pass to exercise the privileges of a pilot certificate.

A member of the population of U.S. pilots was defined originally as one who passed a flight physical from a certified Aviation Medical Examiner (AME), leading to a third-, second-, or first-class medical certificate. The level of medical certificate, the year it was earned, and the age of the airman at the time of the medical exam determines the length of time the airman is qualified to remain in the population. Within the time frame of this study, an airman can remain in the population for as long as three years, based upon a single exam. Disqualifying conditions and the different types and duration of medical certificates are described in the *Guide for Aviation Medical Examiners* (13).

Medical certificates have varying durations:

- A first-class airman medical certificate is required to exercise the privileges of an airline transport pilot (ATP) certificate. This certificate is valid for the remainder of the month of issuance, plus six months, for activities requiring a first-class medical certificate. After that time, the certificate is valid for another six months for activities requiring a second-class medical certificate, plus an additional 12 to 24 months for activities requiring a third-class medical certificate, depending on the age of the pilot at the time of the exam.
- A second-class airman medical certificate is required for commercial, non-airline duties (e.g., for crop dusters or corporate pilots) and is valid for the remainder of the month of issuance, plus one year. After that time, the certificate is valid for an additional 12 to 24 months for activities requiring a third-class medical certificate, depending on the age of the pilot at the time of the exam. Those exercising the privileges of a

Table I. Duration of Medical Certificates by Class

Prior to September 16, 1996

Certificate Class	First	Second	Third
Privilege	ATP	Commercial	Private
Duration	6 Months +	1 Year +	2 Years +

\+ The remainder of the month of issuance

Post-September 16, 1996, Amendment

			Age	
			≥ 40	< 40
Certificate Class	First	Second	Third	Third
Privilege	ATP	Commercial	Private	Private
Duration	6 Months +	1 Year +	2 Years +	3 Years +

\+ The remainder of the month of issuance flight engineer certificate, a flight navigator certificate, or acting as an air traffic control tower operator must hold a second-class airman medical certificate.

- A third-class airman medical certificate is required to exercise the privileges of a private pilot, recreational pilot, or a student pilot. This certificate is valid for the remainder of the month of issuance, plus three years for pilots under age 40, or two years for pilots 40 and over. Prior to September 16, 1996, before the FAA revised 14 CFR, §61.23, the third-class medical certificate was valid for two years, regardless of age (Table I). Individuals were defined as active during a specific year as long as their medical certificate was valid for at least one month of that year. The exact length of time an airman was considered active was captured in a variable called *Months Contributed*, which records the number of months in the current year that the airman was considered an active member of the U.S. civil airman population (3). On 24 July, 2008, the durations of first- and third-class medical certificates were extended to one and five years, respectively, for pilots under the age of 40 (14). This study cannot research the effects of those changes until new data, generated under the 2008 policy changes, are available.

The airmen records within the SIS were, in turn, linked to other datasets such as the National Transportation Safety Board (NTSB), the FAA Accident Incident Database System (AIDS), and the FAA Comprehensive Airman Information System (CAIS). The Structured Query Language (SQL) scripts and the order of their execution in building and defining the resulting airman population within the SIS is referred to as the *Active Airmen Algorithm* (3). The data in the SIS represent the entire population of pilots, rather than just a sample. Thus, the statistical results are population parameters, rather than statistical estimates, and are not subject to sampling error (15).

The variables of interest in our study were age, gender, medical class, measures of experience, and the overall size of the U.S. civil pilot population. Each of these will be examined to determine how they have changed over the study period. Some of these changes are due to policy decisions; others are due to changing demographics, while others can be attributed to fluctuations in the aviation industry.

In building the dataset and observing the number of medical exams conducted per year, data anomalies for years 1986, 1989, and 1993 were revealed, as seen by the "dips" in Figure 1. The 1986 anomaly was first observed during the consolidated database portion of the Age 60 project in 1994 and was omitted in the calculation of accident rates for that study (9). There is no explanation for the missing records during the years 1986 and 1993. It was deemed that enough records remained in 1986 and 1993 to be included in the analysis of age and active aviator counts by year in our study, as there were not enough missing records to significantly affect the annual median age or the coefficient of determination in our segmented linear regression model for aviator counts.

The 1989 anomaly was due to technical issues in the electronic systems of the day. For example, data were manually entered into these systems, and only pilot medicals that required little medical review (those from primarily younger applicants) were forwarded for electronic submission. This approach resulted in approximately 75% of the 1989 electronic exams to go missing in the dataset, an anomaly severe enough to introduce significant bias into our model regarding the counts and the ages of the U.S. civil pilot population. When we examined the median age for only those airmen who had a flight physical in a given year, we confirmed that the surviving exams for year 1989 are from younger pilots (Figure 2). The length of active airman membership for each individual was calculated based on the date of their most recently passed medical examination that was required to exercise the privileges of a pilot certificate. An airman who passed his/her aviation 1989 medical examination without limitations was qualified to remain in the active airmen population for the remainder of the month issued, plus two years, before another exam was required. The electronic medical records from 1989 were used to determine which airmen were active for years 1989, 1990, and 1991. Therefore, we considered the summary statistics for age and overall counts to be biased for these three years due to the way our active pilot population was defined in the SIS dataset.

The data were modeled using Statistical Analysis Software (SAS) version 9.1.3 and Insightful Miner version 7.0; the database scripts were written in Transact-SQL and Procedural Language SQL (PL/SQL) to accommodate both the Microsoft SQL Server 2000 and Oracle version 8.1.7 platforms. Graphs were produced in the SAS, Insightful Miner, and Microsoft Excel software packages.

Adjusting for the known data anomalies, a mathematical model was constructed to explain, describe, and predict the size of the U.S. civil pilot population. Statistical significance was defined at an alpha of 0.05 ($\alpha = 0.05$). We also examined the results in terms of age, gender, and measures of experience to identify trends over time.

Added to the difficulties posed by the data anomalies were the problems introduced by policy changes affecting eligibility in our defined population using the active airman algorithm. This is why our model was based upon a segmented regression analysis involving interrupted time

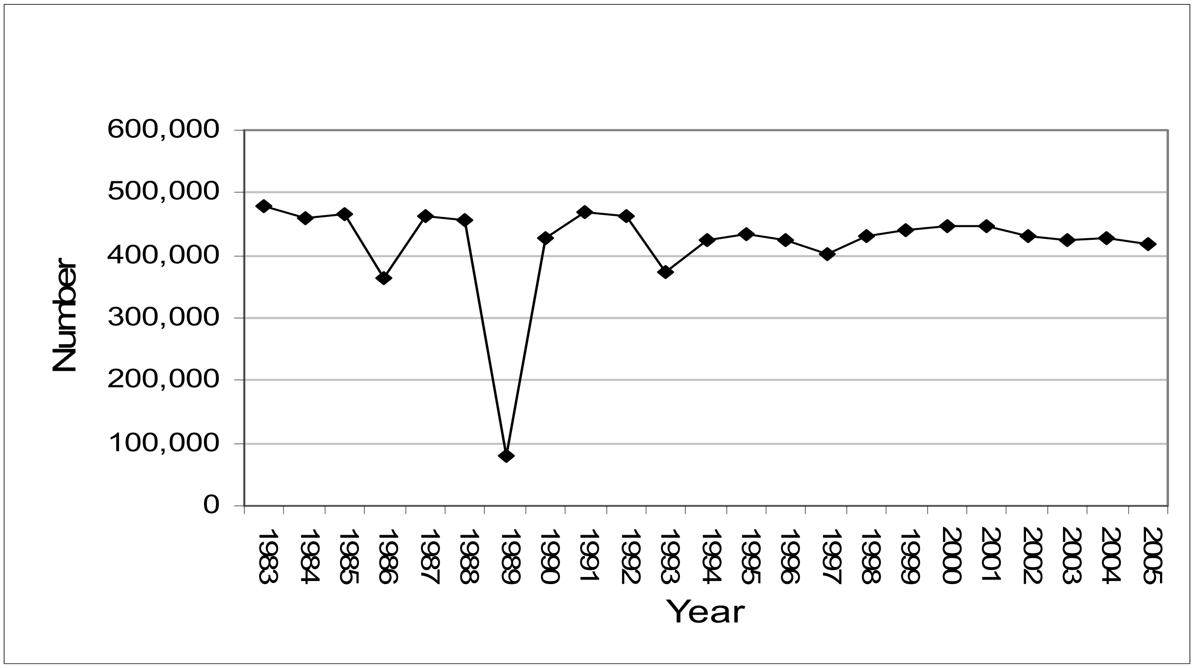

Figure 1. Number of Medical Exams per Year.

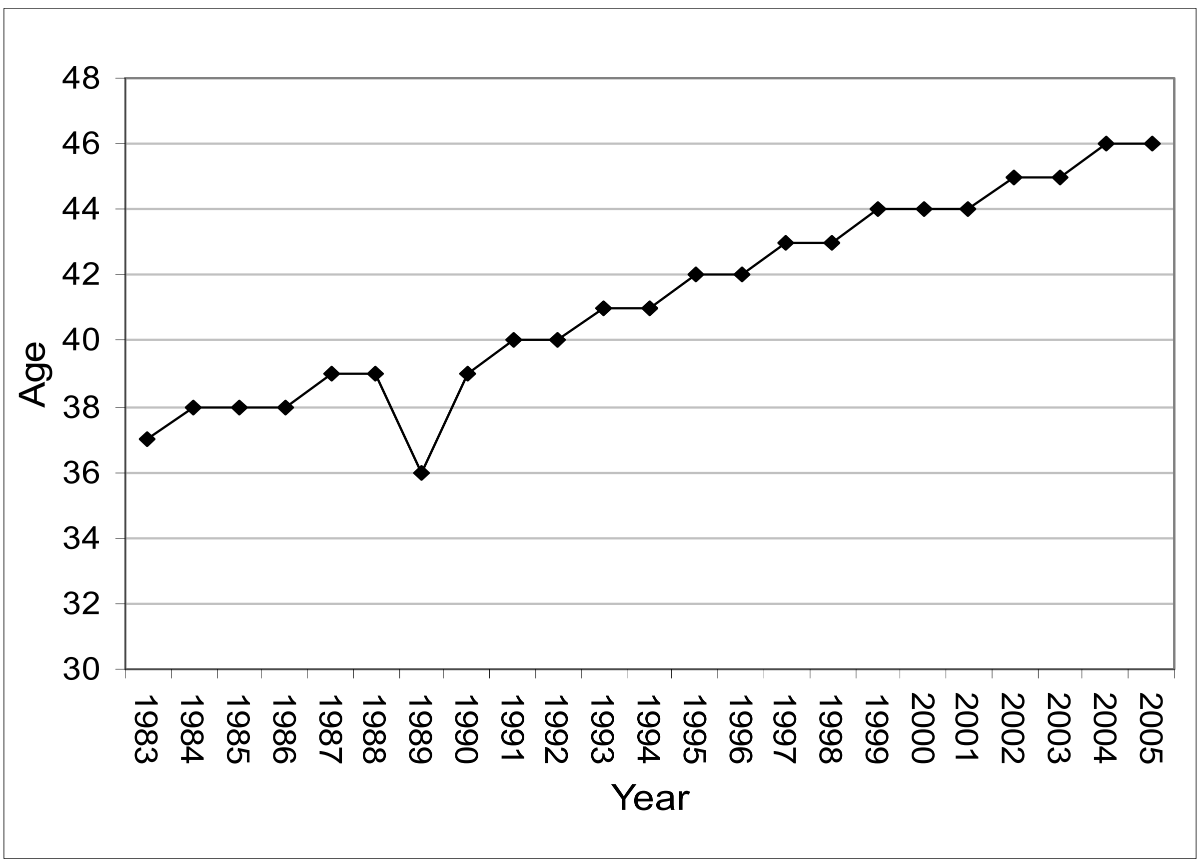

Figure 2. Median Age (in Years) of Airmen Who Received a Flight Physical, 1983-2005.

series. The model must be able to compensate for these policy changes to accurately predict their effects upon the size of the U.S. civil airman population.

RESULTS

Population Frequencies From 1983-2005

Observing the frequencies of the U.S. civil pilot population via the active airmen algorithm tells us a great deal about the size and demographics of this population and how it has changed over time. The SIS data revealed the 1989 electronic medical records anomaly, as well as the effects of the rule change in 1996 that significantly affected membership in our population. The data anomaly caused by the lack of medical exams for the year 1989 created a dip in our overall active pilot population from 1989 through 1991 (Figure 3). For the purposes of our analysis and modeling efforts these years were treated as being biased in regard to overall counts and age.

In September of 1996, a rule change extended the length of the medical certificates for people under the age of 40. Pilots not yet 40 at the time of their medical exams were certified for a maximum of three years, as opposed to two. Airmen who had been issued a medical certificate in late 1996 or 1997 normally would have been dropped from our active population unless they renewed their certificate, but they were allowed to remain an additional year in the population due to this policy change, resulting in an artificially increasing trend in overall numbers from 1999 through 2000. The population, as defined by our active airmen algorithm, appeared to decline when the initial impact of the policy change on the population was over, beginning in 2001. However, even with the rule change that allowed younger pilots less than 40 years of age to remain an extra year as members of our defined pilot population, the number of pilots declined over the 23-year period (1983-2005) by approximately 200,000. Had the rule not changed in 1996, we would have observed a larger disparity between 1983 and 2005. Thus, the overall numbers of the U.S. civil pilot population is declining. This finding differs from Booze's 1968 finding, that the U.S. civil pilot population was on the increase (4). This is an indication that the industry has gone through deep-seated changes over the last 40 years.

We modeled the frequencies of our pilot population to extrapolate changes and predict the population's size at future points. To accomplish this, we accounted for the impact of the 1996 policy change regarding the length of time an airman can retain a medical certificate. This change in policy affected the size of the population, starting in 1999, the year we demonstrated the displacement in frequencies. Taking this policy change into account, we

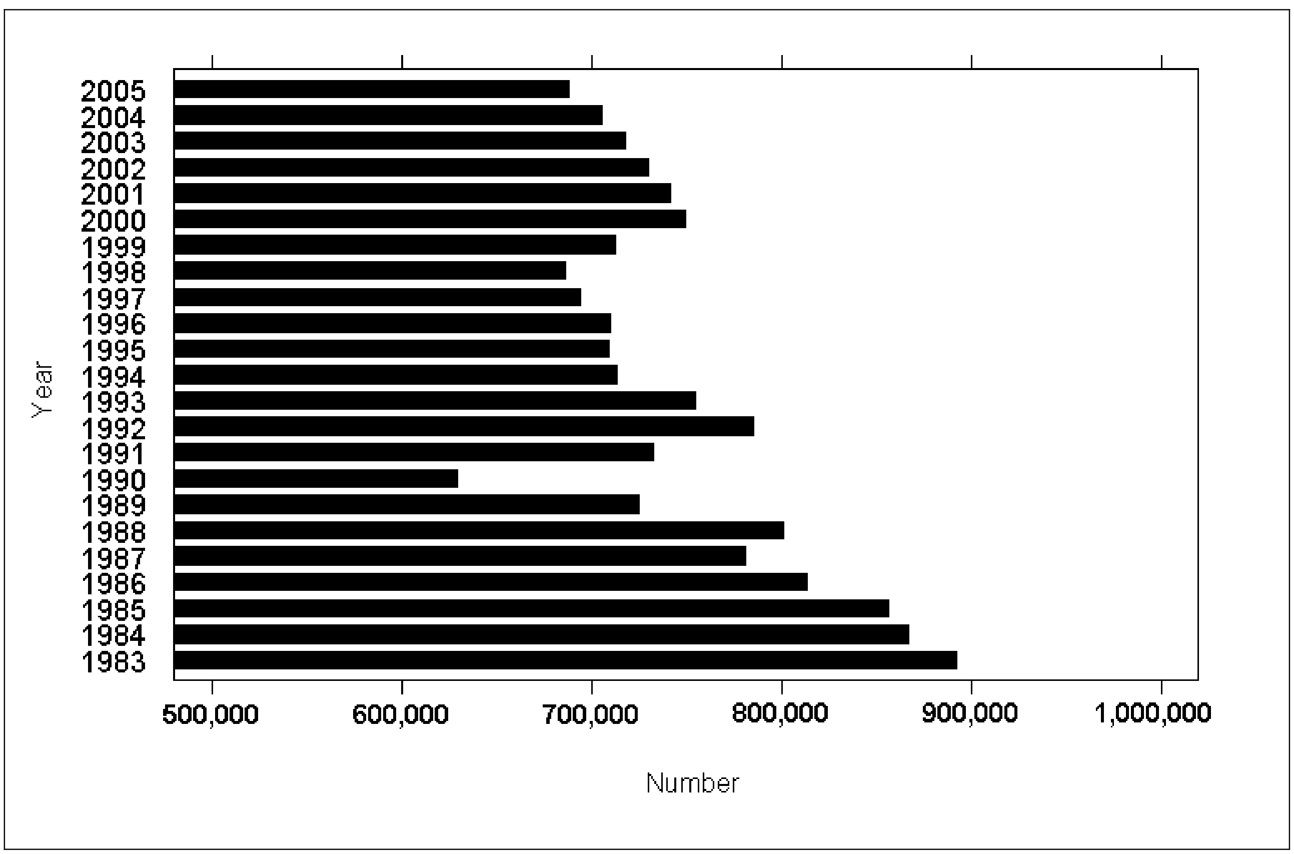

Figure 3. Number of Active Airman per Year.

modeled the frequencies using segmented linear regression involving interrupted times series analysis (16). The model accounted for the policy changes and still allowed testing of our data for a linear relationship. The model initially took the form:

$Y = \beta_0 + \beta_1 * (time) + \beta_2 * (policy\ change) + \beta_3 * (time\ after\ policy\ change) + error\ term$

In the model, *time* represents any of the 23 years of the study. The *policy change* is an indicator variable that takes a value of 0 for years before 1999 and 1 in 1999 and beyond. The *time after policy change* represents the number of years post-*policy change* (1999). The *error term* represents the random variability that our model could not explain. The regression coefficient β_0 represents the y-intercept; β_1 is the slope of the population over time *before* the effect of the policy change. The regression coefficient β_2 represents the offset at the point at which the policy change took effect. That is, the difference in numbers caused by the policy change in the U.S. civil pilot population from 1999 forward. The regression coefficient β_3 is similar to β_1 in that it represents the slope in the population over time but *after* the year 1999; therefore, we were able to determine if there was a statistically significant change in the overall slope of the model after the policy change took effect.

Modeling the frequencies of the U.S. pilot population using segmented regression analysis and omitting the biased years (1989, 1990, and 1991) generated the results in Table II.

The p-value for β_3 was greater than 0.05; therefore, it was considered statistically insignificant, meaning that the rate of decline did not change significantly after the year 1999. When this insignificant term was dropped, the final most parsimonious regression model became:

$Y = \beta_0 + \beta_1 * (time) + \beta_2 * (policy\ change) + error\ term$

The model was considered a second time using only the significant terms to generate the results for the parsimonious model (Table III).

Given this result, our predicted regression model looks like Figure 4, where our equation:

$Y = \beta_0 + \beta_1 * (time) + \beta_2 * (policy\ change) + error\ term$

becomes: $\hat{Y} = 25{,}136{,}096.54 + (-12{,}238.28)(time) + (85{,}692.80)(policy\ change)$

Note that in Table III, our coefficient of determination (R-square) is 0.913, which means the model has accounted for 91% of the variability in the dataset. Based on this model, we calculated where the population will be in the future, if existing conditions hold. In Table IV it was estimated how large the active airman population would be through 2008, with a 95% confidence band.[1]

Figure 5 represents the predicted values from the parsimonious regression model. The grey lines indicate the 95% confidence band for the predicted population values. From this regression model, we concluded that the 1996 policy change, which was designed to allow younger airmen to keep a valid medical certificate for a longer period of time, did not change the rate of decline of the active pilot population. If this were the final state of our model, then Figure 5 would represent our predicted

Table II. Full Segmented Regression Model

	Coefficient	Standard Error	t-statistic	p-value	R-square
Intercept β_0	26054379.92	2008185.039	12.97	<.0001	0.926
Baseline Trend β_1	-12699.69	1008.823	-12.59	<.0001	
Level Change β_2	66885.70	18081.045	3.70	0.0019	
Trend Change β_3	6014.72	3642.740	1.65	0.1182	

Table III. Parsimonious Segmented Regression Model

	Coefficient	Standard Error	t-statistic	p-value	R-square
Intercept β_0	25136096.54	2025246.102	12.41	<.0001	0.913
Baseline Trend β_1	-12238.38	1017.393	-12.03	<.0001	
Level Change β_2	85692.80	14738.029	5.81	<.0001	

[1]Hand calculations may differ slightly from those estimated by SAS since the regression coefficients are computed to only two significant figures.

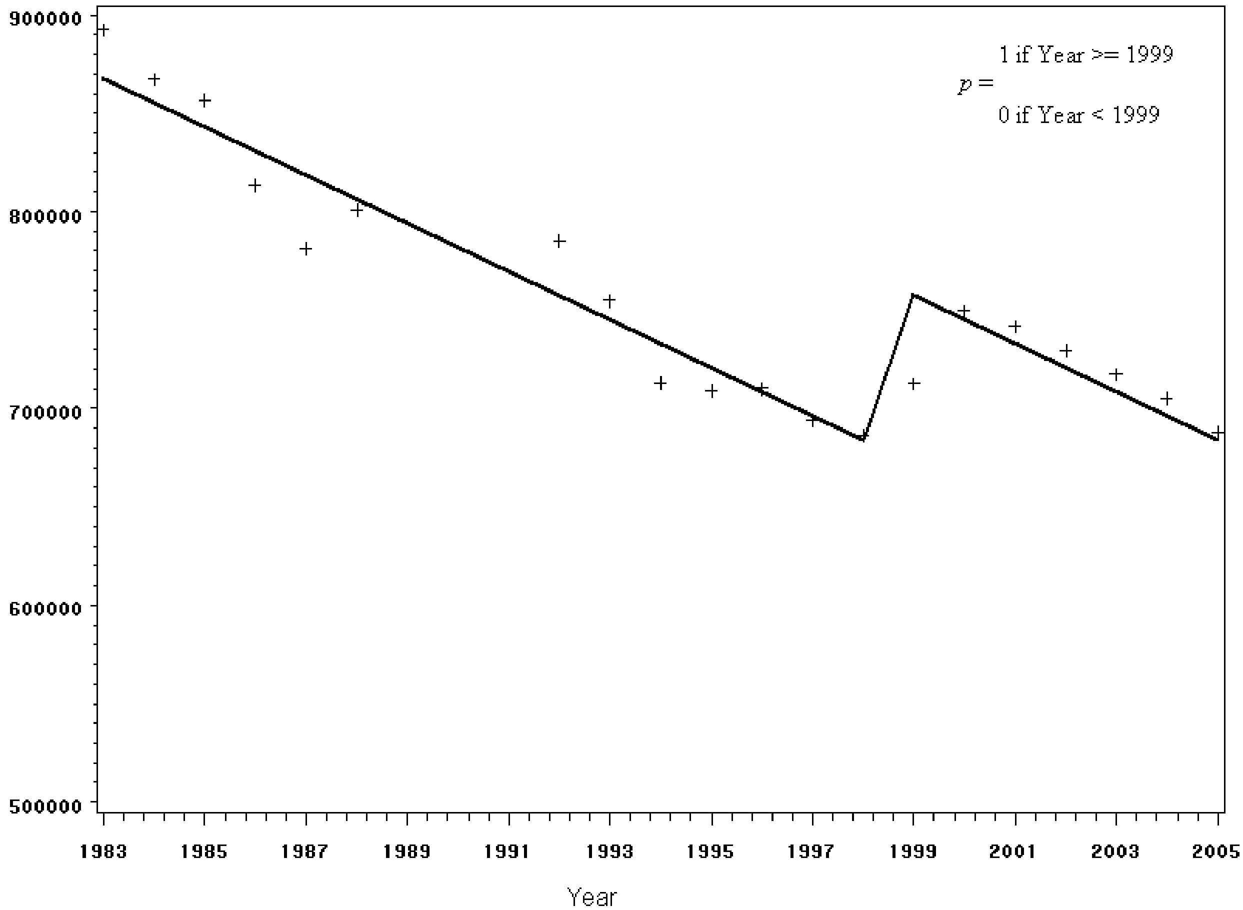

Figure 4. Parsimonious Regression Model.

Table IV. Population Projections With Upper (UCL) and Lower (LCL) Confidence Intervals Through 2008

Year	Population Size	LCL	UCL
2006	671595	653874	689315
2007	659356	640502	678211
2008	647118	626964	667272

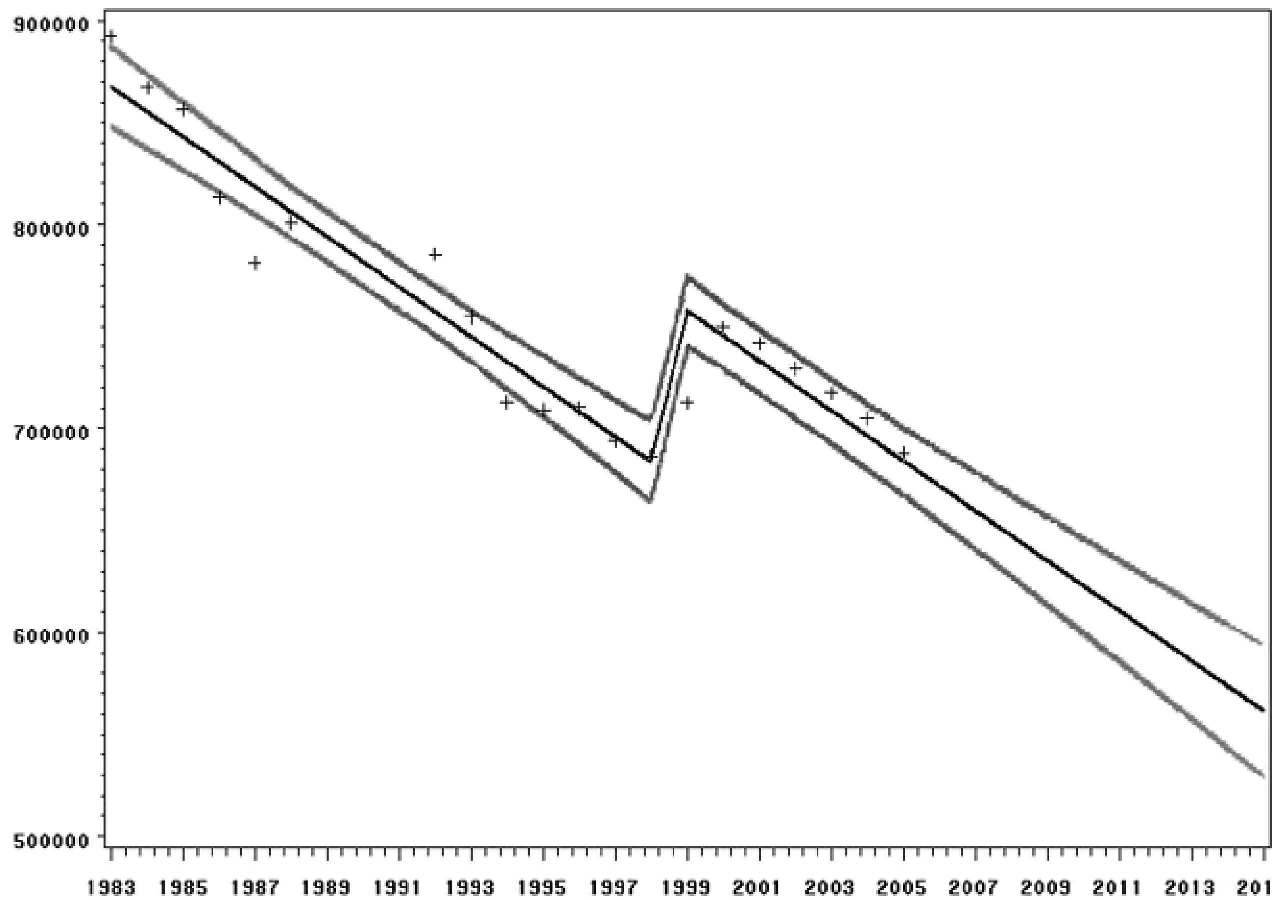

Figure 5. Parsimonious Regression Line With 95% Confidence Band.

values through 2015, but there were more policy changes in 2008 that are not covered by our current dataset. These policies also affected the duration of medical certificates (14). Additional data are needed to allow the modeling of the regulatory changes implemented in 2008 and to finalize our regression model.

Population Frequencies by Gender

When gender was considered, we found that women comprise a small percentage of the active airmen population, and this percentage remains fairly constant over the 23-year interval (Figure 6). The percentage of women ranges from 6.4% to 7% over this period with their greatest numbers at the start of the study period in 1983 (58,847). At the end of the study, in 2005, women numbered 42,536. The lowest number of women occurred in 1990 at 40,327, but this is one of the years affected by the bias caused by the missing medical records; the next lowest year occurred in 1998 at 41,063.

To better view the variation in the numbers of female pilots over the 23-years of the study, Figure 7 shows the same graph of women from Figure 6 on a condensed scale. The same data anomalies and policy changes that affected the number of active airmen per year (Fig. 3) are also evident in Figure 7.

Population Frequencies by Medical Class

Medical class is a dynamic variable that can change annually for any individual airman. Airmen with a first-class certificate can have that certificate become second-class, and it, in turn, can drop to a third-class certificate if the airman fails to renew it as required for each class. A third-class certificate, if not renewed prior to its expiration date, leaves the airman without a valid medical certificate and legally unable to fly.[2] To gain an accurate understanding of the distribution of the three medical classes, a constant point in the year was chosen, and an algorithm was developed for determining the current medical class held by all individuals at that time; this approach led to what was referred to as *Effective Class*. Effective Class is essentially the *point prevalence* of the

[2] The exception to this is the rule regarding Sport Pilots, which was enacted in 1994 under 14 CFR §61.23.

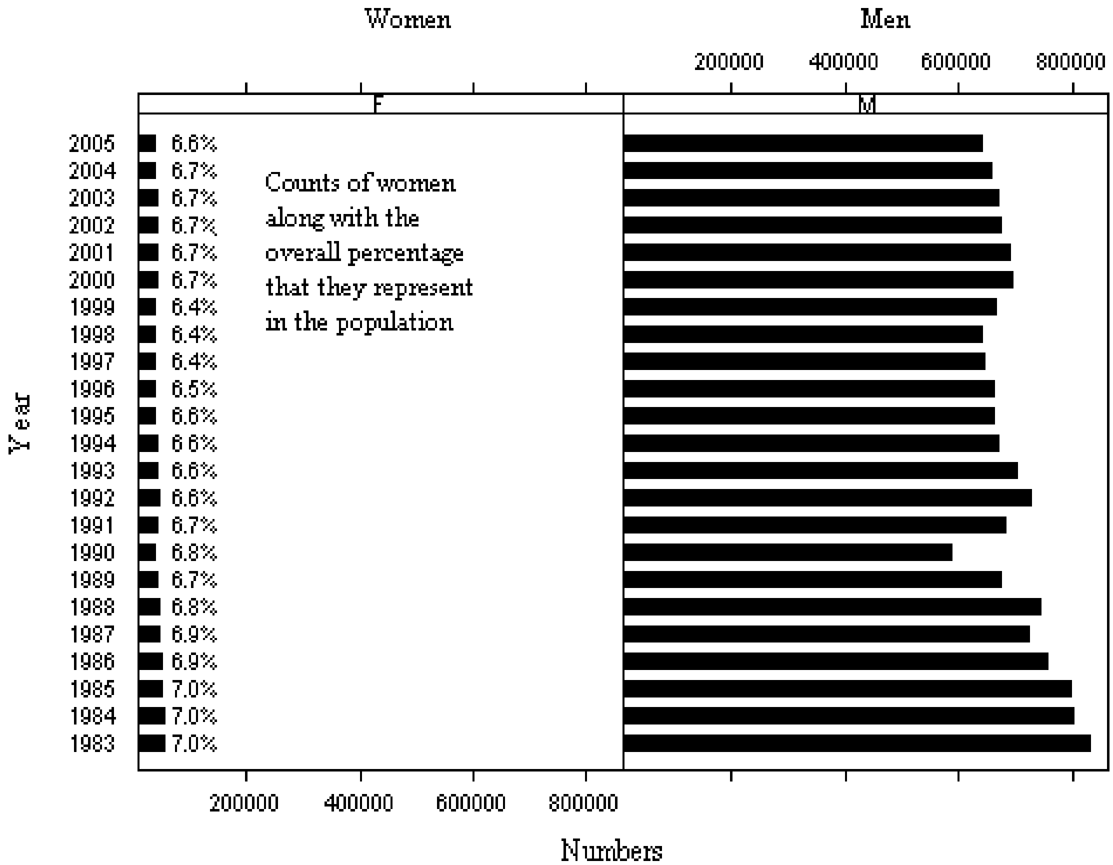

Figure 6. Active Airman per Year, by Gender.

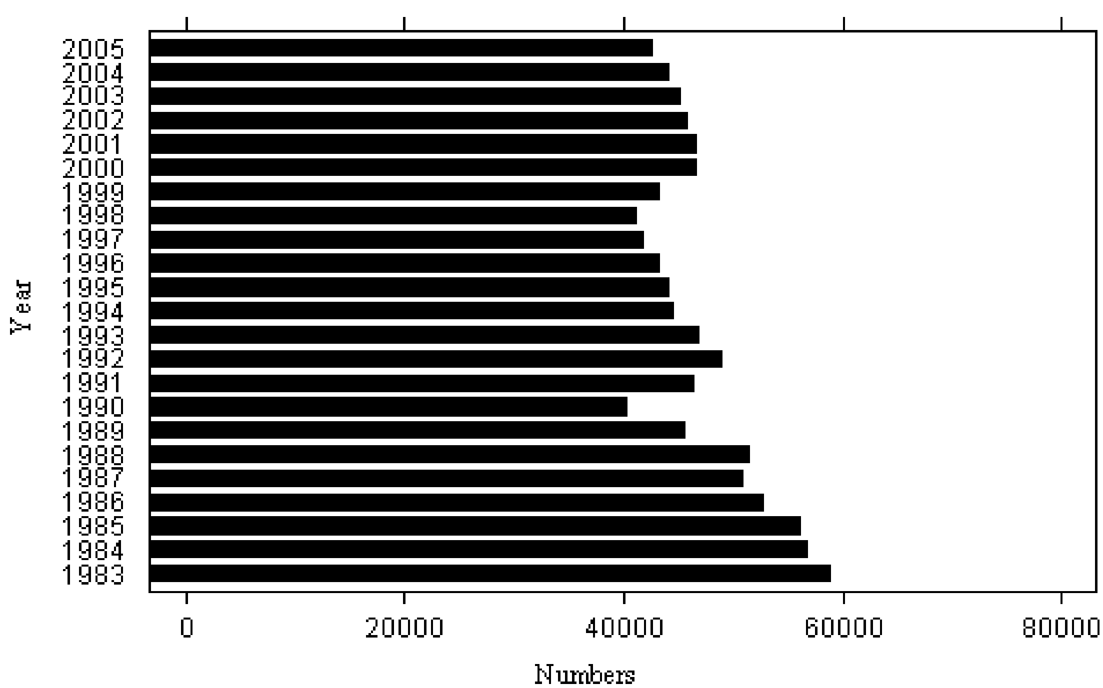

Figure 7. Active Female Aviators, by Year.

three classes of medical certificates. For this study, the last day of each year was used to calculate this variable. Considering the prevalence of medical certificates (Fig. 8) over the 23-year span of this study reveals a tale of contrasts.

There were more third-class medical certificate holders than any other, but those numbers were in decline. Second-class medical certificate holders numbered less than half that of third-class medical certificate holders, and they too were in decline. First-class medical certificate holders initially numbered less than either second- or third-class medical certificate holders but were generally increasing and were close to overtaking second-class medical certificate holders in recent years, in terms of overall numbers.

Population Frequencies by Age

The population dataset has the recorded age of the pilots reported at the time of their medical exam, which makes it a static variable, just as it was for Bruckart's study (8). An algorithm was used that incorporated the age of the pilot as a dynamic variable and computed the exact age of every individual on the last day of each year. Figure 2 displayed the median age of airmen who had successfully passed a physical in the given year. Figure 9 shows the median age of *all airmen considered active* in the given year. When we view the median age of active airmen by year (Fig. 9), we see that age is increasing year to year, just as Bruckart observed. The scarcity of medical records for 1989 is reflected in the median age for that year; those numbers are overwhelmed by airmen who had medical exams from previous years and were still considered active in 1989. The median age ranged from 37 in 1983 to 45 in 2005. Clearly, the U.S. civil airman population is growing older.

When our population was categorized by gender, it seemed the trend affects men and women alike, as seen in Figure 10.

It is evident that the median age increased for both men and women from 1983 through 2005. For men, the minimum median age was 37 in 1983, and the maximum was 45 in 2005. The women's minimum median age was 32 in 1983; the maximum was 38 in 1998, 1999, and 2005. Although women, as a group, were gradually aging, they were still younger than male aviators. The explanation for why female aviators, as a group, were younger than their male counterparts remains unknown.

To consider how the population changed regarding the different age categories, refer to the population pyramids in Figures 11 and 12. The graphs display how the age distribution for men and women changed from the start and the last year of the study.[3]

Population Measures of Experience

Measuring levels of experience for individual airmen involves many factors. For the purposes of this study, we observed the total number of flight hours reported by each airman on their most recent medical exam and classified them by gender, age, and class of medical certificate. At the time of their medical exam, airmen were asked how many total hours they had accumulated. The answer was assumed to be an estimate or an approximation by the airman based upon when they last tallied the flight hours in their logbook.

We expected that age and reported flight hours should be highly correlated. That is, the longer an airman had maintained a medical certificate, the more accumulated total flight time would be acquired. Since female aviators tended to be younger than their male counterparts, we categorized total flight time by gender. Breaking our analysis down by gender revealed that, since female pilots were younger than their male counterparts, their accumulated flight time was lower (Figure 13). The fact that the few medical records for 1989 belonged primarily to younger, inexperienced aviators is reflected in the average hours calculated for that year.

We further subdivided our analysis by gender and class of medical exam. Figures 14, 15, and 16 show the average hours reported at the time of the airman's medical exam by these variables.

The trends shown in Figures 14, 15, and 16 were very similar, suggesting that all female medical classes, as a group, tended to be younger than their male counterparts, and, therefore, have accumulated fewer flight hours than men.

DISCUSSION

One of the purposes of this study was to develop a method to track changes in the counts of various data categories that may be of interest to aviation safety regulators, accident investigators, and researchers. When there are factors that change during the course of a study, it is important to try to take these changes into account. In this study, the only regulatory change occurred in 1996, the effect of which was delayed until 1999. Other researchers, Wagner et al., for example, have found that regulatory effects upon purchasing patterns, adverse events, or other measurable activities can be followed with segmented linear regression modeling. Recent examples include changes

[3] The number of individuals holding medical certificates under the age of 16 is not displayed since they were few in number.

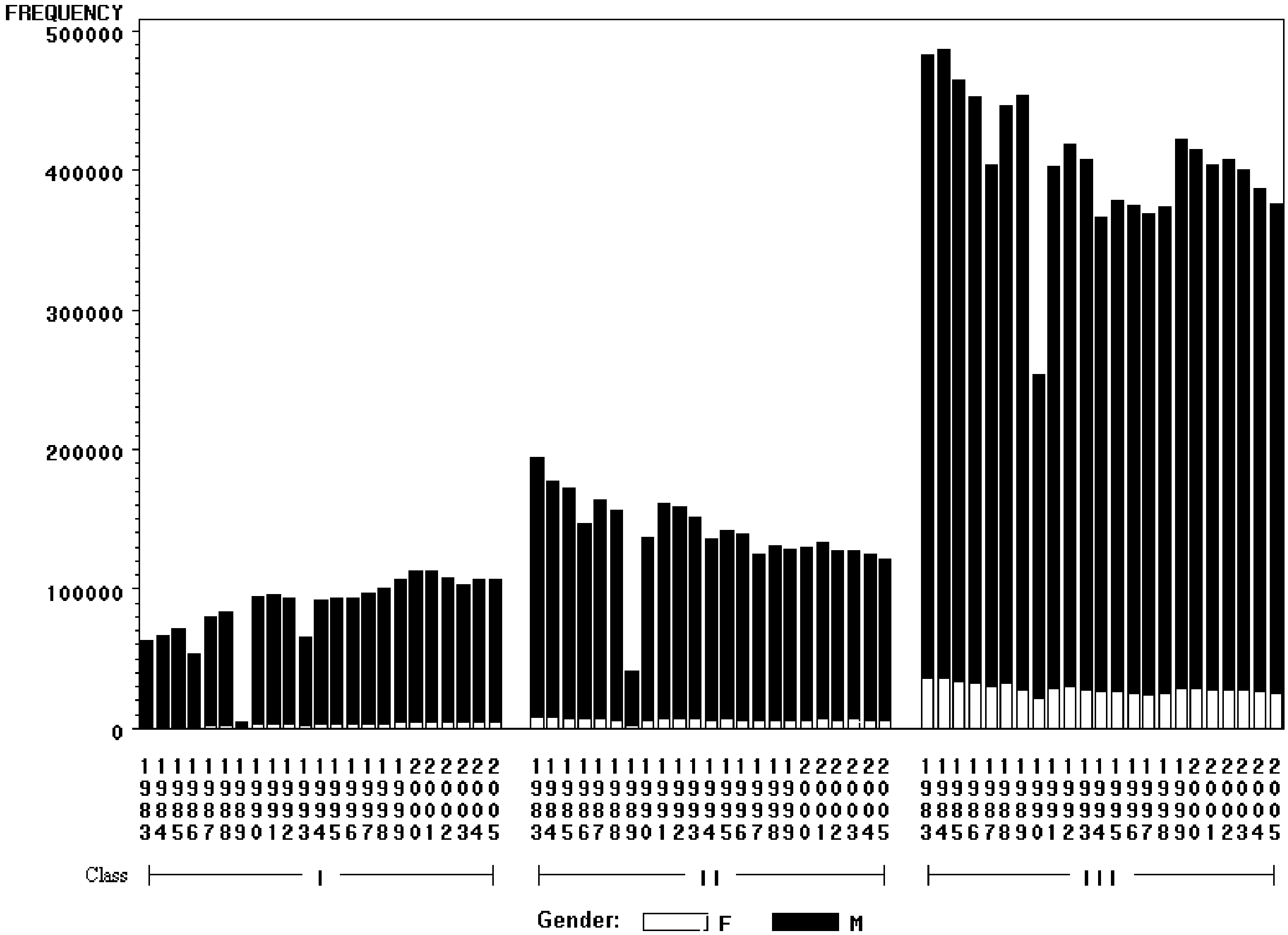

Figure 8. Effective Medical Class, by Gender.

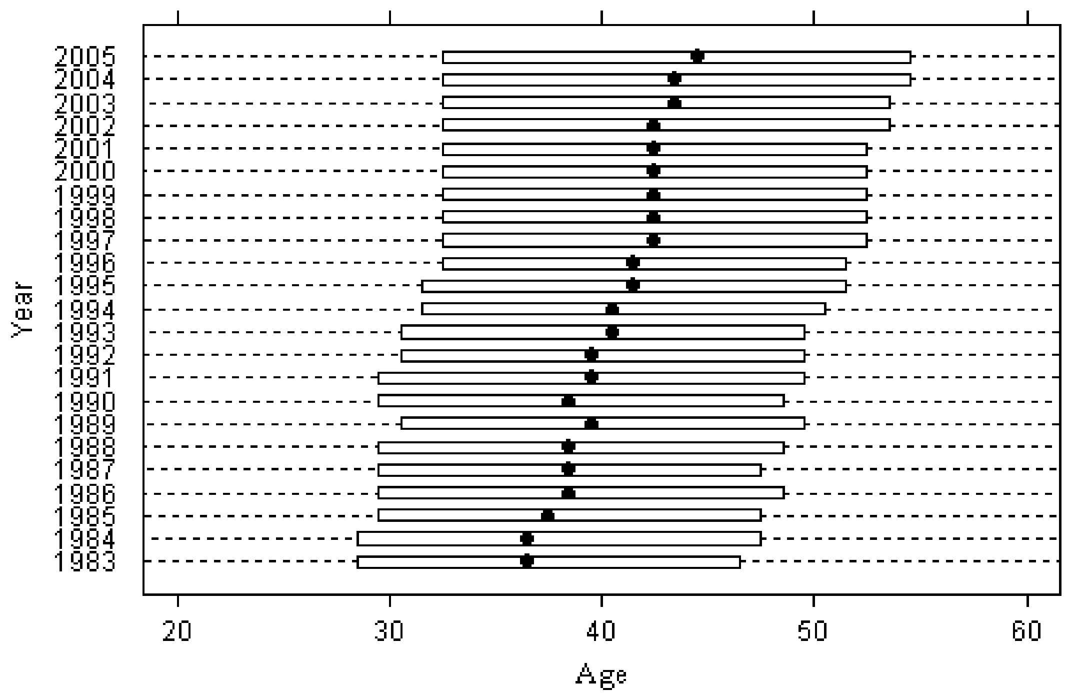

Figure 9. Median Age of Active Airmen at End of Year.

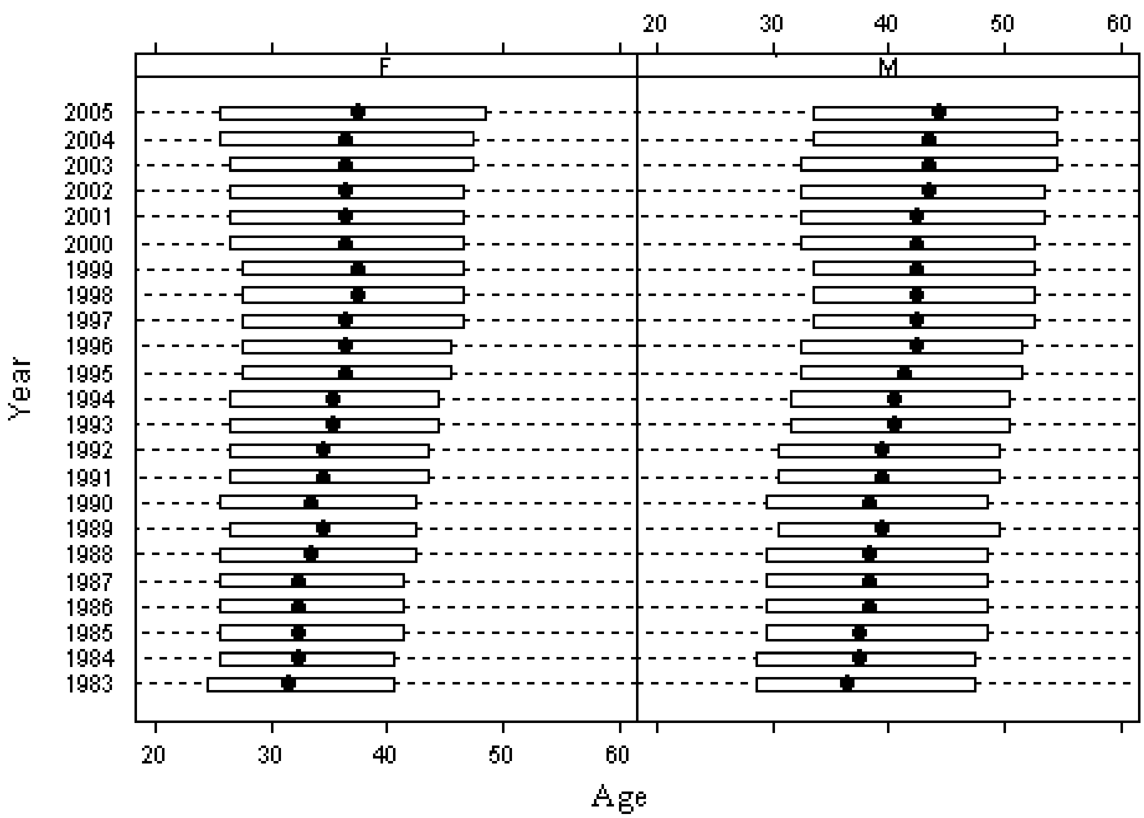

Figure 10. Median Age of Active Airmen at End of Year, by Gender (M = Male and F = Female).

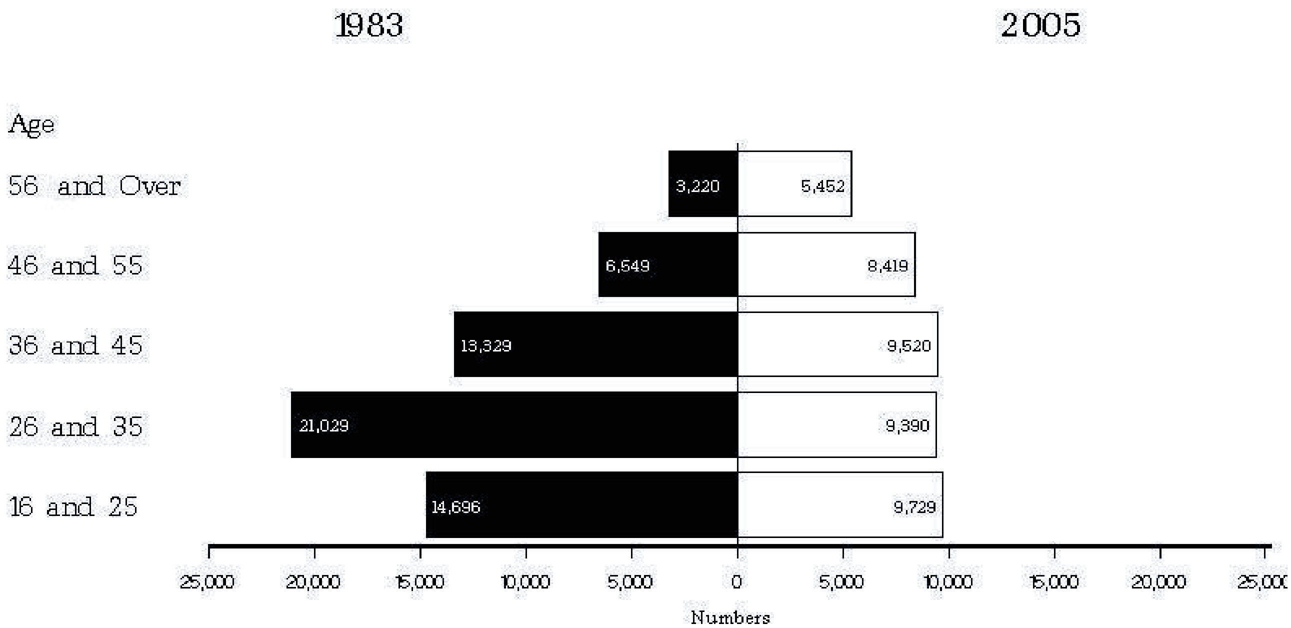

Figure 11. Population Pyramid of Female Pilots, by Age Category and Year.

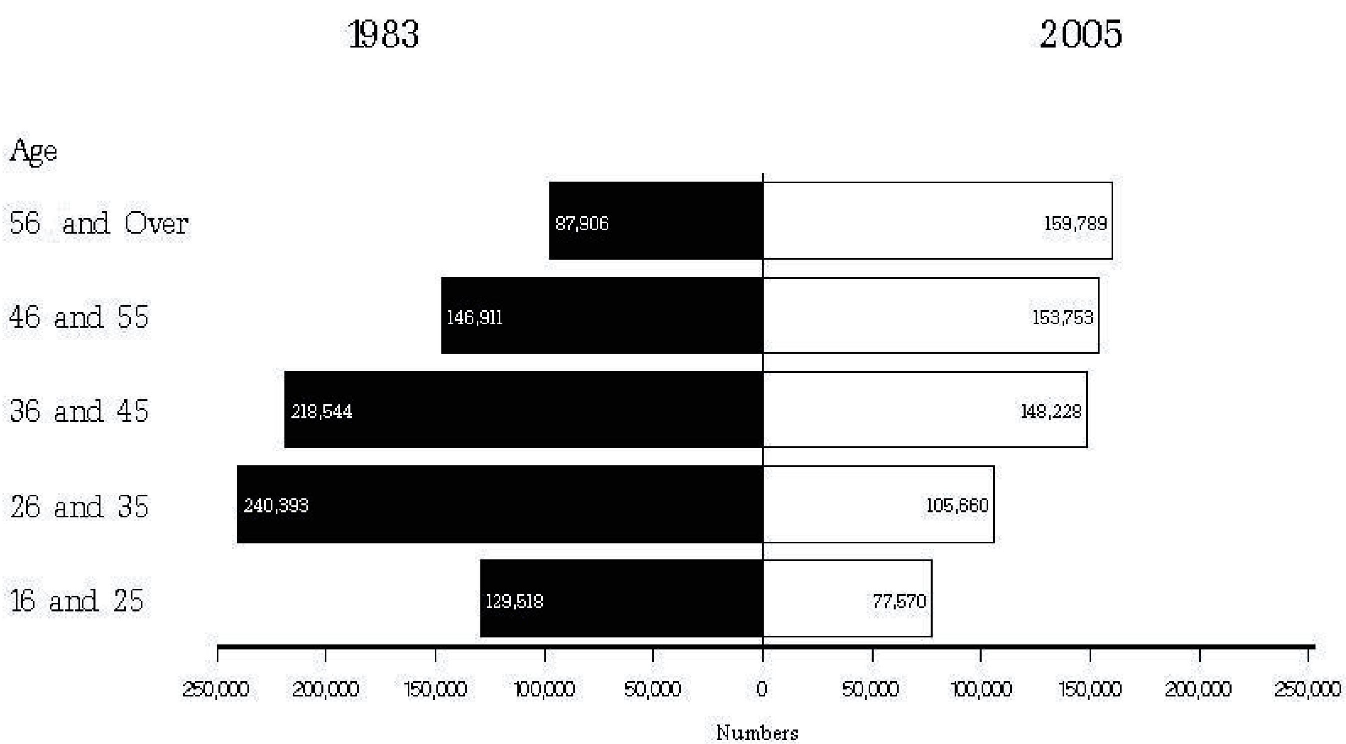

Figure 12. Population Pyramid of Male Pilots, by Age Category and Year.

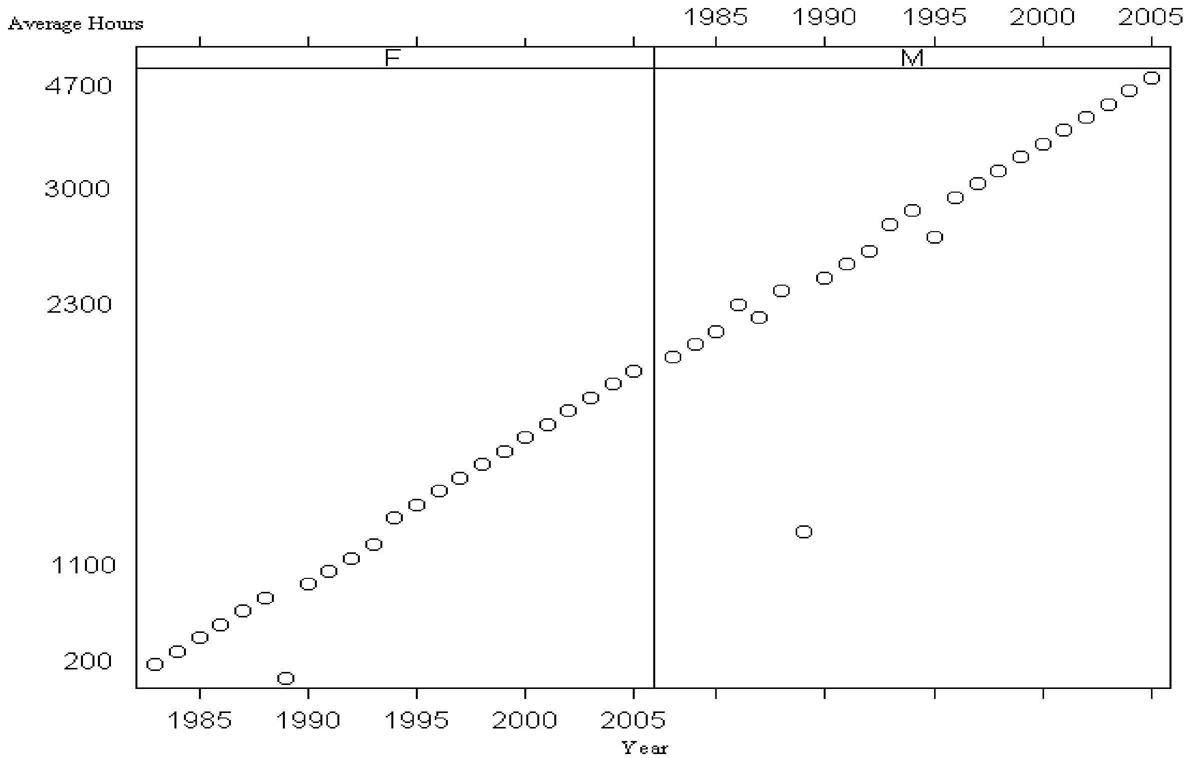

Figure 13. Average Hours Reported at Time of Medical, by Gender (M = Male and F = Female).

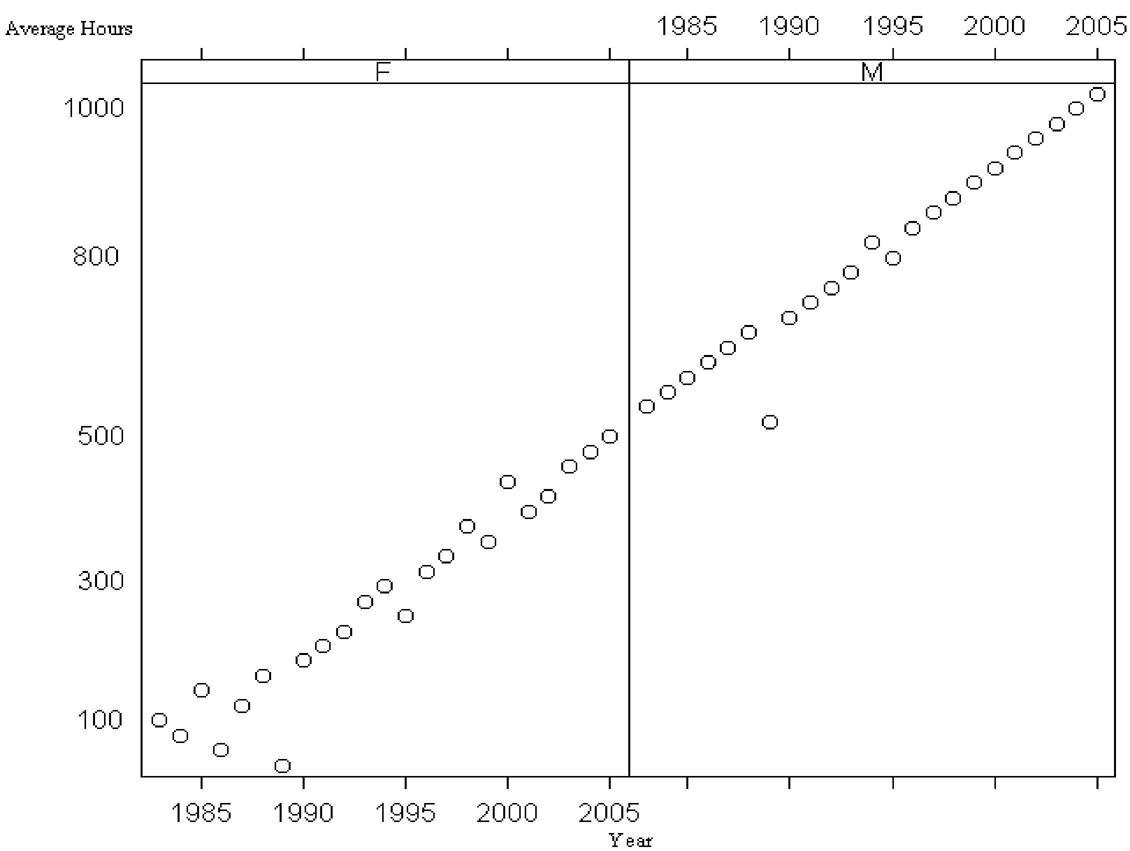

Figure 14. Average Hours Reported at Time of Third-Class Medical, by Gender.

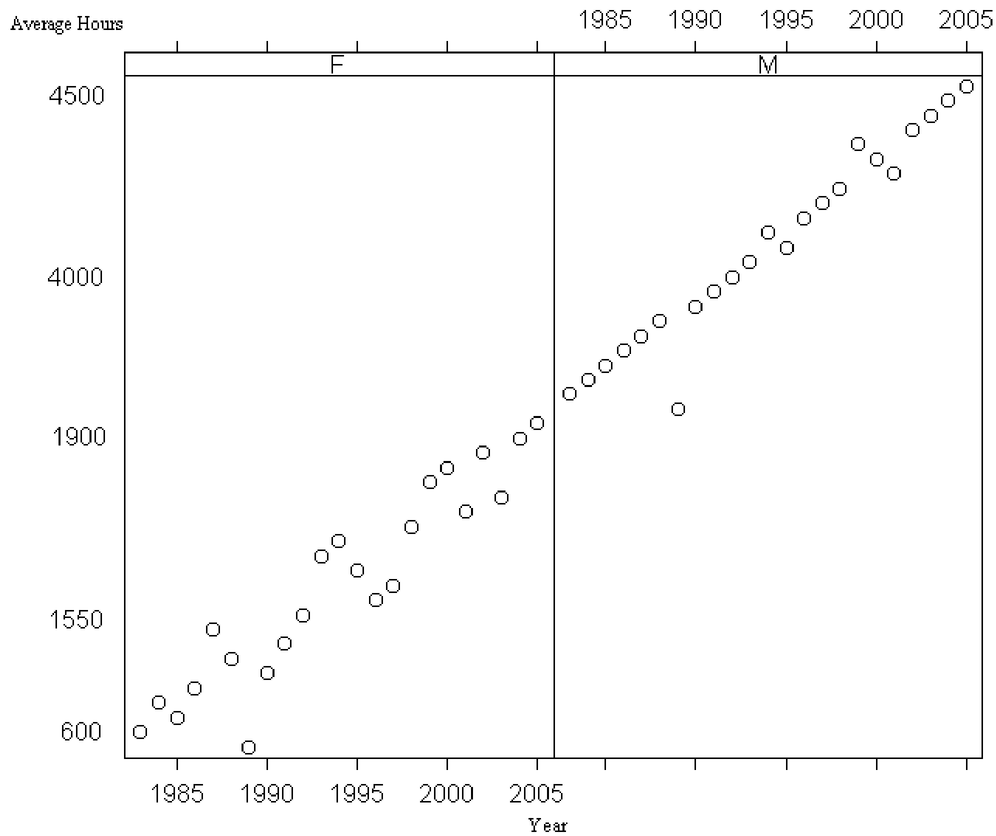

Figure 15. Average Hours Reported at Time of Second-Class Medical, by Gender.

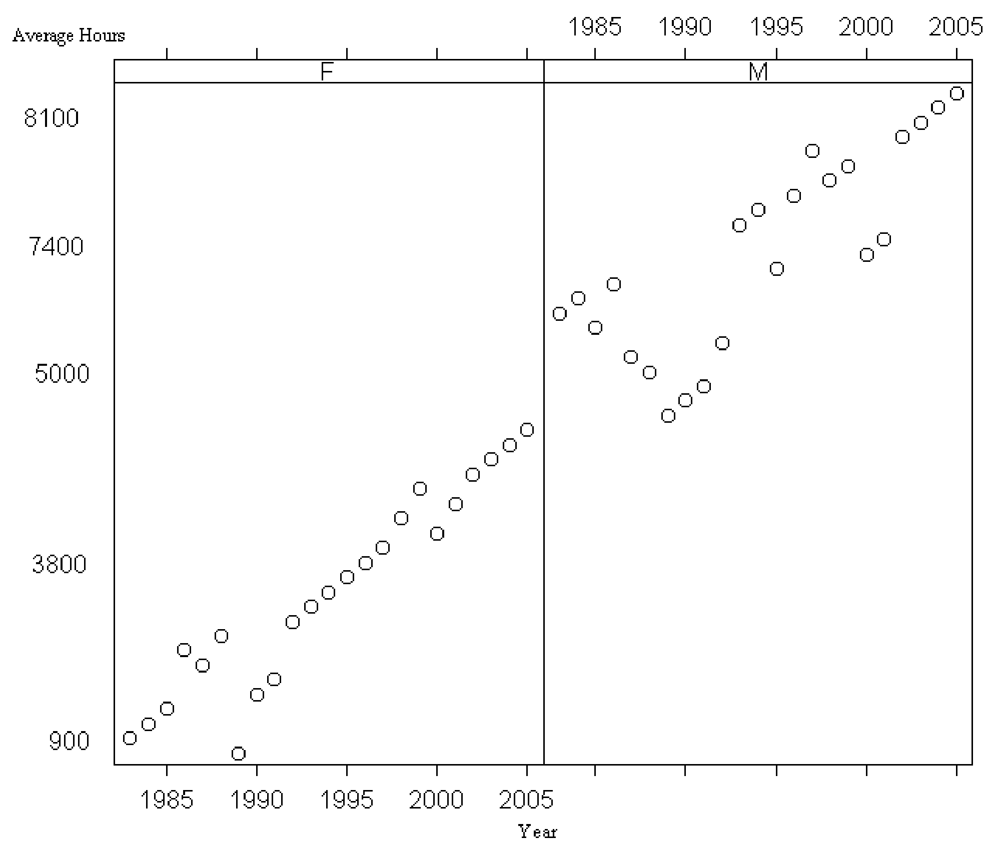

Figure 16. Average Hours Reported at Time of First-Class Medical, by Gender.

in insurance policies and medication use (16). Within our study, we noted that after the regulatory change of 1996, it was immediately apparent that the otherwise straight line marking the counts of active pilots had an upward bump in 1999. If one were to try to make predictions using the entire data series from 1983 to 2005, there would be unexplained variation and error in the estimates predicted by a standard regression model.

Segmented linear regression allows the modeling of before and after changes to examine and predict, using all of the data available, leading to more accurate estimates. This type of model can accommodate multiple changes since more than one segment can be employed in the analysis. It is important to note that the technique does not auto-identify the segments; it is up to the researcher to closely correlate the known factors, such as regulatory change, and include an indicator variable(s) to allow the segmented regression to proceed. One variable establishes the presence or absence of a segment(s), and another variable marks the years after the change occurs. Thus, for our model, zeros were used to precede the change, and ones were used to indicate that the change had occurred. Similarly, after the change, another indicator variable was used in increments of one for each year after the effect of the regulatory change (1, 2, 3, 4, and so on). These indicator variables create structure that linear regression models can use to account for the initial effect of the factor and the possible prolonged effect over the years after the factor change. In this study, only the initial effect of the regulatory change was statistically significant. When new data become available from 2008 forward, we expect to see a jump in the number of active pilots, similar to what was seen in 1999, due to the increased duration of first- and third-class medical certificates. In other words, 2008 will become the next year we place a segment for our regression model. With this new segment, we can once again test to determine if the new policies have any effect on the rate of decline for our population. The benefit of our segmented linear regression model is that any number and type of regulatory change that affects the size of the population can be incorporated in the analysis.

After the 1996 regulatory change to Part 61 (extending the duration of validity of a third-class medical certificate for the under age 40 group), there are two possible explanations for the effect upon the count of active pilots. The first is that more pilots may have become interested in obtaining a medical certificate due to the attention being paid to the regulatory change. From the counts of the medical exams submitted (Fig. 1), it is possible to see that there was a temporary increase in the number of applicants. The second explanation is that the regulatory change had the direct effect of elevating the number of active pilots by increasing the validity period, beginning in exams submitted in 1996 and reflected in 1999 (Fig. 3). This threshold effect means, in modeling terms, that there would be a different Y-intercept for post-1999 data compared to the pre-1999 data. While the overall effect was to increase the number of active pilots by ~86,000, most of this increase came as a result of the extension of the certificates of existing pilots, and a much smaller contribution (which waned as the years went by) was due to more pilots applying for a medical certificate.

The rate of loss of pilots before the regulatory change in 1996 and the rate of loss after the effect of the regulatory change appears in 1999 is not statistically different. That is, there was a statistically significant change in the number of pilots after the initial effects of the regulatory change, but the slopes of the model (rate of loss) remained the same. In practical terms, the rate at which pilots are leaving the medical certification system was unaffected after the regulatory change. It is likely that the change in the regulation was sought to increase the number of pilots by decreasing the frequency of the mandatory medical exam for younger pilots, saving them time and expense without compromising aviation safety. The exam frequency was decreased, but the number of pilots not maintaining a medical certificate continued its multi-year decline. Operators of gliders, ultralights, balloons, and, more recently, sport aircraft, do not require a medical certificate to fly; increases in the number of such pilots would not show up in our study of active airmen, which includes only pilots with valid medical certificates. Perhaps pilots who previously might have held a medical certificate and flew in general aviation activities are changing to perform flying activities that do not require a medical certificate.

There may be other impediments to flying such as the increasing costs of aircraft, fuel, maintenance, insurance, landing and hangar fees, all of which may be contributing to the decreasing number of active pilots. This study did not have access to pilot surveys or other data that might be examined to explain the prolonged trend of decreasing numbers of active pilots.

CONCLUSIONS

Based on the results of this study, the U.S. civil aviator population is indisputably in an overall decline. The segmented linear regression model developed to help describe and quantify the numbers of the U.S. civil pilot population over the 23 years of the study period was used to project future numbers through the year 2008 (Table IV). If current conditions hold, the model predicts that the U.S. civil pilot population will continue to decline and fall to new lows. The model displays the declining numbers, along with the effects of regulations that changed the length of validity of a medical certificate for aviators under the age of 40. The model will be modified to reflect future policy decisions, both in 2008 and beyond, when data concerning those years are available.

When we categorized the population by Effective Class over the 23 years of the study, we are able to see third- and second-class medical certificate holders are in decline. Holders of first-class medical certificates are increasing. These trends in medical class may be representative of changes within both the general and commercial aviation industries. Perhaps there is a waning number of the general public interested in general aviation, for which only a third-class medical certificate is needed. Non-airline commercial operations may also be diminishing, which would explain the decreasing numbers of second-class medical certificate holders. More first officers may be seeking first-class medical certificates to be able to upgrade to captain status or may be fulfilling requirements from their companies that they hold higher medical certificates than required by the federal regulations. Finally, commercial operations requiring a first-class medical certificate such as airline operations may be expanding, which is why we have observed an increase in this category. Our findings suggest that one or more general aviation components are declining, while air carrier and other commercial operations requiring a first-class medical certificate are growing (2).

In our initial look at the parameters of the U.S. civil pilot population, we have definitive evidence of an aging population that is shrinking in overall numbers. This population, although gradually growing older, confirmed that women, as a group, are generally younger than their male counterparts. We found that female aviators, although a very small part of the overall population, differed in median age by as much as seven years from men by the year 2005. The data suggest that in the younger age categories, there are proportionately more women than men. Within the older age categories, the proportion of women drops off considerably. The reason for this age difference between the genders is unknown.

Measures of experience show that total accumulated flight time, as reported by aviators at the time of their last medical exam, is greatest for holders of a first-, second-, and third-class medical certificate, respectively. These differences may be due to the involvement of holders of first- and second-class medical certificates in commercial aviation. Pilots involved in commercial activities would be expected to earn more flight time than infrequent fliers. It is not surprising that the greatest average flight time was held by those with a first-class medical certificate. This group of aviators is composed largely of professional pilots that log many hours of flight time annually. The data suggests that women logged hours at the same rate as men, but since women, as a group, tend to be younger than their male counterparts, the accumulated female flight experience, as measured in total flight time, was less. This trend was also observed for the different classes of medical certificates. Total annual flight times for women lagged behind those reported by men in all categories of medical certificates because women pilots, on average, are younger than their male counterparts and generally have fewer years of aviation experience.

As people are living longer and with the aging of the Baby Boomers, the U.S. general population is becoming older (17). Increasing age is one of the risk factors for many chronic diseases. Other factors include tobacco use, lack of physical activity, and poor nutrition. Therefore, the incidence of many chronic diseases in the U.S. general population is increasing. As better treatments for chronic disease and disability are developed, we would expect an increase in life expectancy. This, in turn, will lead to a corresponding increase in the prevalence of chronic disease and disability. U.S. demographic projections indicate that the proportion of people 65 and older will swell from 12% in 1995 to 20% by 2050 (18). Since the U.S. civil pilot population is a subset of the overall U.S population, we would expect to see similar results in terms of increasing prevalence and incidence of chronic disease. Future epidemiological studies will target some of these chronic conditions, along with their prevalence and effects within the aviation community to include flight safety.

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