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Examining Crucial Demographic Trends in General Aviation

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GRADUATE RESEARCH PAPER

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ABSTRACT

America's General Aviation sector has witnessed significant demographic shifts since the turn of the century. The number of certified, private pilots, non-fatal aircraft accidents, fatal aircraft accidents, and number of general aviation hours flown are all in decline. Meanwhile, the average age of an American private pilot has increased by several years. All of these factors indicate that the industry is in decline. This study determined – via mathematical, linear regression – that time's relationship to the number of annual, fatal General Aviation accidents *and* the number of certified private pilots is negative. It also proved that the average age of the private pilot demographic is increasing, as the overall size of the demographic decreases. These findings prove ominous for a shrinking community that relies on its size to leverage the government and the public for support and recruitment.

This study – however – also failed to prove strong, linear relationships between the number of General Aviation hours flown annually and the number of accidents or the number of private pilots. The data also compelled an acceptance of null hypotheses for private pilot population size in explaining fatal or non-fatal accident rates or the average age of a pilot explaining the same. These results fly in the face of conventional wisdom and disprove common knowledge within the aviation community.

These results call on the FAA and General Aviation to act. If negative trends continue, the latter may not survive the coming decades. Clues as to how to address General Aviation's decline in popularity and influence *may* be found in the relationship between a pilot's average age and the shrinking demographic. Further – more detailed – assessment into the relationship between average pilot age and income or average pilot age and behavioral patterns while away from the airfield may help to explain causation.

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1. INTRODUCTION AND LITERATURE REVIEW

Flying is one of America's most fulfilling, but expensive past times. The 664,000 active pilots in this country – non-airline commercial, private, and student – sustained more than 1.1 million jobs and $246.8 billion in economic output in 2019 (FAA, 2020 and General Aviation News, 2020). Businesses within and supporting the general aviation sector constituted more than 8.7% of US Gross Domestic Product (GDP) that same year! While private and instructional flying (General Aviation [GA]) are far less visible than that of the airlines, the importance of this industry to our major air carriers and even US economic health cannot be understated. The Federal Aviation Administration (FAA) currently endorses 584 civilian flight training institutions – each hosting any number of instructors and students at all levels (FAA, 2020). While each of these schools constitutes a privately owned business (save those sponsored by public universities), it would also be true to assert that they play a vital role in sustaining our nation's air transportation infrastructure.

General Aviation – whether for pleasure or as a gateway to the commercial world – is uniquely hazardous. Between 1984 and 2017, the GA sector accounted for 94% of all aviation accidents in the US – 1,143 in 2014 alone (Boyd, 2017). General Aviation has also not benefited from any real improvements in safety over the past three and a half decades *with respect to crash rates*. Meanwhile, Commercial Aviation witnessed a crash reduction of 16% between 1986 and 1995 and a further 6% reduction between 1996 and 2005 (Guohua and Baker, 2007). Pundits within the industry have identified two primary causes behind GA's relatively lackluster safety record.

First, the majority of the 664,000 private pilots in this country are over the age of 55 (Causse, Chua, and Remy, 2019). GA's aged demographic may be attributable to financial constraints. The average Part 61 (part-time) flight school will charge a student $10,000 over the course of a program that may take several months to a year to complete (Houston, 2019). This author personally spent $8,000 for all aerial and classroom training for a Private Pilot's License that concluded just last fall. The financial burden proves an even greater challenge with a family to support and college educations and retirement to save for.

Working men and women in this country also lack the free time. The time that each individual pilot spends in the air, on the ground and in class with an instructor, and at home preparing and studying for examinations and flight varies. This author flew twice each week – three total hours in the air and another hour preparing the plane for each flight – invested three hours each week reviewing knowledge with his flight instructor, and then invested a further two hours each day in self-study. The average American spends 44 hours a week working and several hours every evening completing chores, running errands, and sustaining a family (Ward, 2017). Setting aside a further 20 hours each week to commit to pilot training is a challenge that appears all the more daunting with a family and children.

The second reason most aviation experts illuminate as a leading cause of GA's less than sterling safety record is the weather. Instrument Meteorological Conditions (IMC) – encountered when flying through clouds and poor weather – account for 28% of all GA-related fatalities (Boyd, 2017 and Guohua and Baker, 2007). This author's instructor explained IMC's deadly reputation via a common moniker within the piloting world: "get-there-itis" (Ritzhammer, 2020). The phrase denotes a condition whereby a pilot is so acutely focused on reaching their destination that they will continue a flight and brave poor weather conditions in spite of training deficiencies or a lack of proficiency in IMC conditions. Conversing pilots also commonly employ this phrase when they suspect a party to a recent accident pushed past their limits for fatigue and on to their final destination – when a layover and rest may have restored their motor function and decision-making critical to a safe baseline.

There is much more than meets the eye when it comes to age and the cause of GA accidents, however. David Ison's 2015 study – *Comparative Analysis of Accident and Non-Accident Pilots* – revealed an age-related gap between the two groups. After examining the records of 21,650 GA pilots, Ison identified the median age of pilots involved in an accident to be 42, but the median age of pilots non involved in an accident was a much older 57 (Ison, 2015). These figures appear to defy conventional wisdom, even amongst aviation enthusiasts. It also calls into question the Federal Aviation Administration's (FAA) lawfully mandated retirement age of 65 for all commercial pilots employed by major airlines (FAA, 2009). Another 2002 study appears to support Ison's later finding. Li, Baker, Grabowski, Qiang, McCarthy, and Rebok found the crash rate – per capita – of pilots over age 60 to be similar to that of younger pilots (Li, Baker, Grabowski, Qiang, McCarthy and Rebok, 2002). A third study did confirm conventional wisdom by identifying a strong link between age and cognitive decline in complex tasks. In 2019, Causse, Chua, and Remy put a cohort of 61 "highly educated pilots aged from 19 to 74 years" through a series of tests designed to measure the capacity of their short-term memory. The study found that low to moderate levels of difficulty (eight simultaneous tasks) did not produce a statistically significant difference between age groups. Higher levels of cognitive load (10 to 12 simultaneous tasks) did illuminate a significant difference between the younger and older portions of the cohort and in the form of higher error rates. At the highest level of difficulty (12 tasks), the error rate between the youngest and oldest pilots differed by a factor of well over two – 7.5 mean errors versus 19 mean errors (Cause, Chua, and Remy, 2019). When taken as a whole, the link between age and GA-related accidents is neither clear nor conclusive.

Older pilots are less prone to accidents after examining the raw statistics, but neurological testing suggests that are at increased risk.

Overall health also factors into GA accident risk and partly explains the FAA's mandatory retirement age of 65 for commercial operators. The Centers for Disease Control and Prevention (CDC) states that 42.5% of Americans over the age of 20 are obese (CDC, 2021). Individuals with obesity are more prone to a myriad of health issues such as cardiovascular disease, type two diabetes, and sleep apnea. GA pilots are by no means an exception to our obesity statistics. In fact, the average age of private pilots in this country – 55 years – increases their risk of the aforementioned conditions (Causse, Chua, and Remy, 2019).

Obstructive Sleep Apnea (OSA) is of immediate concern to aviators whose performance depends upon their situational awareness. OSA is a condition whereby adipose (fatty) tissue builds in the neck, throat, and linings of the airway. More than 90% of those with a Body Mass Index of 40 or more have this condition – whether they are diagnosed or not (Boyd, 2017). Snoring is what most laymen think of when they hear of OSA, but its impact goes far beyond interrupting their spouse's sleep. Sufferers cannot adequately breath while lying down and as their Blood Oxygen Content (%O2) level drops below safe levels, the brain awakens briefly to allow the body adjust position and for normal breathing to resume. This happens hundreds or more times throughout the night – preventing OSA patients from securing adequate rest and impacting their ability to function effectively throughout the day (Mayo Clinic, 2021 & Ho and Brass, 2011). One National Institute of Health (NIH) study found that sleep apnea increased the likelihood of a motor vehicle accident by nearly five times – .08 crashes per person, per year to as much as .39 crashes per person, per year (Tregear, Reston, Shoelles, and Phillips, 2009). OSA's impact on the ability to safely pilot an airplane is obvious. Autopsies in aviation crashes are of limited value given the forces victims' bodies sustain on impact, but it is likely that cardiovascular disease or sleep apnea may explain the cause behind many GA accidents.

When it comes to GA aircraft, size matters. GA activities typically involve aircraft that weigh less than 12,500 pounds. The Cessna 172s this author flew at three different training locations were each at least 40 years old according to their Airworthiness Certificates – not one was manufactured later than 1977! Private pilots and training schools tend to purchase lighter, older aircraft in light of financial considerations. This author is currently in the market for a Cessna-172 – and while costs vary depending on year and instrument layout – most used, airworthy aircraft of this make, model, and age will cost between $50,000 and $75,000. Small, slower moving aircraft – however – are more prone to weather-related phenomenon ("Guided," 2015:12-21 & Guohua and Baker, 2007). A 737-airliner weighing 187,800 pounds (94 tons) moving at 500 knots might experience mountain-wave turbulence as a few bumps, but a Cessna-172 that weighs no more than 2,300 pounds at maximum gross weight and traveling at 100 knots may very well exceed maximum design load (g-force) and experience structural failure in that same scenario (Boeing, 2014). Newton's first law regarding objects and their inertia is much more applicable to GA than the commercial industry and almost certainly accounts for a portion of the higher accident rate.

Older model GA aircraft also lack the benefit of more reliable, electronic instruments and flight displays. Electronic instruments and moving maps do not require any moving parts and so do not wear as quickly as analogue instruments driven by vacuum-powered or electronic gyros. Modern, electronic instruments exhibit a much higher mean time between failure rate than do their analogue counterparts and enhance safety in IMC conditions. Electronic flight systems also allow for greater automation and provide near-real-time navigation and weather maps (Boyd, 2017). Pilots flying GA aircraft equipped with such systems need not manage as many simultaneous tasks as pilots flying analogue aircraft, thus freeing their attention to focus more on situational factors. Moving maps also reduce the risk of pilots losing their way and allow for routing around inclement weather. Several GA accidents are attributable to fuel starvation due to loss of position awareness (i.e., “getting lost”) or flying headlong into squalls that exposed those small aircraft to structural loads well beyond design limits.

GA aviators also fall far behind their commercial counterparts when it comes to experience – measured in “flight hours.” Dave Ison’s 2015 study is revealing in this regard as well. After measuring the statistics of the 21,650 pilots included in his study, he found that the mean Total Flight Hours (TFH) for non-accident pilots to be 1,300 hours, while the accident pilots’ TFH was only 50 hours (Ison, 2015). This statistic is of particular importance to flight school owners and Instructor Pilots (IPs). The FAA has measured the mean TFH to earn a Private Pilot’s License at approximately 60 hours (Houston, 2019). These figures suggest that a large percentage of the accident pilots in the Ison study crashed while still in training and before they earned a license. Ison went on to fit a “gamma distribution” to his crash rate versus TFH statistic and identified a window of enhanced risk for GA accidents: 50 – 350 hours of experience. Not only are students at increased risk, but so too are newly licensed private pilots for their first several hundred hours. Ison identified “overconfidence” as a likely culprit worthy of further investigation (Ison, 2015).

In a 2011, Bazargan and Guzhva made as significant conclusion in their own study: while the accident rate decreases with experience, the fatality rate increases as the type of crashes are more likely to be fatal (Bazargan and Guzhva, 2011). As pilots accumulate more experience, the location of crashes moves further and further away from the airfield. Students are more likely to wreck during takeoff and landing – a critical skill that can be mastered with a fair degree of practice. More experienced pilots – on the other hand – encounter trouble when them make ill-fated decisions about continuing through weather, IMC conditions, or when they are fatigued (Ritzhammer, 2020 & Bazargan and Guzhva, 2011). A 2002 study completed by Li, Baker, Grabowski, Qiang, McCarthy, and Rebok examined similar data and concluded with similar results on a larger scale. Pilots with less than 5,000 hours were more than twice as likely to be involved in a crash (8.2 versus 4.4 crashes per million flight hours). Pilots with between 5,000 hours and 9,999 hours saw a 57% reduction in crash risk (Li, Baker, Grabowski, Qiang, McCarthy, and Rebok, 2002). Bilal Killic's study of American GA accidents this last year found that "skill-based errors accounted for 80% of all accidents" (Killic, 2019).

Experience in GA can be difficult to come by in light of its cost, however. This author pays $125 an hour to rent a Cessna-172, fuel included. A typical 100-hour inspection – mandated by the FAA for all aircraft used in training and for rentals – can cost upwards of $3,000. Operating your own aircraft can produce a cost savings provided no major repair work is needed in a given time period, but repairs can be prohibitively expensive. A 150-horsepower engine powering a Cessna-172 will cost the owner more than $10,000 to overhaul at most reputable repair operations. A new pilot exiting initial training might not fly more than a few times each month due to financial barriers. Unlike his or her commercial counterparts – who are paid to fly *and* to train – the private aviator must pay his or her own way. Frequency of flight varies from one individual to the next based on income, employment responsibilities, and family obligations, etc. Therefore, it may take decades for a private pilot to accumulate only a fraction of the experience a commercial aviator might accumulate in a few short years.

2. HYPOTHESES

The aforementioned data sources make some interesting connections worth investigating. Ison's 2015 study identified a median age gap between accident and non-accident pilots – 42 and 57 years of age, respectively. Causse, Chua, and Remy's 2019 study appears to contradict Ison's finding – confirming common knowledge regarding aging and cognitive performance. The FAA, Bureau of Transportation Statistics, and Elena Mazareanu's 2020 report titled *Number of Fatal and Non-Fatal Accidents in General Aviation in the United States Between 2000 and 2019* provide us with sufficient statistics to perform a comparative analysis and either confirm or disprove the above studies (Mazareanu, 2020). The study proposes the following hypotheses to determine the link between pilot age and accident rates:

Ho: The Average Pilot Age does not impact the annual number of Non-Fatal Accidents

Ho: The Average Pilot Age does not impact the number of Fatal Accidents

Examining the above data sources also begs further questions. There appears to be an obvious decline in private pilot age, the number of active private pilots, the frequency of non-fatal GA accidents, and the frequency of fatal GA accidents with respect to *time*. To prove or disprove a relationship, this study also proposes the following null hypotheses:

Ho: Time does not impact the number of Private Pilots

Ho: Time does not impact the number of Non-Fatal Accidents

Ho: Time does not impact the number of Fatal Accidents

Ho: Time does not impact the Average Pilot Age

Ho: The number of Private Pilots does not impact Average Pilot Age

A cross-check between the obvious decline in the number of private pilots and the decline in both fatal and non-fatal GA accidents suggests another link. Perhaps the declining number of aviators translates into fewer accidents. This study will examine possible relationships between these three variables as well:

> Ho: The number of Private Pilots does not impact the number of Non-Fatal Accidents
>
> Ho: The number of Private Pilots does not impact the number of Fatal Accidents

The Bureau of Transportation Statistics statistical summary also provides the total number of GA hours flow every year. This annual number has also been in decline since at least the FAA's data suggest a decline in the number of private pilots. This study will examine four further null hypotheses:

> Ho: Time does not impact the number of GA Hours Flown
>
> Ho: The number of Private Pilots does not impact the number of GA Hours Flown
>
> Ho: The number of GA Hours Flown does not impact the number of Non-Fatal Accidents
>
> Ho: The number of GA Hours Flown does not impact the number of Fatal Accidents

3. DATA SOURCES AND ANALYTICAL PLATFORM

For this project, the author chose to collect the majority of the data from the Federal Aviation Administration (FAA) website (FAA.gov). The FAA maintains more than 664,000 active pilot records at its Aeronautical Center in Oklahoma City. The agency harvests data from those records to produce its annual *Active Civil Airmen Statistics* summary and publishes the results electronically via downloadable Microsoft Excel files. Published data go back as far as 2005, which served as the historical limit for this study. Figures for the "#private pilots" and "avg pilot age" variables are lifted from this FAA report.

The FAA's data come in the form of annual, summary statistics. Individual pilot records are protected by the National Security Act and public access is prohibited. Even if the FAA availed those records to us, the standard eight gigabyte personal computer and JMP software do not possess the RAM to process the large volume of data points. Each of those 664,000 active pilot records contain up to perhaps a dozen data points of their own. The tools available cannot process the eight million-plus data points individual pilot records present. Individual statistics might prove more accurate, but we are limited by the technology.

Data for the "#GA hours flown" variable originates from the Bureau of Transportation Statistics (BTS) website (bts.gov) (BTS, 2021). The BTS also published its data in Microsoft Excel Format. This collection of data dates back to 1960, but this study only harvested data as far back as 2005. Without FAA data dating back any further, we cannot analyze and compare before that year.

The last two variables included in our analysis – "#fatal accidents" and "#non-fatal accidents" – originated from Elena Mazareanu 2020 report titled *Number of fatal and non-fatal accidents in general aviation in the United States between 2000 and 2019*. This report summarizes and discusses the number of GA fatal and non-fatal accidents during the inclusive years (Mazareanu, 2020). While the data date back to 2000, only those data from 2005 were included. The FAA's available data do not permit us to analyze any further back in time.

The JMP program – authored by the SAS Institute – served as the analytical engine for this research study. The program offers fit modeling, residual analysis, linear regression, and predictive modeling (forecasting) tools. This author downloaded a 30-day free trial from the SAS Institute's website to power the analysis.

4. RESEARCH METHODS

This study chose to cross-examine six variables: "#private pilots," "avg pilot age," "#GA hours flown," "#fatal accidents," "#non-fatal accidents," and "Yr" for mathematical relationships. The final variable – time – is inferred. Our sources published their data versus time and so it serves as a logical, independent variable in several parts of the analysis.

After identifying our variables, the study moved on to establishing linear, mathematical correlation. This study sought to perform linear regressions to prove relationships *between* variables – a process this type of correlation is best suited for. Linear correlation measures the "linear association between *x* values and *y* values in the sample" and is donated by the character *r*. Simply stated, linear correlation tells us how well the data points between two variables form a straight line when plotted on an *x* and *y* graph. An *r* value of zero or near-zero boasts no correlation. An absolute *r* value of greater than .7 denotes "strong correlation" between the variables (McClave, Benson, and Sincich, 2014). Negative *r* values denote negative linear associations in which the slope of a fitted line will be negative. Positive *r* values denote positive relationships and linear slopes. JMP identified nine variable relationships where absolute *r* values were greater than .7 (i.e., strong correlation).

The study then plotted those nine variable relationships and attempted to fit a trend line. This type of mathematical analysis is better known as "linear regression" – a process by which a researcher attempts to explain the behavior of the data using a linear mathematical function. The JMP software also calculates several other mathematical figures to *gauge* the fit of the line or regression. The most telling is the "r-squared" value. R-squared – denoted as *r^2* – tells the researcher how many of the data points are adequately explained by the fitted trend line. Put in simpler terms: approximately what percentage of the values in the data set rest on the regression line itself. Researchers generally consider R-squared values of greater than .9 to be highly accurate, but this study chose .8 to as the mathematical floor (McClave, Benson, and Sincich, 2014). The graphs and regressions JMP performed on four of this study's variable relationships met the .8 R-squared standard.

A relatively high R-squared value is only relevant measure of a trend line's fit. The study then dove deeper into the variable relationships – examining residual plots for auto correlation and p-values. The presence of auto-correlation gives us further information regarding the accuracy of the regression line's fit, while the p-values can tell us more about prospective hypothesis testing results on the X-variable and Y-intercept for the function on which it is performed. Low p-values are an effective, affirmative answer to rejecting the null hypothesis. A null hypothesis is presented for each variable relationship – this study does not attempt to answer one question about data relationships, but several.

5. RESULTS

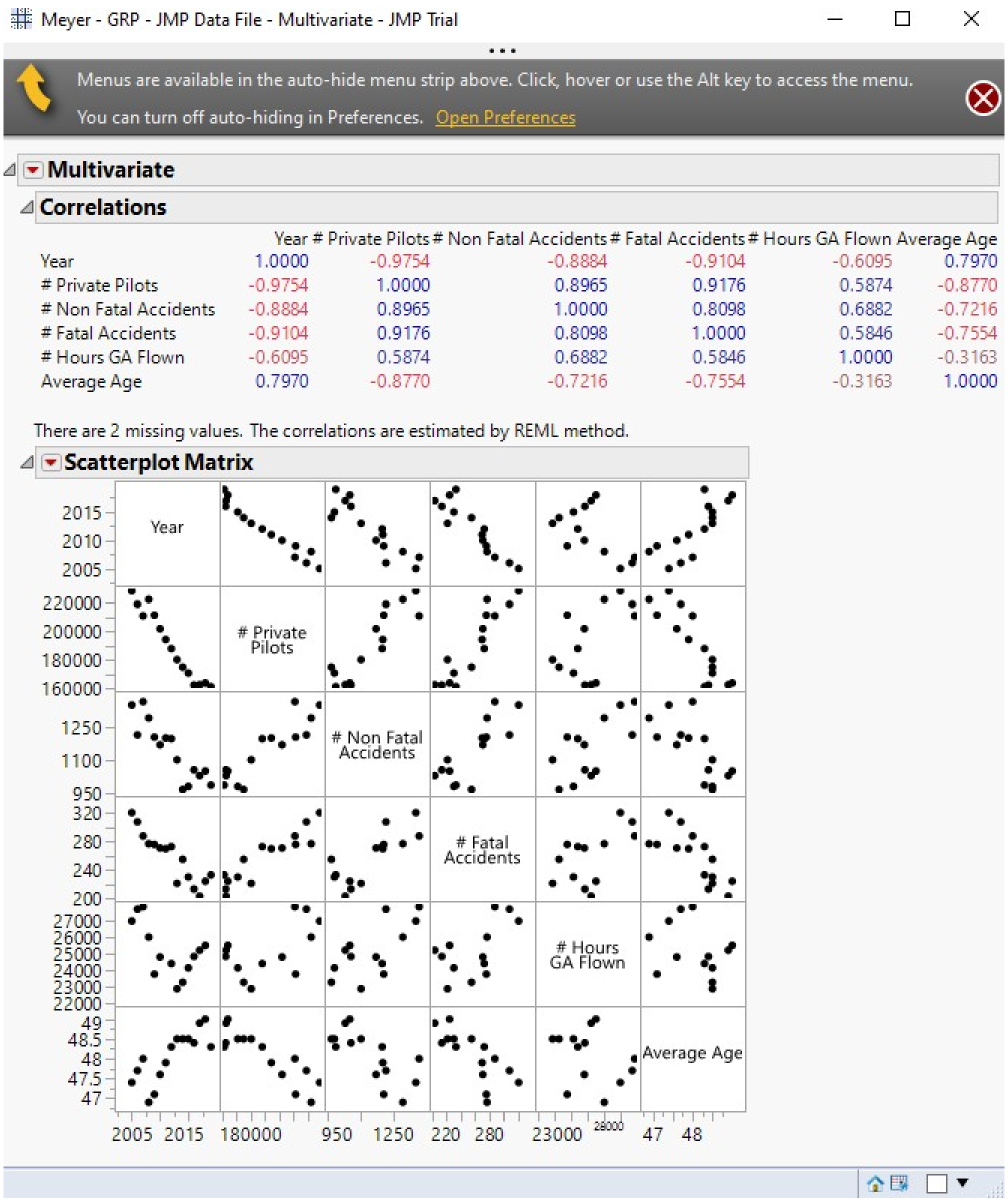
5.1 Examining Variable Correlation

The below chart is the initial aggregation of the data for our five variables dating back to 2005:

Year	# Private Pilots	Average Age	# Hours Flown	Non-Fatal Accidents	Fatal Accidents
2005	228,619	47.4	26,982	1351	321
2006	219,233	47.7	27,705	1215	308
2007	211,096	48	27,852	1366	288
2008	222,596	46.9	26,009	1292	277
2009	211,619	47.1	23,763	1205	276
2010	202,020	47.6	24,802	1170	271
2011	194,441	47.9	-	1201	270
2012	188,001	48.3	24,403	1198	273
2013	180,214	48.5	22,876	1102	221
2014	174,883	48.5	23,271	967	255
2015	170,718	48.5	24,142	981	230
2016	162,213	48.4	24,833	1056	213
2017	162,455	48.9	25,212	1030	203
2018	163,695	49	25,506	1051	224
2019	161,105	48.3	-	987	233

After reviewing the numbers, some obvious patterns emerge. The number of private pilots is steadily decreasing, while the average age of a private pilot has steadily increased. There exists and inverse correlation between time and both of these variables as well as between one another. The number of GA hours flown annually also appears to be decreasing steadily, suggesting a positive relationship between the number of pilots and the average age of those pilots. This decrease in hours flown also suggests and inverse correlation with respect to time. The number of non-fatal and fatal accidents both decrease over the same time span. Their relationship to the number of private pilots and hours flown is positive, but their correlation with respect to pilot age and time appears negative.

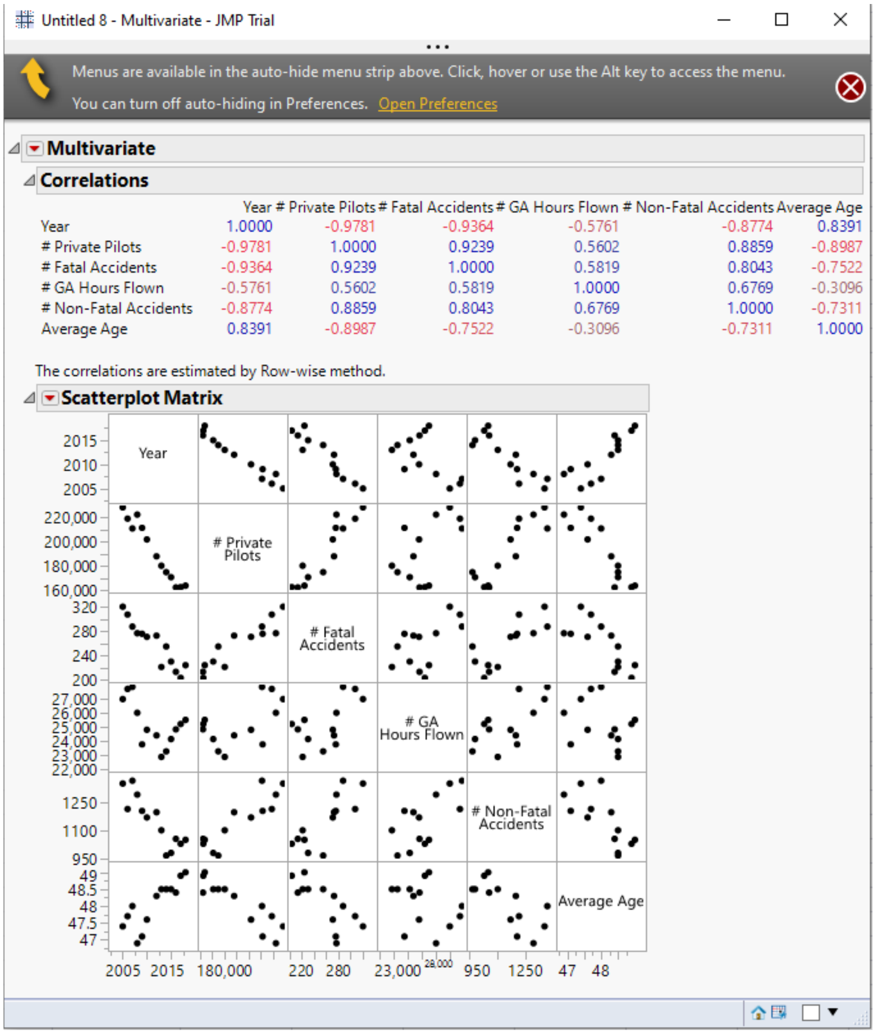
To confirm these initial observations, these data points were loaded into JMP and analyzed using the correlation function to produce the below depiction:



	Year	# Private Pilots	# Non Fatal Accidents	# Fatal Accidents	# Hours GA Flown	Average Age
Year	1.0000	-0.9754	-0.8884	-0.9104	-0.6095	0.7970
# Private Pilots	-0.9754	1.0000	0.8965	0.9176	0.5874	-0.8770
# Non Fatal Accidents	-0.8884	0.8965	1.0000	0.8098	0.6882	-0.7216
# Fatal Accidents	-0.9104	0.9176	0.8098	1.0000	0.5846	-0.7554
# Hours GA Flown	-0.6095	0.5874	0.6882	0.5846	1.0000	-0.3163
Average Age	0.7970	-0.8770	-0.7216	-0.7554	-0.3163	1.0000

It would appear those initial, mathematical assumptions are correct. Both positive and negative *r* values appear where we might have initially expected. This chart goes deeper than just proving correlation, however. JMP returned corresponding *r* values for each variable relationship – indicating just how strong the positive or negative correlation is. The below scatterplot matrix shows us what a graph of each relationship *may* look like, but caution must be exercised in their interpretation. These charts are *not* generated to-scale and are subject to visual distortion that might confuse the researcher. To-scale depictions were performed later while performing linear regressions. McClave, Benson, and Sincich tell us that “strong correlation” exists between variables when their *r* value is .7 or higher (McClave, Benson, and Sincich, 2014). Based on that standard, this study excludes four relationships: “Yr” versus “#GA Hours Flown,” “#Private Pilots” versus “#GA Hours Flown,” “#GA Hours Flown” versus “#Fatal Accidents,” and “#GA Hours Flown” versus “#Non-Fatal Accidents.” One possible explanation for such low *r* values within the relationships could be attributed to the two missing data points for the “#GA Hours Flown.” Thus, the researcher performed a second correlation table and corresponding matrix in JMP – this time excluding all of the data from the other variables for the two years for which there are no figures for “#GA Hours Flown”:

Year	# Private Pilots	Average Age	# Hours Flown	Non-Fatal Accidents	Fatal Accidents
2005	228,619	47.4	26,982	1351	321
2006	219,233	47.7	27,705	1215	308
2007	211,096	48	27,852	1366	288
2008	222,596	46.9	26,009	1292	277
2009	211,619	47.1	23,763	1205	276
2010	202,020	47.6	24,802	1170	271
2012	188,001	48.3	24,403	1198	273
2013	180,214	48.5	22,876	1102	221
2014	174,883	48.5	23,271	967	255
2015	170,718	48.5	24,142	981	230
2016	162,213	48.4	24,833	1056	213
2017	162,455	48.9	25,212	1030	203
2018	163,695	49	25,506	1051	224



	Year	# Private Pilots	# Fatal Accidents	# GA Hours Flown	# Non-Fatal Accidents	Average Age
Year	1.0000	-0.9781	-0.9364	-0.5761	-0.8774	0.8391
# Private Pilots	-0.9781	1.0000	0.9239	0.5602	0.8859	-0.8987
# Fatal Accidents	-0.9364	0.9239	1.0000	0.5819	0.8043	-0.7522
# GA Hours Flown	-0.5761	0.5602	0.5819	1.0000	0.6769	-0.3096
# Non-Fatal Accidents	-0.8774	0.8859	0.8043	0.6769	1.0000	-0.7311
Average Age	0.8391	-0.8987	-0.7522	-0.3096	-0.7311	1.0000

This second matrix did not yield improved results for "#GA Hours Flown" versus each of the other variables. If we look at the values in the column corresponding to this variable versus the four others, each of the *r* values still failed to reach the .7 standard. The study then preceded to examine the nine variable relationships – those that did meet or exceed the .7 *r* value standard – in greater detail:

1. "Yr" versus "#Private Pilots"
2. "Yr" versus "#Non-Fatal Accidents"
3. "Yr" versus "#Fatal Accidents"
4. "Yr" versus "Avg Pilot Age"

5. "#Private Pilots" versus "#Non-Fatal Accidents"

6. "#Private Pilots" versus "#Fatal Accidents"

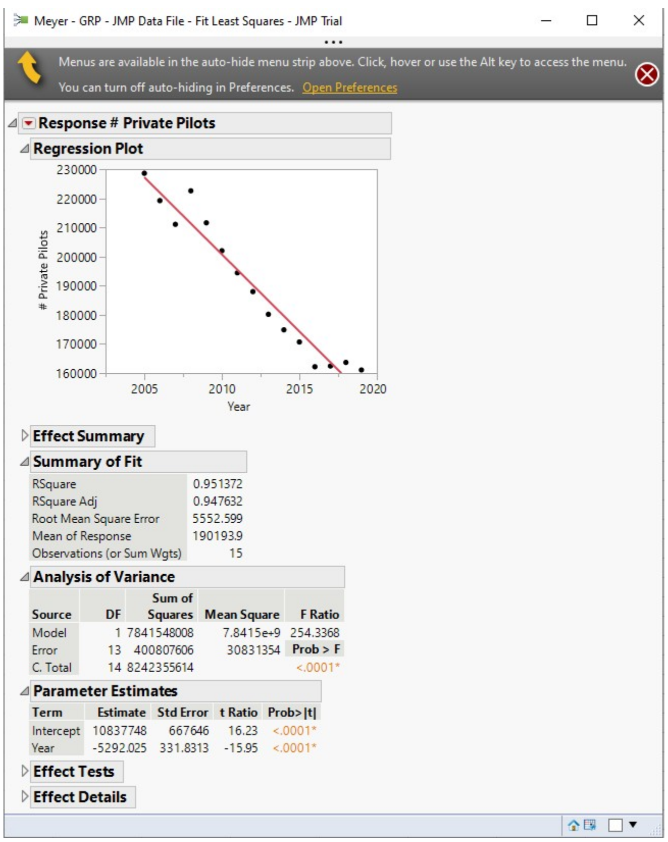
7. "#Private Pilots" versus "Avg Pilot Age"

8. "Avg Pilot Age" versus "#Non-Fatal Accidents"

9. "Avg Pilot Age" versus "#Fatal Accidents"

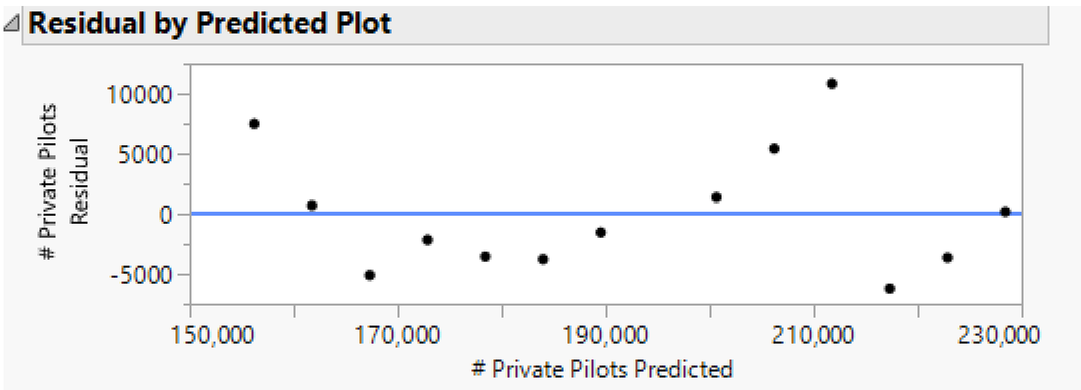
5.2 "Yr" versus "#Private Pilots"

Performing a linear regression analysis between time ("Yr") and "#Private Pilots" yielded the following plot and figures in JMP:



The scatter plot and linear regression line are consistent with the negative *r* value determined by JMP in the correlation matrix (-.9781). The negative correlation manifested as a downward – or negative – line slope that closely matched the data points. The R-squared value is a highly accurate .9513! This means that a linear regression closely matches the presented data and *may* be useful in determining past values beyond the data set or even forecasting values into the future. The prediction equation corresponding to this line is: y = -.5292.025(X) + 10837748. Each of the p-values JMP returned for this equation – for both the X-variable and the Y-intercept – are approaching zero (less than .0001).

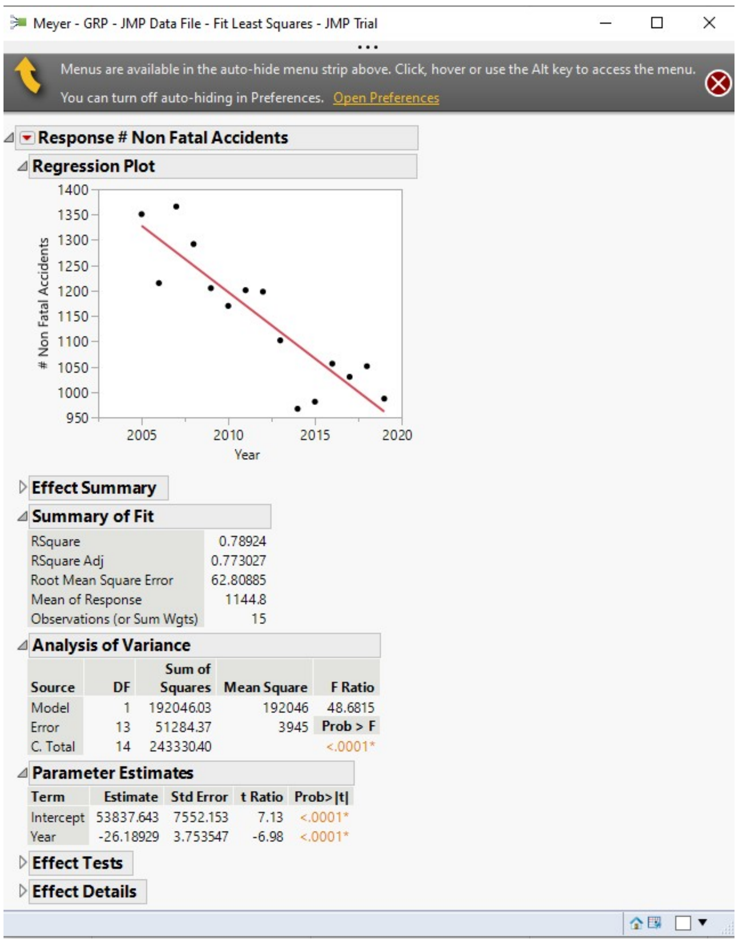
The study moved on to examine the residuals and plotted the following in JMP:



There does not appear to be any significant negative auto-correlation in this data set as it relates to the linear regression line. There does appear to be some degree of positive auto-correlation. McClave, Benson, and Sincich define positive auto-correlation as residual errors of one type proceeded by residual errors of the opposite type (McClave, Benson, and Sincich, 2014). Looking at this residual plot, we do see a serious of positive values, followed by negative values, then more positive values, etc. The R-squared value for this linear regression is strong, but the presence of auto-correlation dictates that we take care in using this linear function in predicting past or future values. Auto-correlation means significant variance is present and must be accounted for. McClave, Benson, and Sincich go on to explain how residual plots can tell us what mathematical function better fits the data set (McClave, Benson, and Sincich, 2014). Having said that, the residual does not readily resemble any sort of mathematical function and so a regression line is likely the most appropriate fit for this comparison between time and the number of private pilots in a given year. A poly-numeric function may fit the data, but is beyond the scope of this study.

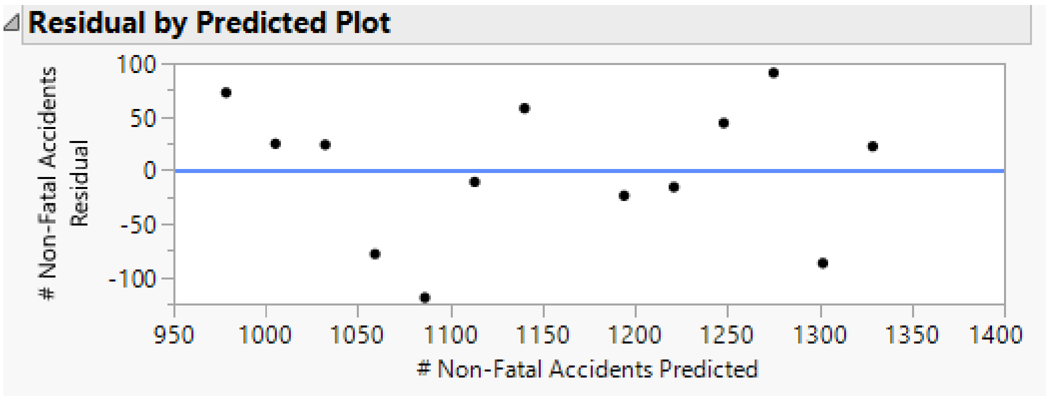
5.3 "Yr" versus "#Non-Fatal Accidents"

Performing a linear regression analysis between time ("Yr") and "#Non-Fatal Accidents" yielded the following plot and figures in JMP:



The scatter plot and linear regression line are consistent with the negative *r* value determined by JMP in the correlation matrix (-.8884). The negative correlation manifested as a downward – or negative – line slope that closely matched the data points. The R-squared value is a reasonably accurate .7892. This means that a linear regression reasonably matches the presented data and *may* be useful in determining past values beyond the data set or even forecasting values into the future. The prediction equation corresponding to this line is: y = -26.19(X) + 53837.6. Each of the p-values JMP returned for this equation – for both the X-variable and the Y-intercept – are approaching zero (less than .0001).

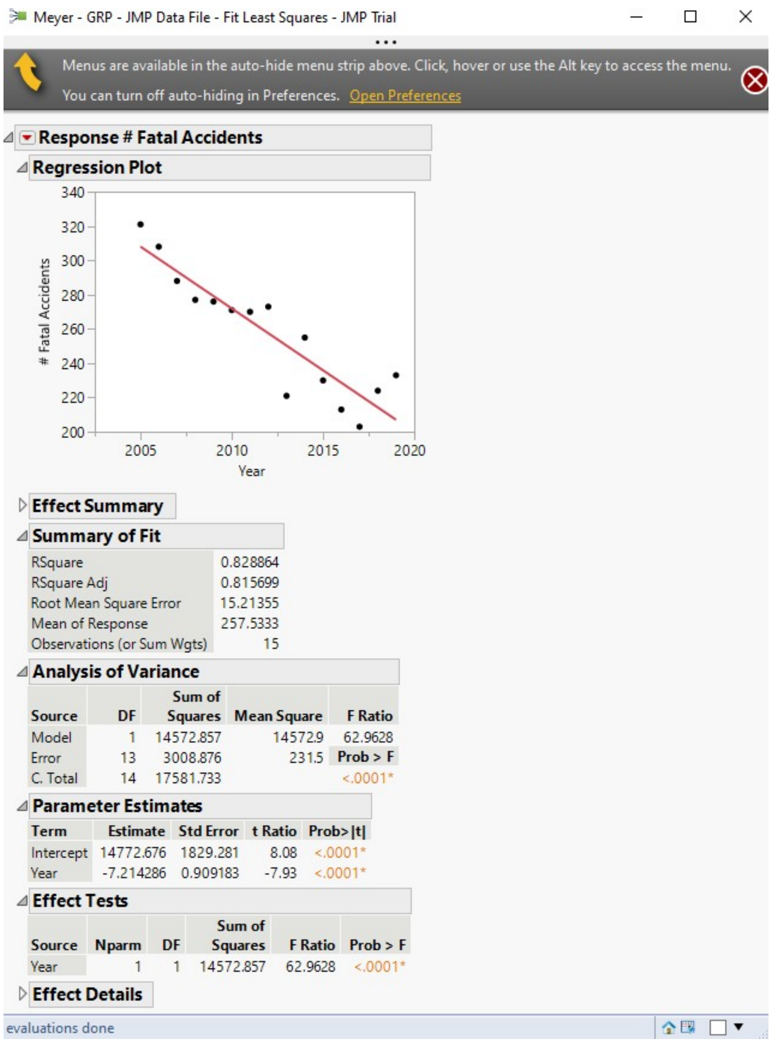
The study moved on to examine the residuals and plotted the following in JMP:



There does appear to be some positive auto-correlation present in the data – where groups of positive values are preceded by negative values throughout the function. A poly-numeric mathematical function may better fit the data as is presented on the residual chart. Between the auto-correlation present in the function *and* the lower R-squared value between these variables, this relationship cannot be said to be overwhelmingly strong. The very low P-values may weigh heavily on hypothesis consideration, however.

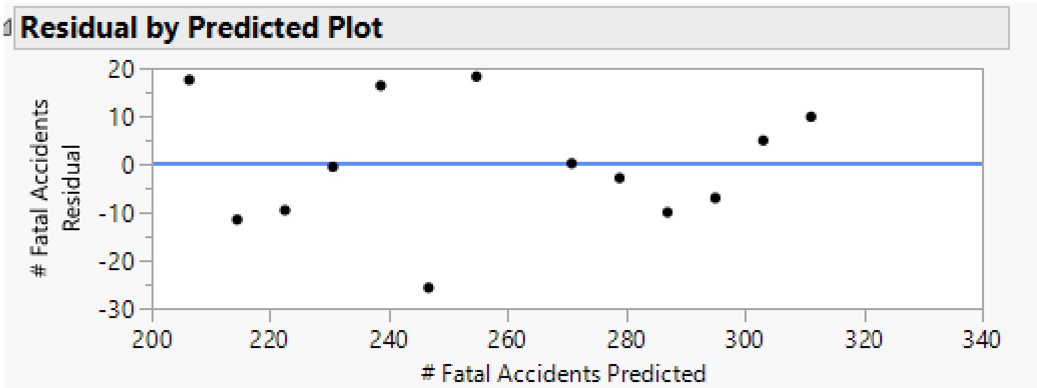
5.4 "Yr" versus "#Fatal Accidents"

Performing a linear regression analysis between time ("Yr") and "#Non-Fatal Accidents" yielded the following plot and figures in JMP:



The scatter plot and linear regression line are consistent with the negative *r* value determined by JMP in the correlation matrix (-.9104). The negative correlation manifested as a downward – or negative – line slope that closely matched the data points. The R-squared value is a reasonably accurate .8288. This means that a linear regression closely matches the presented data and *may* be useful in determining past values beyond the data set or even forecasting values into the future. The prediction equation corresponding to this line is: $y = -7.214(X) + 14772.67$. Each of the p-values JMP returned for this equation – for both the X-variable and the Y-intercept – are approaching zero (less than .0001).

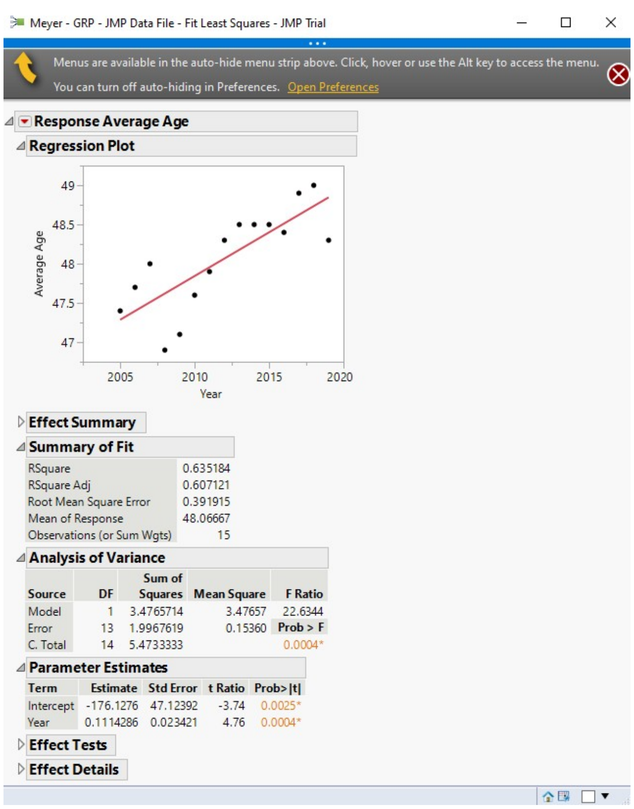
The study moved on to examine the residuals and plotted the following in JMP:



Positive auto-correlation is present in this sample of data as well. A poly-numeric mathematical function may better fit the data as is presented on the residual chart. The relatively high R-squared value and very low P-values might lead us to reject any null-hypothesis.

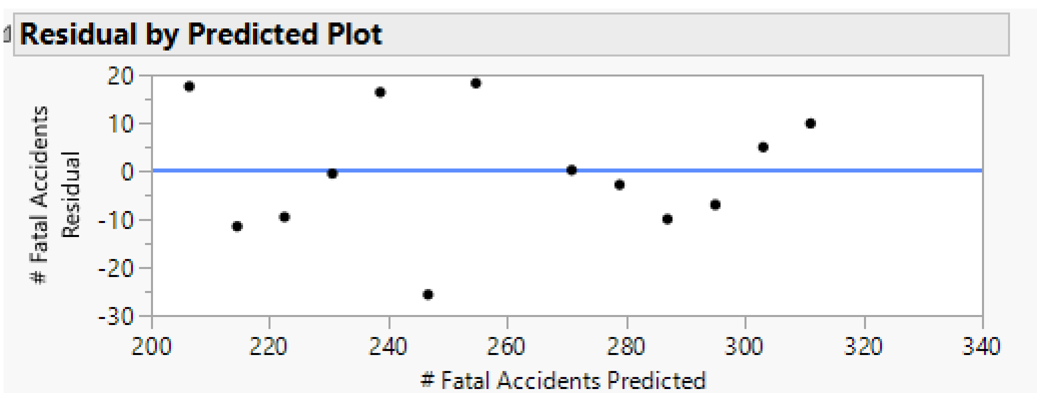
5.5 “Yr” versus “Avg Pilot Age”

Performing a linear regression analysis between time (“Yr”) and “Avg Pilot Age” yielded the following plot and figures in JMP:



The scatter plot and linear regression line are consistent with the positive *r* value determined by JMP in the correlation matrix (.7970). The positive correlation manifested as an upward – or positive – line slope that matched the data points. The R-squared value is a relatively low .6352. This means that a linear regression does not closely match the presented data and *may not* be useful in determining past values beyond the data set or even forecasting values into the future. The prediction equation corresponding to this line is: y = .1114(X) + -176.13. Each of the p-values JMP returned for this equation – for both the X-variable and the Y-intercept – are very low (.0025 and .0004).

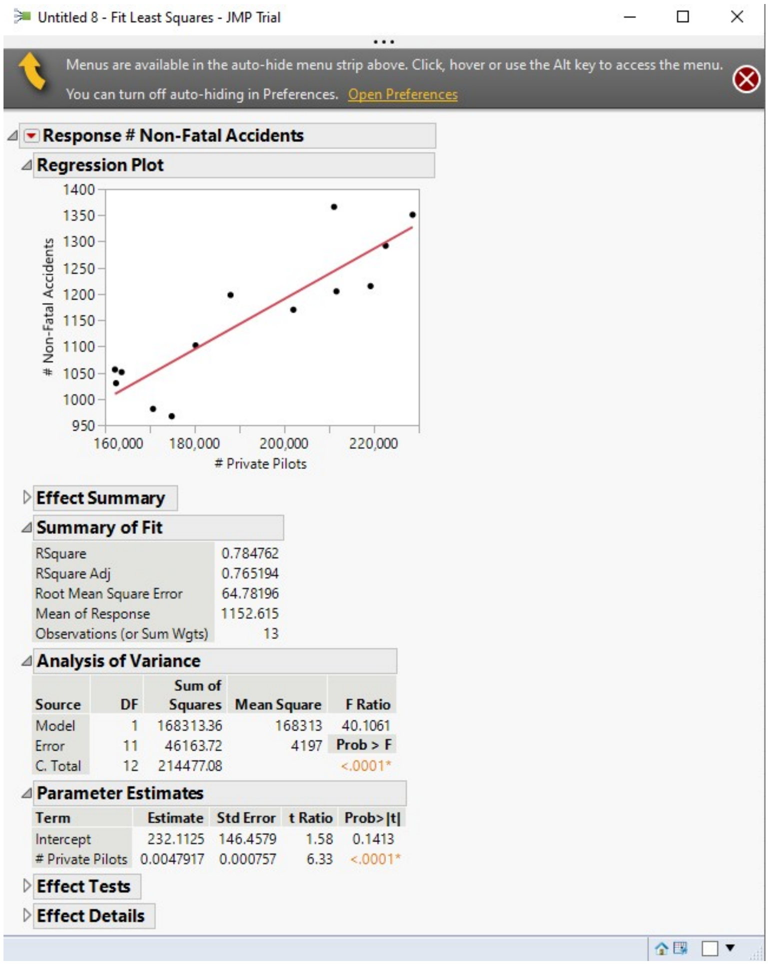
The study moved on to examine the residuals and plotted the following in JMP:



Positive auto-correlation is present in this sample of data. A poly-numeric mathematical function may better fit the data as is presented on the residual chart. The relatively low R-squared value, but low P-values suggest that this function may not be sufficient to reject a null hypothesis.

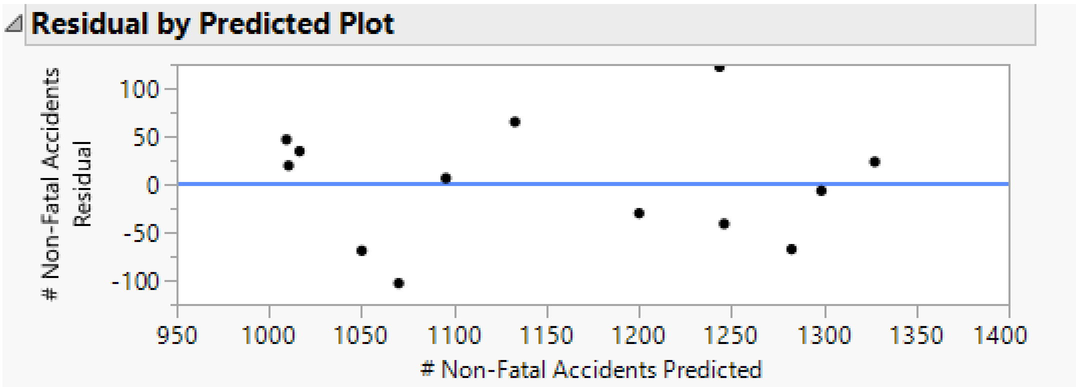
5.6 "#Private Pilots" versus "#Non-Fatal Accidents"

Performing a linear regression analysis between "#Private Pilots" and "#Non-Fatal Accidents" yielded the following plot and figures in JMP:



The scatter plot and linear regression line are consistent with the positive *r* value determined by JMP in the correlation matrix (.8965). The positive correlation manifested as an upward – or positive – line slope that matched the data points. The R-squared value is a modest .7847. This means that a linear regression reasonably matches the presented data and *may* be useful in determining past values beyond the data set or even forecasting values into the future. The prediction equation corresponding to this line is: y = .00479(X) + 232.11. The p-value for the intercept was a relatively high .1413, but he p-value for the X-variable approached zero.

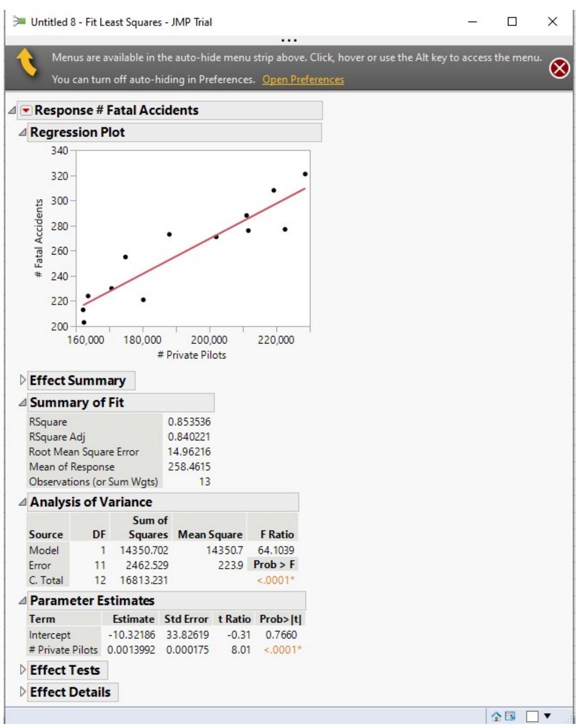
The study moved on to examine the residuals and plotted the following in JMP:



Positive auto-correlation is present in this sample of data as well. A poly-numeric mathematical function may better fit the data as is presented on the residual chart. The modest R-squared value, but mixed P-values, suggest that this function may not be sufficient to reject a null hypothesis.

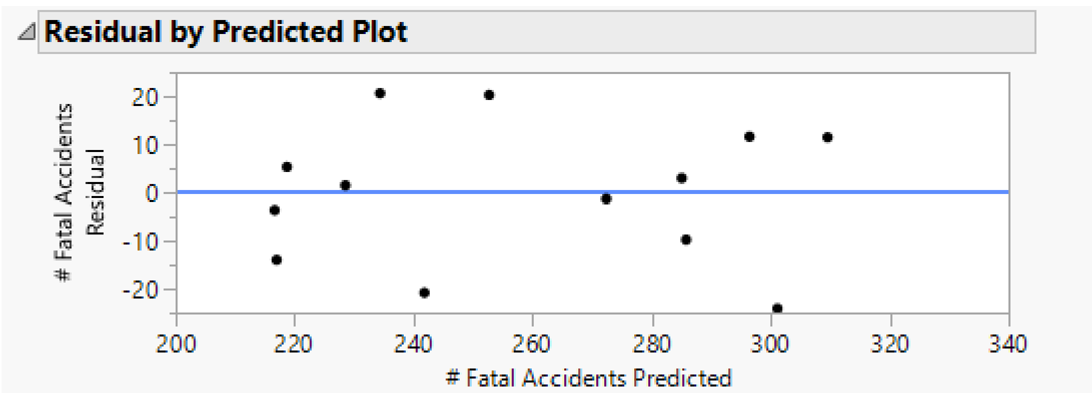
5.7 "#Private Pilots" versus "#Fatal Accidents"

Performing a linear regression analysis between "#Private Pilots" and "#Fatal Accidents" yielded the following plot and figures in JMP:



The scatter plot and linear regression line are consistent with the positive *r* value determined by JMP in the correlation matrix (.9176). The positive correlation manifested as an upward – or positive – line slope that closely matched the data points. The R-squared value is relatively strong .8535. This means that a linear regression closely matches the presented data and *may* be useful in determining past values beyond the data set or even forecasting values into the future. The prediction equation corresponding to this line is: y = .0014(X) + -10.32. The p-value for the intercept was a relatively high .7660 but he p-value for the X-variable approached zero.

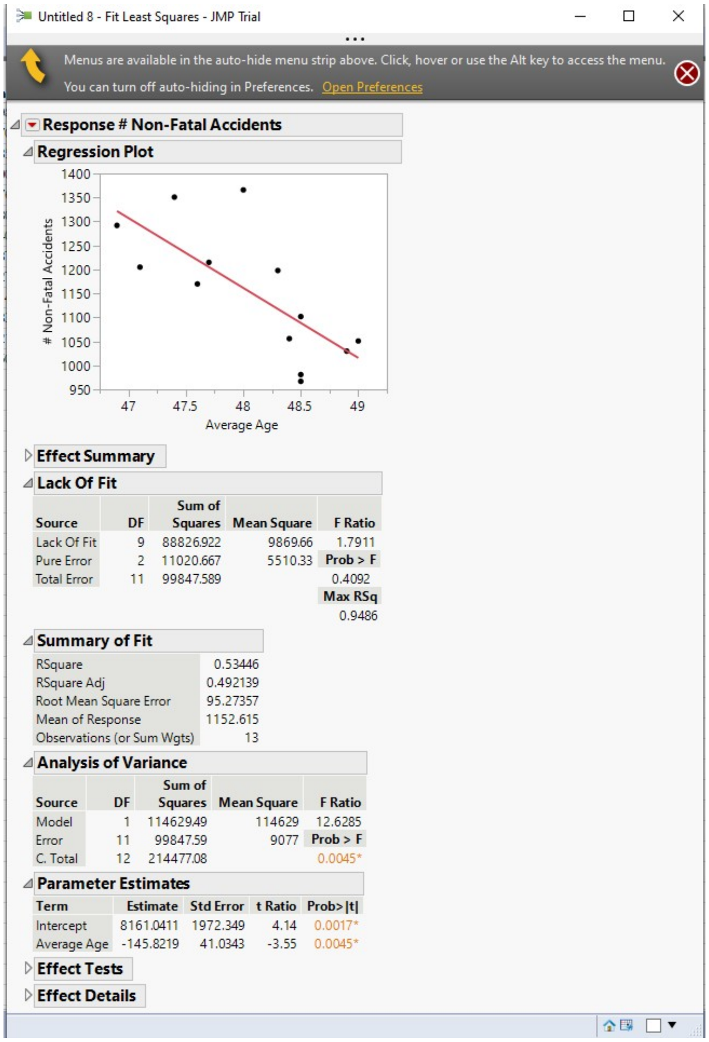
The study moved on to examine the residuals and plotted the following in JMP:



A small amount of both positive and negative auto-correlation are present in this sample of data. A poly-numeric mathematical function may better fit the data as is presented on the residual chart. The strong R-squared value, but mixed P-values suggest that this function may not be sufficient to reject a null hypothesis.

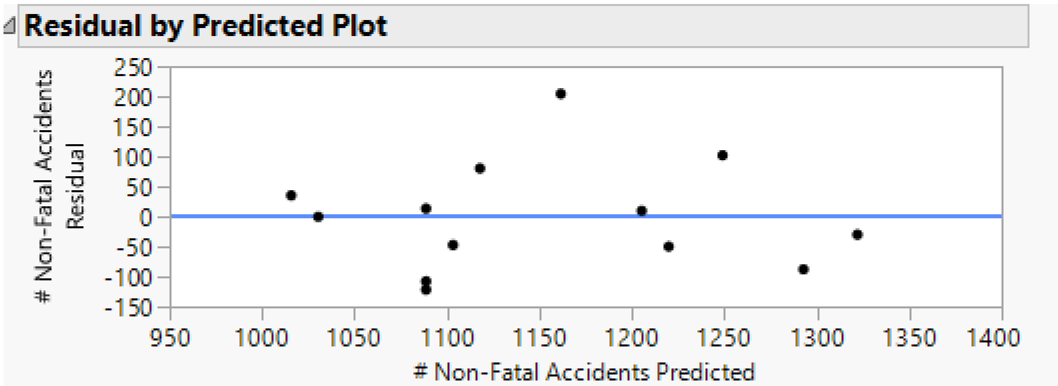
5.8 "Avg Pilot Age" versus "#Non-Fatal Accidents"

Performing a linear regression analysis between "Avg Pilot Age" and "#Non-Fatal Accidents" yielded the following plot and figures in JMP:



The scatter plot and linear regression line are consistent with the negative *r* value determined by JMP in the correlation matrix (-.7216). The negative correlation manifested as a downward – or negative – line slope that closely matched the data points. The R-squared value is a relatively low .5345. This means that a linear regression does not closely match the presented data and *may not* be useful in determining past values beyond the data set or even forecasting values into the future. The prediction equation corresponding to this line is: y = -145.82(X) + 8161.04. Both p-values are approach zero.

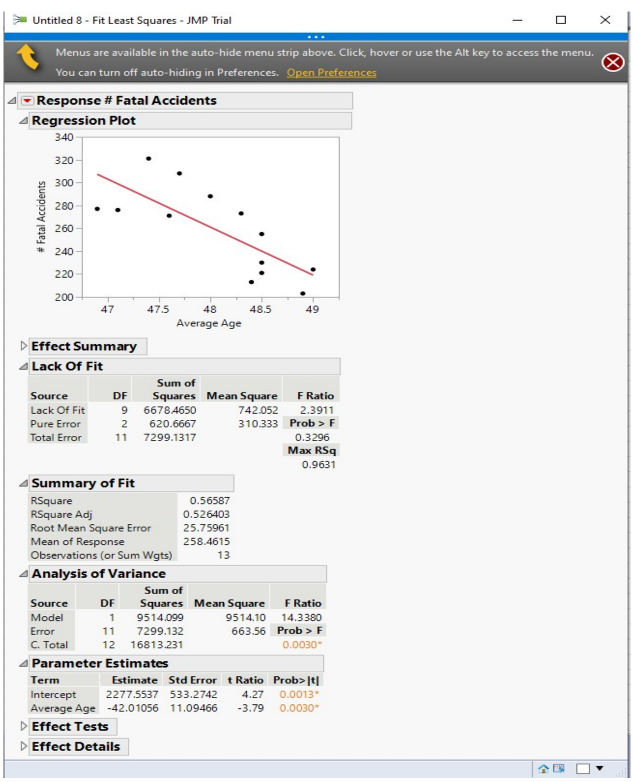
The study moved on to examine the residuals and plotted the following in JMP:



A small amount of positive auto-correlation are present in this sample of data. A poly-numeric mathematical function may better fit the data as is presented on the residual chart. The weak R-squared value, but strong P-values suggest that this function may not be sufficient to reject a null hypothesis.

5.9 "Avg Pilot Age" versus "#Fatal Accidents"

Performing a linear regression analysis between "Avg Pilot Age" and "#Non-Fatal Accidents" yielded the following plot and figures in JMP:



Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	9	6678.4650	742.052	2.3911
Pure Error	2	620.6667	310.333	Prob > F
Total Error	11	7299.1317		0.3296
				Max RSq
				0.9631

Summary of Fit

RSquare	0.56587
RSquare Adj	0.526403
Root Mean Square Error	25.75961
Mean of Response	258.4615
Observations (or Sum Wgts)	13

Analysis of Variance

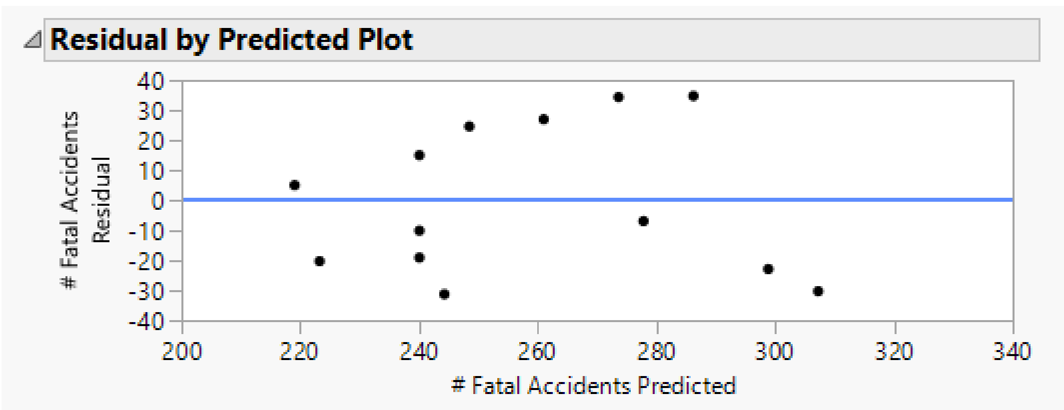
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	9514.099	9514.10	14.3380
Error	11	7299.132	663.56	Prob > F
C. Total	12	16813.231		0.0030*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2277.5537	533.2742	4.27	0.0013*
Average Age	-42.01056	11.09466	-3.79	0.0030*

The scatter plot and linear regression line are consistent with the negative *r* value determined by JMP in the correlation matrix (-.7554). The negative correlation manifested as a downward – or negative – line slope that closely matched the data points. The R-squared value is a relatively low .5658. This means that a linear regression does not closely match the presented data and *may not* be useful in determining past values beyond the data set or even forecasting values into the future. The prediction equation corresponding to this line is: y = -42(X) + 2277.55. Both p-values are approach zero.

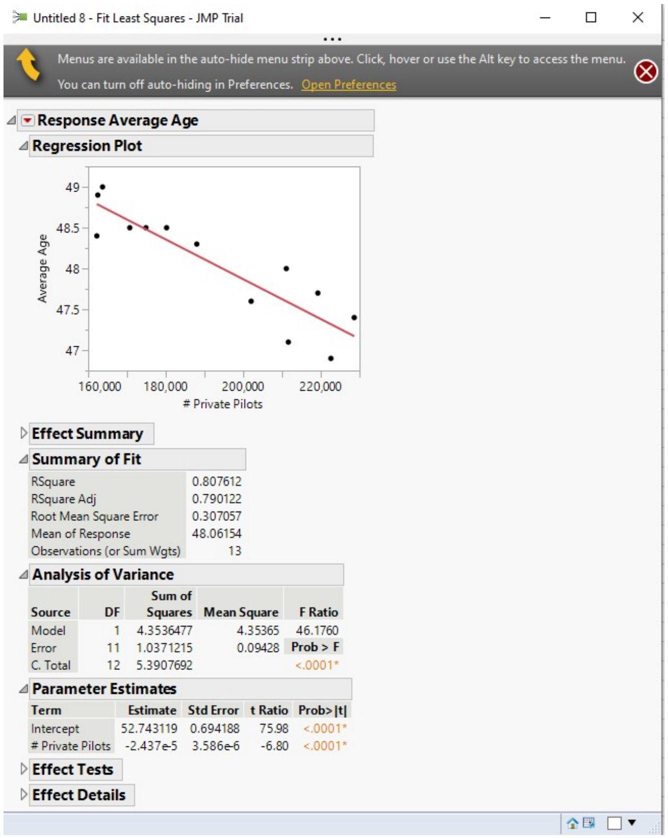
The study moved on to examine the residuals and plotted the following in JMP:



A small amount of both positive and negative auto-correlation are present in this sample of data. A poly-numeric mathematical function may better fit the data as is presented on the residual chart. The weak R-squared value, but strong P-values suggest that this function may not be sufficient to reject a null hypothesis.

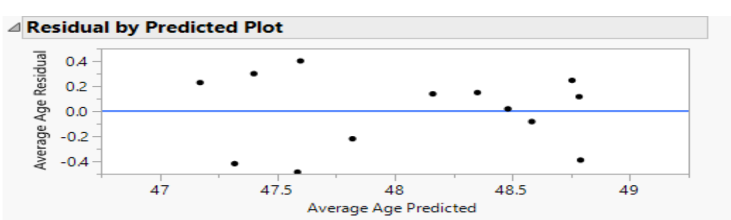
5.10 "#Private Pilots" versus "Avg Pilot Age"

Performing a linear regression analysis between "#Private Pilots" and "Avg Pilot Age" yielded the following plot and figures in JMP:



The scatter plot and linear regression line are consistent with the negative *r* value determined by JMP in the correlation matrix (-.8770). The negative correlation manifested as a downward – or negative – line slope that closely matched the data points. The R-squared value is a modest .8076. This means that a linear regression reasonably matches the presented data and *may* be useful in determining past values beyond the data set or even forecasting values into the future. The prediction equation corresponding to this line is: y = -2.437(xe^5) (X) + 52.74. Both p-values are approach zero.

The study moved on to examine the residuals and plotted the following in JMP:



A reasonable amount of both positive and negative auto-correlation are present in this sample of data. A poly-numeric mathematical function may better fit the data as is presented on the residual chart. The modest R-squared value, but strong P-values suggest that this function may be sufficient to reject a null hypothesis.

6. DISCUSSION

6.1 "Yr" versus "#Private Pilots"

Based on the above analysis, this study will *reject* the following null hypothesis:

Ho = Time does *not* impact the number of private pilots

The high correlation of .9754, high R-squared value of .9513, and p-values approaching zero leave little doubt that the linear regression JMP fitted to the comparison of a given year to the number of active private pilots is accurate. The number of private pilots is proven to be steadily decreasing on an annual basis. The *why* behind this finding will serve as an excellent foundation for further study. Socio-economic factors such as wage stagnation may be depriving would-be pilots of the financial resources to pursue certification and flying as a hobby (Mishel, 2015). The cost of aviation gas, rental fees, hangar and parking fees, and maintenance costs amount to significant financial barriers to entering the community. How Americans prefer to spend their free time may help to explain the decline. Television has been an American staple for decades, but online gaming is on the rise and there is evidence out there to suggest that bright computer screens are psychologically addictive (Roberts, 2019). The evidence is conclusive, but these findings do not prove *causation*.

6.2 "Yr" versus "#Fatal Accidents"

Based on the above analysis, this study will *reject* the following null hypothesis:

Ho = Time does *not* impact the number (frequency) of Fatal GA Accidents

The high correlation of -.9104, modest R-squared value of .8288, and p-values approaching zero leave little doubt that the linear regression JMP fitted to the comparison of a given year to the number of active private pilots is accurate. This finding – along with the decline in the number of private pilots overall – suggests a link. More on this in sub-section 5.4. What is clear from this data – however – is the number of fatal accidents is declining on an annual basis. The declining number of pilots might explain causation. One might also hypothesize that the falling number of GA hours flown may be a contributing factor, but the low *r* value produced between "Yr" and "#GA Hours Flown" suggests only a *modest* correlation. Other factors might be at work. Review of the literature suggested that little has been done to improve safety in the GA community and that the number of accidents has flatlined, but this finding certainly suggests otherwise. Guohua and Baker's 2007 study and Boyd's 2017 study appear at odds with this one regarding increasing safety in GA.

6.3 "#Private Pilots" versus "Avg Pilot Age"

Based on the above analysis, this study will *reject* the following null hypothesis:

> Ho = The overall number of private pilots does *not* impact the overall age of the pilot population

The high correlation of -.8770, modest R-squared value of .8076, and p-values approaching zero leave little doubt that the linear regression JMP fitted to the comparison between the size of the private pilot population and its average age is accurate. Put more simply: as the demographic of private pilots decreases, the average age has increased. Socio-economic factors may contribute to this in much the same that time affects the number of private pilots. Older pilots may benefit from pension systems and higher relative wages than younger, prospective pilots. Those financial barriers to entry may prove more surmountable to the older generation. Older prospective fliers might be less addicted to today's technologies and enjoy spending more time out of doors. These results do not prove causation, but these speculations might prove a fruitful place to begin deeper analysis into *why*.

6.4 "#Private Pilots" versus "#Fatal Accidents"

Based on the above analysis, this study will *accept* the following null hypothesis:

> Ho = The overall number of private pilots does *not* impact the overall number of fatal accidents in GA

There is high correlation of .9176. The R-squared value is a robust .8535. The p-values – however – suggest accepting the null hypothesis insofar as a linear regression explaining the data is concerned. The X-variable p-value approached zero, but the Y-intercept p-value was a relatively high .7660. This means that the Y-intercept will almost certainly not stand the scrutiny of hypothesis testing. This is unfortunate. The linear regression line appears to do a great job of explaining most of the data and was the strongest candidate of the remainder of the variable relationships. There is certainly a link between these two variables, but further study is required to prove it.

6.5 Remaining Hypotheses

Based on the above analysis, this study will *accept* the following null hypotheses in spite of high correlation (*r*) values:

> Ho = Time does *not* impact the number of non-fatal accidents in GA
>
> Ho = Time does *not* impact the average age of the private pilot demographic
>
> Ho = The number of private pilots does *not* impact the number of non-fatal accidents in GA
>
> Ho = The average age of a private pilot does *not* impact the number of non-fatal accidents in GA
>
> Ho = The average age of a private pilot does *not* impact the number of fatal accidents in GA

The R-squared and p-values for the above variable relationships did not meet the standards for accepting the null hypothesis of a linear regression. Based on the above analysis, this study will also *accept* the following null hypotheses given their *r* values were below the study's standard of .7:

Ho = Time does not impact the number of GA hours flown

Ho = The number of private pilots does not impact the number of GA hours flown

Ho = The number of GA hours flown does not impact the number of fatal accidents in GA

Ho = The number of GA hours flown does not impact the number of fatal accidents in GA

7. Cautions in Interpreting Data and Hypothesis Rejection and Acceptance

This study chose the strength of a linear regression to prove the likely existence of a link between variables. The study also examined residual data for each to determine if some other form of mathematical function might explain the relationships. The only function that *may* fit some of the data sets better than a linear regression is a polynomial function – which is notoriously difficult to determine. JMP software has its limits in that regard. The residual data sets were also pitted against illustrations for square, cube, square root, logarithmic, exponential, beta, and even gamma distributions. None of these functions readily explain the behavior of the data points. This is not to say that some mathematical function might better prove a link than a linear regression, however. Insofar as this study is concerned, linear regression was the most accurate option and the regression performed proved or disproved hypothetical relationships.

8. RECOMMENDATIONS

This study rejected three null hypotheses on the strength of accurate linear regressions:

Ho: Time does not impact the number of Private Pilots

Ho: Time does not impact the number of Fatal Accidents

Ho: The number of Private Pilots does not impact the Average Pilot Age

Each of these has considerable implications on the GA community. Time's negative impact on the number of private pilots is not beneficial. As the number of private pilots declines, so too may their relevance. The government *may* realize a cost savings in the number of FAA personnel and hours those personnel must labor to support the community. Fewer pilots translate into a smaller administrative workload in processing applications, licenses, advanced ratings, etc. Fewer pilots translate into fewer GA aircraft airborne at any given time that FAA controllers must account for. The community's shrinking size does not bode well for its own survival and well-being, however. Fewer pilots translate into less leverage in negotiations with the FAA for programs to enhance safety and efficiency. While fatal accident rates are also in decline, the same cannot be said on a per-capita basis. There is still work the GA community can do to increase safety and further study into why the number of Private Pilots is declining is relevant, now more than ever.

The study's link between the size of the GA community's impact on Pilot Age (i.e., increasing) also proves ominous for the GA community. It is further proof of GA's declining relevance, but it also gives future researchers clues as to its cause. Perhaps older generations are more apt to spend time out of doors and away from their computer and television screens. Older generations might also prove more financially secure and can more readily surmount the high financial barriers to entry GA presents to aspiring aviators. The linear regression'a this study performed in comparing these two variables was insufficient to prove a strong link. This does not prove the absence of a link, however.

The null hypotheses this study *accepted* are also telling. The link between GA hours flown and any of the other variables is relatively weak. This flies in the face of conventional wisdom: the more risk someone assumes by flying more hours, the more likely he or she will be involved in an accident. While there *may* indeed be a link, the relationship is insufficiently strong to prove an acceptable, linear relationship. This study was also unable to establish a strong linear links between the size of the private pilot demographic and the number of accidents or the age of a private pilot in explaining the same. These results also seem to defy common sense. It would seem logical to witness higher overall accident rates with more pilots in the air or a higher rate as pilots age. This study suggests that Ison's 2015 study in identifying an older, median age for non-accident pilots versus accident pilots is correct (Ison, 2015). It also indicates that Cause, Chua, and Remy's idea that pilot proficiency and safety might be measured via cognitive testing may be insufficient (Cause, Chua, and Remy, 2019). There is more to pilot safety than just age.

Future researchers are wise to examine these relationships in greater detail and in the hopes of identifying causality. Older generations cannot hope to sustain this community for nearly as long as younger generations can. If GA will be here in the decades hence, the community must recruit and train new pilots in greater numbers. Conversely, the FAA might consider reviewing its commercial aviation age restrictions given this study's finding of a negative correlation between fatal accident rates and average pilot age. That is not to say that age may *eventually* increase accident rates. Ison's median for non-accident pilots was 57, however, and that calls into question the FAA's mandated retirement age for commercial pilots beyond their 65th birthdays (Ison, 2015).

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14. ABSTRACT

America's General Aviation sector has witnessed significant demographic shifts since the turn of the century. The number of certified, private pilots, non-fatal aircraft accidents, fatal aircraft accidents, and number of general aviation hours flown are all in decline. Meanwhile, the average age of an American private pilot has increased by several years. All of these factors indicate that the industry is in decline. This study determined – via mathematical, linear regression – that time's relationship to the number of annual, fatal General Aviation accidents *and* the number of certified private pilots is negative. It also proved that the average age of the private pilot demographic is increasing, as the overall size of the demographic decreases. These findings prove ominous for a shrinking community that relies on its size to leverage the government and the public for support and recruitment.

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