

# AGING AND THE GENERAL AVIATION PILOT

Research and Recommendations



**AIR SAFETY INSTITUTE**  
A DIVISION OF THE AOPA FOUNDATION  
421 AVIATION WAY  
FREDERICK, MD 21701  
[AIRSAFETYINSTITUTE.ORG](http://AIRSAFETYINSTITUTE.ORG)

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# INTRODUCTION

Like the nation as a whole, the pilot population is growing older. Between 1990 and 2010, the average age of U.S. pilots increased from 40.5 to 44.2. This shift—partly a reflection of broad demographic trends; partly a result of changes in the industry and culture—poses serious challenges for the industry, and raises important questions about the viability of our current flight training model, the perception of general aviation (GA) among non-pilots, and other factors.

One of them is safety. Since 1960, when the FAA instituted the so-called “Age 60 Rule” for air carrier pilots, the relationship between age, piloting performance, and safety has inspired much debate, and many questions. For example:

- » To what extent does age impact the performance of the average pilot?
- » Is there such a thing as an “average pilot”?
- » How far can performance deteriorate without affecting safety?
- » Do all aspects of performance deteriorate at the same rate?
- » What role does experience play in offsetting aging effects?
- » Can laboratory testing predict real-world performance?
- » Do today’s longer lifespans and healthier lifestyles make a difference?

It is largely because of efforts to answer such questions for the airline industry that we have as much data on older pilots as we do: Only a relative handful of studies devoted specifically to aging among GA pilots have been performed. While this raises valid questions about the applicability of airline-oriented research to GA (the typical air carrier pilot is more experienced, more proficient, and possibly healthier), there are reasons to believe that most of the literature has relevance for all pilots.

Foremost among those reasons, perhaps, is a conclusion to which nearly all the studies evaluated for this project point—namely, that there is no one single “older pilot” profile. Simple as it sounds, one of the key insights of all the research seems to be that different pilots experience the aging

process very differently. In some respects this is an oversimplification, but it also reflects a basic truth we see around us in our daily lives: There is chronological age, and there is “true age,” and the two do not always correspond.

As pilots, we play a major role in making important, and sometimes difficult, decisions about our own fitness to fly. This is not a responsibility to be taken lightly. Together, this publication and its companion piece—the Air Safety Institute’s ***Aging Gracefully, Flying Safely*** online course—represent the first systematic attempt to provide older pilots with the guidance they need to make good, well-informed choices.

In this report, we begin with a closer look at the existing body of research on age and pilot performance. Later we discuss insights that can be drawn from that research, and talk about steps pilots can take to keep flying as long, and as safely, as possible. Finally, for those with a deeper interest in the material, we provide an annotated bibliography of selected works on aging and pilot performance.

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## RESEARCH SUMMARY



In preparing this report, the Air Safety Institute performed a literature review covering primarily the years 1990 to 2010, with greater emphasis on studies published since 2000. During that review it soon became apparent that publications devoted solely to aging GA pilots are few and far between: A large majority of published studies are oriented toward commercial and/or airline pilots, and many were accomplished specifically to address the Age 60 Rule.

Among other things, this means that relatively little information exists pertaining specifically to pilots over the age of 70. However, given certain caveats, we believe that many of the issues addressed by these more narrowly focused studies are relevant to all pilots. That conclusion is bolstered by the results of the GA-specific projects, which seem to fit well into a larger pattern established by the others.

In order to address the findings of the various studies in a reader-friendly way, we've grouped them into broad categories based on the type and/or topic of research conducted.

## ACCIDENT INVOLVEMENT

Over the years, a number of studies focused primarily on analysis of accident data have been published. As with many of the studies examined for this report, the findings of these works varied significantly. Although this fact may have significance to broader conclusions about aging, it is important not to read too much into such variances: The studies examined were undertaken to answer a variety of different questions, and in some cases were conducted using entirely different datasets and methods of analysis. Apples-to-apples comparisons are thus difficult to make. However, a broad theme emerges in which age, experience (total and recent), and health (insofar as it tracks with medical certification) interact together in ways that appear to correlate to some degree with accident involvement.

One GA-specific study based on National Transportation Safety Board (NTSB) accident data (Baker 1—see Selected Resources, p. 26) found that, among other things, “Older pilots made fewer errors:



among males age 55-63, 26 percent of crashes were without obvious pilot error compared with only 7 percent at age 40-49.” Note, however, that this does not address the relative accident involvement (or rate) among the various groups of pilots studied. Two other publications (Bazargan 2, Mortimer 8), also working from general aviation accident data, determined that certain groups of accident pilots age 60 and over were involved in more accidents when compared to others examined. Likewise, an unpublished 2006 Air Safety Institute study found that, starting at roughly age 55, pilots began to have more accidents than would be expected given their share of the pilot population.

It’s worth noting that all of these studies were based on analysis of NTSB accident data. Aside from the potential shortcomings of these data, such analyses do not account for potentially higher exposure among older pilots—in other words, the possibility that older pilots (perhaps having more leisure time and/or money) fly more often than their younger counterparts. Nor do they take into account possible differences in the nature of that flying and the severity of the associated accidents. Without data to eliminate these and other confounding factors, solid claims about the relative safety of different pilot age groups are difficult to make.

On the commercial aviation side, one study (Li 7) followed a group of more than 3,000 air carrier and air taxi pilots over a ten-year period, tracking their flight time and accident involvement. In this case, it was found that greater flight experience had a significant positive impact on the risk of accident involvement, while increasing age did not seem to have an offsetting negative effect. However, the authors concluded that the latter fact may reflect a strong “healthy worker effect,” in which the strict FAA medical standards minimize the observable impacts of aging. This is an important point to bear in mind when considering research limited to professional pilots, particularly those subject to Class I medical examinations.

Also notable is a series of FAA studies that approximated accident rates by using estimated annual hours flown by air carrier and charter pilots with Class I and II medicals (Broach 3, 4). Analyses comparing different age groups between 21 and 63 years “...supported the hypothesis that a ‘U’-shaped relationship exists between the age of professional pilots and accident rates.” The authors noted, however, that the mean differences between age groups were small.

Perhaps the most broad-based of the various studies in this category are two dating from the 1980s (Golaszewski 5, 6). These publications analyzed accident data for several groups of pilots with different characteristics—age, certificate level, profession, medical certification, total time, and recent experience—and found multiple interactions between the various factors. Very



generally speaking, older pilots with low total and recent flight time tended to fare worse than their younger counterparts of similar experience, while older pilots with high total and recent flight time did as well or better.

## SIMULATOR PERFORMANCE

One way around the limitations of accident data analysis is to bring pilots into the lab and study their performance under simulated flight conditions. Researchers recruit pilots of different ages, certificate levels, and experience, and test their performance across specific sets of tasks, usually over repeated outings. It should be stressed at the outset that these studies do not attempt to rate performance as “acceptable” or “unacceptable” vis-à-vis any real-world standard. Also worth noting is the possibility that factors related to age, but not to *aging*, may play a role in the results. For example, the simulators used in these studies have generally not presented subjects with a very realistic flight experience. That fact—insofar as it could tilt outcomes in favor of younger pilots, who are perhaps better acclimated to simulation in general—could at least theoretically influence the results.

Of the various simulator studies, the most relevant to the topic of aging among GA pilots is known as the “Stanford Study” (Taylor, 13). Over a 3-year period, the authors performed annual simulator testing on 118 GA pilots aged 40 to 69 years. Performance was scored based on execution of ATC instructions, instrument scan, traffic avoidance, an approach to landing, and an overall score. The authors’ summary conclusions were as follows:

“More expert pilots had better flight summary scores at baseline and showed less decline over time. Secondary analyses revealed that expertise effects were most evident in the accuracy of executing aviation communications, the measure on which performance declined most sharply over time. Regarding age, even though older pilots initially performed worse than younger pilots, over time older pilots showed less decline in flight summary scores than younger pilots...These longitudinal findings support previous cross-sectional studies in aviation as well as non-aviation domains, which demonstrated the advantageous effect of prior experience and specialized expertise on older adults’ skilled cognitive performances.”<sup>1</sup>

In other words, the results serve to reinforce the theory that experience generally works to offset the negative impacts of aging, and may, furthermore, play a greater role in compensating for those areas that are more strongly affected by the aging process (e.g., communication).

A more limited simulator study (Kennedy 12) of instrument-rated GA pilots aged 19 to 79 years found that older pilots were more likely to go ahead and land after an instrument approach to an airport with inadequate visibility. These pilots also demonstrated less precise control of the simulated aircraft while executing approaches. Difficulties with flight control during holding patterns, however, seemed to be offset by increased experience. Two other studies (Hyland 11, Yesavage 14) from the 1990s found that increased age correlated with generally poorer performance on simulator tasks. The author of the former study, however, noted that her results should be interpreted with caution due to issues with sample size and composition.

Again, the broad picture that seems to emerge is of a mild but measurable decrease in overall performance with age, offset to varying degrees by expertise and (to the extent indicated by medical certification) good health.

## COGNITION AND COMMUNICATION

The most frequently voiced concerns about older pilots have to do with changes in cognitive capacity—diminished ability to stay ahead of the aircraft, maintain situational awareness, divide attention among multiple tasks, make good decisions, and communicate effectively. A significant amount of scientific research has been done in these areas, and though there are many points of agreement among the various studies, once again it seems rare to find two publications whose results match precisely. Rather than delve into the various data here (see Selected Resources for further info), we would instead point to a report titled “Age and Pilot Performance,” in which researcher Pamela Tsang provides a good overview of the situation:

“The psychological literature shows definite age-related changes in certain cognitive functions that have been identified to be essential for flight performance (e.g., perceptual processing, certain aspects of memory performance, and certain psychomotor control). The cognitive functions that do not yet exhibit clear effects of age tend to be the more complex ones that involve several stages of information processing such as problem solving, decision making, and time-sharing. On the one hand, there are ample data to suggest that the more complex the performance, the larger the age effect tends to be. On the other hand, complex performance developed through extensive training is found to be more resistant to negative age effects. Since expertise in many complex job performances, including flying, tend

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<sup>1</sup> Taylor, Joy L., Quinn Kennedy, Art Noda and Jerome A. Yesavage, “Pilot Age and Expertise Predict Flight Simulator Performance, A 3-year Longitudinal Study,” *Neurology*, 2007; 68: 648.

to develop with experience and age, the interactive effects of age and experience and their relative contributions need to be carefully studied.”<sup>2</sup>

In other words, there seems to be an interaction between the complexity of a mental task, the degree to which that complexity itself (perhaps by calling upon differentially affected parts of the brain) mitigates against overall difficulty, and the presence of previously developed expertise. Tsang later goes on to say that there is “...certainly no indication that all goes at age 60. Not only does age affect the different cognitive functions to different degrees, the time of onset of significant age effects also differs across cognitive functions.”<sup>3</sup>

A major subset of the literature on cognition deals with radio communication. As mentioned in the Stanford Study (Taylor 13), there is evidence to indicate that communication—which seems to be strongly affected by short-term working memory—is the area in which aging itself has the most obvious and measurable impact. Several different studies have been undertaken specifically to verify and quantify this: In nearly all of them, as expected, older pilots performed worse than their younger counterparts on various different communication tasks. However, greater experience mitigated these performance deficits to a certain extent, as did the use of memory aids such as note-taking. In connection with the latter point, it is worth noting that technological advances in ATC communication—for example, datalink systems that would transmit instructions in textual form—could have real benefits for older pilots.

## PHYSICAL HEALTH

Studies that dealt with health issues were primarily in agreement that issues such as degraded vision, sudden in-flight incapacitation (0.3 percent of all accidents<sup>4</sup>), and cardiovascular abnormalities are of increasing concern for older pilots. This stands to reason, but it’s also worth noting that the studies examined for this report found no evidence that the incidence of these problems increases suddenly at any particular age across the population. Moreover, it is well established in the general scientific literature that the health-related impacts of aging can be significantly offset by regular physical activity, a healthy diet, risk factor mitigation (e.g., not smoking), and regular check-ups with medical professionals.

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<sup>2</sup> Tsang, Pamela S, “Age and Pilot Performance,” in Aviation Training: Learners, Instruction and Organization, edited by Ross A. Telfer and Phillip J. Moore, Aldershot: Avebury Aviation, 1997. Page 32.

<sup>3</sup> Ibid

<sup>4</sup> Booze, Charles F. Jr., “Sudden In-Flight Incapacitation in General Aviation,” Technical Report DOT/FAA/AM/87/7, FAA Civil Aeromedical Institute, Oklahoma City, Oklahoma, August 1987.



## THE BIG PICTURE

The studies and reports examined here represent a number of different approaches to the question of aging in the cockpit. Vision, memory, cognition, accident involvement, airmanship, and health have all been investigated across various segments of the pilot population. Yet for all of the work that has been done, what is perhaps most striking is the relative absence of exact findings. The questions seem to resist efforts at analysis. Indeed, it's tempting to conclude that the question of aging may be a red herring—that, as the saying goes, “There is no there there.”

This overstates things. The situation is extraordinarily complicated from a research standpoint, and there's ultimately no getting around the fact that we are mortal beings. All of us eventually go through a period of decline. The precise nature and steepness of that decline vary tremendously—there are pilots of 60-year-old pilots whose “true age” is closer to 90, and vice-versa—but it always comes; and as with many things in life, we are talking about a bell-shaped curve. Only a lucky handful of us will still be flying safely and confidently at 90. In short, age matters.

But it's not all that matters. The real lesson seems to be that chronological age, for all its convenience as shorthand, is not a terribly good lens through which to examine a particular pilot's ability to function safely in a given capacity. In many studies, individual differences between pilots of the same age were significantly larger than the differences between age groups themselves. And despite all the studies that, on the surface, seem to speak grimly of the performance of older pilots, we are presented every day with strong evidence that age is only one factor among many, and that “safety” is not a line but a gradient. Aircraft piloted by men and women over the age of 70 are not falling out of the sky with any great regularity. The airline accident rate has not increased since the Age 60 Rule became the Age 65 Rule—if anything, it has fallen.

In short, the key insight of all the research, for our purposes, seems to be that different pilots experience the aging process differently, and compensate for it (or fail to) in a variety of different ways. There are, no doubt, certain commonalities among older pilots, but in the broad view it seems that individual factors—experience, proficiency, physical fitness, genetics—come together to play a much greater role than chronological age in determining a given pilot's ability to fly safely on a given day.



## RECOMMENDATIONS FOR PILOTS

The literature on aging may not offer a simple method by which to group pilots into safety categories, but it does point to several steps that can minimize the toll taken by the aging process. In addition to exercises that can help us maintain or improve our physical and mental capabilities, there are various operational steps we can take to compensate for the kinds of changes that can't be avoided. In this section, we outline several areas in which older pilots seem to experience similar effects, and suggest ways they might go about adjusting.

## VISION

For many pilots, changes in visual acuity are among the earliest and most noticeable issues associated with growing older. Peripheral vision narrows, near vision becomes less acute, eyes no longer focus as quickly, and night vision degrades.

### Recommendations:

- » Get a full eye exam on a yearly basis.
- » Purchase an oxygen system, and/or start using it at **lower altitudes**.
- » Allow your eyes more time to adjust at night, and consider switching to low-level white cockpit lighting, which is better than red for focusing.
- » Get bifocals, or progressive lenses. Many pilots do fine with off-the-shelf “readers,” but prescription glasses are generally better.
- » Wear haze-cutting prescription sunglasses.
- » Consider purchasing traffic alert equipment.



## HEARING

Particularly in the high-frequency range, hearing diminishes with age. Pilots tend to be worse off than the general population in this respect.

### Recommendations:

- » Consider purchasing active noise cancelling headsets; many pilots are surprised at the reduction in ambient noise.
- » Be prepared to ask controllers to “say again” if necessary.
- » Consider purchasing hearing aids.

## STRENGTH, FLEXIBILITY, AND ENDURANCE

Many pilots report decreased flexibility and loss of strength as they get older. Most notice that cockpit fatigue sets in earlier than it once did, and some find it more difficult to perform fine motor tasks, like pressing small buttons.

### Recommendations:

- » Get a yearly physical, starting no later than age 50.
- » Maintain an exercise regimen: 30 minutes of physical activity a day, even simple things like walking, can have a tremendous impact on overall well-being.
- » Try to schedule flights for the morning, or late afternoon, when it tends to be smoother and cooler. Avoid early mornings and late nights, however. After-lunch flights can also lead to fatigue problems.
- » If cockpit fatigue is a problem, allow more time, and plan more frequent stops. Noise-cancelling headsets can be helpful here as well.
- » Stay well-hydrated, but avoid coffee and other caffeinated drinks. If in-flight discomfort is an issue, plan shorter legs or carry on-board relief products.
- » Stay well-fed. Hypoglycemia (low blood sugar) can take a real toll.
- » Proper rest is even more important as an older pilot. Most of us can’t just “power through” as we did in college or our early 30s.

## MEMORY

Working memory is used often in flying, and seems to be the type most affected by normal aging. Many older pilots find it more difficult to remember things like altitude assignments, transponder codes, and radio frequencies.

Recommendations:

- » Take notes. Have a pen and paper handy anytime you're dealing with ATC.
- » Consider purchasing an altitude reminder device, or adapt something else to the purpose.
- » Try to fly when you're "fresh." Older pilots often perform better on memory tests in the morning.
- » Enlist the aid of cockpit companions to "back you up" on the numbers and help with things like radio tuning and GPS programming.

## DECISION MAKING

Although experience can have a real impact, aging can also make it more challenging to handle decision-making tasks.

Recommendations:

- » Spend more time doing preflight and contingency planning. Any "pre-thinking" you do will make things easier later.
- » Fly when well-rested, and make it a point to stay particularly alert to changes in the cockpit (e.g., mechanical issues, weather, etc.).
- » Always have a solid "Plan B" ready to go ahead of time. Make sure it's realistic—something you're actually prepared to use.

## PROFICIENCY

In addition to expertise, recency of experience can have a dramatic effect on overall airmanship, regardless of age.

Recommendations:

- » Take an organized approach to recurrent training. Set a schedule—an instrument proficiency check every six months, for example—and stick to it.
- » Look for a good instructor who works well with you and isn't afraid to throw challenges your way.
- » Get involved in new activities, start work on a new rating, read books, take **Air Safety Institute online courses and quizzes**—anything to keep your mind active.
- » If the cost of flying is a concern, mass-market PC flight simulators (like Microsoft Flight Simulator and X-Plane) are surprisingly inexpensive and realistic ways to stay sharp—particularly for instrument flying.

## “RIGHT-SIZING”

For most pilots, it makes sense to start adjusting the kinds of flying they do as they grow older.

Recommendations:

- » Plan shorter cross-country legs, and shorter flights overall.
- » Re-examine your “comfort zone,” and increase your personal minimums if necessary.
- » Bring along a co-pilot or instructor on more challenging flights—for example, when transiting busy airspace, at night, or in low instrument conditions.
- » Use oxygen for night flights, or try to complete flights during daylight hours.
- » Consider moving to slower and/or less complex aircraft. Bear in mind, however, that there's a learning curve associated with any new type, particularly if you've been flying one aircraft exclusively for years.







## SELECTED RESOURCES

The following bibliography is a representative sample of the literature on aging and pilot performance, grouped into the same categories used in this research summary. Notes on each study are derived primarily from the publication abstracts. No independent attempts have been made to assess the validity of research methodology utilized or conclusions drawn.

## ACCIDENT INVOLVEMENT

1. Baker, Susan, Margaret W. Lamb, Jurek G. Grabowski, George Rebok, and Guohua Li. Characteristics of general aviation crashes involving mature male and female pilots. *Aviation, Space, and Environmental Medicine*, 2001; 72(5): 447-452.

Analyzed general aviation accidents to identify differences between male and female pilots in the circumstances of their crashes and the types of pilot error involved. For male pilots, the more common crashes involved mechanical failure, gear up landings, improper IFR approaches, and collisions with wires or poles. Loss of control on landing and/or takeoff was more common in crashes of female pilots. Accidents involving older pilots showed a lower incidence of pilot error.

2. Bazargan, Massoud and Vitaly S. Guzhva. Impact of gender, age and experience of pilots on general aviation accidents. *Accident Analysis and Prevention*, 2011; 43: 962-970.

Investigated the significance of pilot gender, age, and experience in influencing the risk for pilot errors. Results showed no evidence that accident rates differ by gender. It did, however, find some evidence to show that more experienced male pilots over age 60 were more likely to be involved in fatal accidents.



3. Broach, Dana, Kurt M. Joseph, and David J. Schroeder. Pilot age and accident rates report 3: an analysis of professional air transport pilot accidents rates by age. Study for OAM research task AAM-00-A-HRR-520. Civil Aeromedical Institute, Human Resources Research Division, Federal Aviation Administration, Oklahoma City, Oklahoma. Revised June 27, 2003.

The third of four studies conducted by the FAA on pilot age and accidents. The accident rate defined in this study was the ratio of the number of accidents occurring under 14 CFR Parts 121 and 135 to the annual hours flown by professional pilots holding Class I medical and ATP certificates. Analyses of various age groups between 21 and 63 years of age supported the hypothesis that a “U”-shaped relationship exists between the age of professional pilots and accident rates.

4. Broach, Dana, Kurt M. Joseph, and David J. Schroeder. Pilot age and accident rates report 4: an analysis of professional ATP and commercial pilot accident rates by age. Study for OAM research task AAM-00-A-HRR-520. Civil Aeromedical Institute, Human Resources Research Division, Federal Aviation Administration, Oklahoma City, Oklahoma. Revised June 27, 2003.

The fourth of four studies conducted by the FAA on pilot age and accidents. The accident rate defined in this study was the ratio of the number of accidents occurring under 14 CFR Parts 121 and 135 to the annual hours flown by professional pilots holding Class I or II medical and ATP or Commercial certificates. Findings were consistent, showing that a “U” shaped relationship exists between the age of professional pilots and their accident rate; that the accident rate for the 60 to 63 year old pilots was statistically greater than the accident rate for 55 to 59 year old pilots; and that the main effect for age was statistically significant in all analyses.

5. Golaszewski, Richard. The influence of total flight time, recent flight time and age on pilot accident rates. Final report prepared for the U.S. DOT/Transportation Systems Center and the Federal Aviation Administration. June 30, 1983.

Presented initial findings of an analysis of recent flight time, total flight time, and age on general aviation accident rates in the United States from

1976 to 1980. Analyses used combined data from the NTSB accident database and the FAA Medical History files. Summary findings show that on the basis of recent flight time, accident rates decrease as flight time increases. For low values of recent flight times, older pilots exhibit higher accident rates. For high values of recent flight time, younger pilots exhibit a slightly higher accident rate. Accident rates decrease as total flight time increases for all pilot populations (Class I, II, and III medicals). However, pilots who hold a Class III medical show a higher overall accident rate at all levels of total flight time. For pilots with a Class II medical and low total flight time, accident rates generally decrease as age increases when recent flight time exceeds 50 hours per year. Accident rates increase with age when recent flight time is less than 50 hours per year. The accident rate for the entire pilot population with less than 1000 hours total time and less than 50 hours recent flight time increases with age.

6. Golaszewski, R. S. General Aviation Safety Studies Preliminary Analysis of Pilot Proficiency. Report prepared by Abacus Technology Corporation, Chevy Chase, MD. In association with Gelman Research Associates, Jenkintown, PA.

Looked at the relationship between pilot characteristics (age and gender), experience (recent and total flight hours), and accidents. Accident data from 1983-1985, 1987, and 1988 were used in the analyses. The following were excluded from the database: airline pilots, student pilots, aero-applicators, airmen who were not pilots (e.g. air traffic controllers), and pilots who reported no recent or total flight hours. Accident data were compiled for three groups of pilots: Group A—professional pilots with a Class I medical certificate; Group B—professional pilots with a Class II medical certificate and flight instructors with either a Class I or Class II medical certificate; and Group C—pilots of all classes who were not professional pilots. Accident rates for Group A pilots declined from age 17-19 through age 40-49 after which rates increased. Rates for Group B increased in a linear fashion for pilots aged 17-19 through 60-69. Group C pilots exhibited a general increase in accident rates through age 50-59 then declined for the 60-69 age group. Gender did not appear to have a significant influence on accident rates. Recent Flight Time (abbreviated as RTF in original report) displayed a good



relationship with accident rates, rates declined as RTF increased. A similar decline in accidents was evident when considering Total Flight Time (TFT). The author points to several interactions between RTF, TFT, and pilot group. Recommendations for additional analyses are provided.

7. Li, Guohua, Susan P. Baker, Jurek G. Grabowski, Yandong Qiang, Melissa L. McCarthy and George W. Rebok. Age, flight experience, and risk of crash involvement in a cohort of professional pilots. *American Journal of Epidemiology*, 2003; 157(10): 874-880.

From 1987 to 1997, the authors followed a group of 3,306 commuter air carrier and air taxi pilots aged 45-54 years. During the study, the pilots accumulated a total of 12.9 million flight hours and had 66 accidents, yielding a rate of 5.1 accidents per million pilot flight hours. Accident risk remained fairly stable as the pilots aged. Flight experience shows a significant protective effect against the risk of crash involvement. Adjusted for age, pilots with 5,000 to 9,999 hours of total flight time had a 57 percent lower risk of a crash than their less experienced counterparts. The protective effect of flight experience leveled off after 10,000 hours. The authors concluded that the lack of an association between pilot age and crash risk may reflect a strong “healthy worker effect” stemming from rigorous medical standards and periodic physical examinations required for professional pilots.

8. Mortimer, Rudolf G. Some factors associated with pilot age in general aviation crashes. *Proceedings of the 6th International Symposium on Aviation Psychology*, 1991, Columbus, OH. Pages 770-775.

More than 1,000 NTSB Accident Brief reports for 1985-1986 were analyzed to discern age differences of pilots in the characteristics of general aviation airplane accidents. Pilots aged 60 or older were more involved in taxiing accidents, and those under 30 more in maneuvering accidents. The accident rates of pilots aged 60 or more and younger pilots were estimated using data from another study and 1986 FAA accident data. Pilots aged 60 or older had an accident rate about twice that of the younger pilots.

9. Rebok, George W., Yandong Qiang, Susan P. Baker, Melissa L. McCarthy and Guohua Li. Age, flight experience, and violation risk in mature commuter and air taxi pilots. The International Journal of Aviation Psychology, 2005; 15(4): 363-374.

Examined the risk of violation in relation to pilot age and other pilot characteristics based on exposure to flight. A fixed group of 3,306 commuter air carrier and air taxi pilots, who in 1987 were aged 45 to 54 years, was studied for 11 years. Violation rate increased significantly with age from age 40 to the late 50s. Pilots who were 50 to 54 years old at baseline experienced almost twice the rate of violation involvement as pilots who were 45 to 49 years old at baseline. Total flight time at baseline, an indicator of flight experience showed a significant protective effect against risk of violation. With adjustments for age, pilots who had 5,000 to 9,999 hours of total flight time were at significantly lower risk of violation than their less experienced counterparts.

10. Rebok, George W., Yandong Qiang, Susan P. Baker and Guohua Li. Pilot age and error in air-taxi crashes. Aviation, Space, and Environmental Medicine, 2009; 80(7): 647-651.

Examined whether pilot age is associated with the prevalence and patterns of pilot error in air-taxi crashes. NTSB reports on crashes involving non-scheduled Part 135 operations in the US between 1983 and 2002 were reviewed to identify pilot error and other contributing factors. Crash circumstances and the type of pilot error were analyzed in relation to pilot age. Analyses showed that crashes among older pilots were more likely to occur during the daytime than at night, and off airport than on airport. The patterns of pilot error in air-taxi crashes were similar across age groups. The authors concluded that pilot age is associated with crash circumstances but not with the prevalence and patterns of pilot error in air-taxi crashes. Lack of age-related differences in pilot error may be attributable to the “safe worker effects.”

## SIMULATOR PERFORMANCE

11. Hyland, Diane T. Experimental evaluation of aging and pilot performance. *Proceedings of the 7th International Symposium on Aviation Psychology*, 1993, Columbus, OH. Pages 389-393.

The primary research objective was to develop a procedure for assessing pilots' performance in a simulator. A second goal was to develop a test battery and examine its relationship to the simulator criterion measure. A final goal was to conduct a preliminary examination of the relationship between pilot age and performance on the simulator and test battery. Pilot age was found to be related to simulator performance. Increasing age correlated with poorer evaluator ratings on simulator performance. Pilot age was also found to be significantly correlated with performance on predictor tests. The author warns that while the findings are interesting, they should not be over interpreted since the sample size was small, the age range was broad and varied widely, and the pilots who participated were older than typical air carrier pilots.

12. Kennedy, Quinn, Joy L. Taylor, Gordon Reade and Jerome A. Yesavage. Age and expertise effects in aviation decision making and flight control in a flight simulator. *Aviation, Space, and Environmental Medicine*, 2010; 81(5): 489-497.

Examined the roles of age, expertise, and their relationship on aviation decision making and flight control performance during a flight simulator task. Seventy-two instrument rated general aviation pilots, aged 19 to 79 years, made multiple approach, holding pattern entry, and landing decisions while navigating under IFR conditions. Results showed that older pilots (41+ years) were more likely than younger pilots to land when visibility was inadequate. They also showed less precise flight control for components of the approach. Expertise attenuated an age-related decline in flight control during holding patterns. The authors state that their conclusions have implications regarding specialized training for older pilots and for understanding processes involved in older adults' real world decision making and performance.

13. Taylor, Joy L., Quinn Kennedy, Art Noda and Jerome A. Yesavage. Pilot age and expertise predict flight simulator performance: a 3-year longitudinal study. *Neurology*, 2007; 68: 648-654.

Investigated the influence of age and aviation expertise on flight simulator performance. Over a 3-year period, 118 general aviation pilots aged 40 to 69 years were tested annually, in which their flight performance was scored in terms of executing air traffic controller communications, traffic avoidance, scanning cockpit instruments, executing an approach to landing, and a flight summary score. Results revealed that the more expert pilots had better flight summary scores at baseline and showed less decline over time. Analyses also revealed that expertise effects were most evident in the accuracy of executing aviation communications, the measure on which performance declined most sharply over time. Older pilots initially performed worse than younger pilots but over time they showed less decline in flight summary scores than younger pilots. Analyses also revealed that the oldest pilots did well over time because their traffic avoidance performance improved more than the younger pilots. The findings support previous studies which demonstrate the advantageous effect of prior experience and specialized expertise on older adults' skilled cognitive performances.

14. Yesavage, Jerome A., Joy L. Taylor, Martin S. Mementaler, Art Noda, and Ruth O'Hara. Relationship of age and simulated flight performance. *Journal of the American Geriatrics Society*, 1999;47:819-823.

Attempted to determine the relationship between age and pilot performance on a flight simulator. One hundred pilots aged 50 to 69 were tested on a Frasca 141 flight simulator, which generated graphics of the environment in which the pilots flew and collected data concerning the aircraft's flight conditions. Results found that increased age was significantly associated with decreased aviator performance on a flight simulator. The conclusion shows that although there was a significant relationship between increased age and decreased pilot performance, age explained 22 percent or less of the variance of performance on different flight tasks. Other factors are also important in explaining the performance of older pilots.

## COGNITION AND COMMUNICATION

15. Hardy, David J., Paul Satz, Louis F. D'Elia and Craig L. Uchiyama. Age-related group and individual differences in aircraft pilot cognition. *The International Journal of Aviation Psychology*. 2007; 17(1): 77-90.

The effect of age on cognition was examined with a variety of neuropsychological tests in 220 pilots. The tests included psychomotor speed, information processing speed, attention and executive ability, verbal learning and memory, and visual learning and memory. The ages of the pilots were between 28 and 62. Age was significantly associated with test performance across several domains. Pilot age was not associated with immediate verbal recall or recognition or with immediate visual recall. Almost all performance outliers occurred in pilots over 40. Implications of a gradual decline in pilot cognition are discussed.

16. Hardy, David J. and Raja Parasuraman. Cognition and flight performance in older pilots. *Journal of Experimental Psychology: Applied*, 1997; 3(4): 313-348.

Reviewed studies of cognitive proficiency and flight performance. Age-group differences were found in pilots in perceptual motor skills and memory and, to a lesser extent in attention and problem solving. Flight experience does not alter this age-related decline, with the possible exception of the metacognitive skill of time sharing. Age-group differences in flight performance are most evident in the secondary task of air traffic control communications. Age-related differences in current measures of pilot cognition are minimally predictive of primary measures of flight performance.

17. Milke, Ramon M., James T. Backer, Peter Lambrou, Howard C. Harris, Jr., and David J. Schroeder. The effects of age and practice on aviation-relevant concurrent task performance. Final report DOT/FAA/AM-99/22 for the Civil Aeromedical Institute, Federal Aviation Administration, Oklahoma City, OK. August 1999.

Involved the administration of an aviation-relevant neuropsychological test battery to sixty individuals over a two day period of time. The subjects were



divided into three age groups of equal size and analyses of variance examined the relationship between chronological age and practice on performance. The performance of the subjects in the oldest group was consistently poorer and slower than that of the subjects in the youngest group for all of the measures. There were main effects of practice such that performance after five sessions was significantly better than that on the first practice session. In the case of divided attention tasks, it was revealed that performance was poorer by the older subjects and was poorer in concurrent performance conditions relative to when the tasks were performed alone.

18. Morrow, Daniel, Christopher Wickens, Esa Rantanen, Dervon Chang and Jamie Marcus. Designing external aids that support older pilots' communication. *The International Journal of Aviation Psychology*, 2001; 18(2): 167-182.

Compared an electronic notepad positioned next to the instrument panel of a flight simulator to conventional note-taking on a kneepad during a read-back task. Older and younger instrument-rated pilots listened to and read back ATC messages while using the notepad, kneepad, or no aid. Read-back accuracy was higher when pilots used either aid compared to no aid, and the pattern of results suggested a smaller age difference with either aid than in the no-aid condition. External aids such as note-taking help pilots manage communication demands, and may especially benefit older pilots. Emerging technologies provide new opportunities for external aids that are integrated with other systems.

19. Morrow, Daniel G. and Von Leirer. Aging, pilot performance, and expertise. *In Handbook of Human Factors and the Older Adult*, edited by Arthur D. Fisk and Wendy A. Rogers. Academic Press, Inc., 1997. Pages. 199-230.

A review of the general literature on expertise and aging was used to develop predictions concerning the effects of age on pilot performance. Specific attention was focused on how experience may mitigate the effects of age on complex task performance. Complicating the analysis of the pilot age and performance literature are the different manners of conceptualizing task complexity and experience. The authors found that while pilot expertise does reduce age differences in some tasks, there

are aspects of performance that may not benefit from experience. The authors suggest that improved understanding of the nature of the aviation environment can support efforts to identify the aspects of flight that are most influenced by aging and determine countermeasures that would minimize the age-related effects.

20. Morrow, Daniel G., Lisa M. Soederberg Miller, Heather E. Ridolfo, Clifford Magnor, Ute M. Fischer, Nina K. Kokayeff and Elizabeth A.L. Stine-Morrow. Expertise and age differences in pilot decision making. *Aging, Neuropsychology, and Cognition*, 2009; 16: 33-55.

Examined the influence of age and expertise on pilot decision making. Older and younger expert and novice pilots read at their own pace scenarios describing simpler or more complex flight situations. Then in a standard interview they discussed the scenario problem and how they would respond. All groups accurately identified the problem, but experts elaborated problem descriptions more than novices did. Experts also spent more time reading critical information in the complex scenarios, which may reflect time needed to develop elaborate situation models of the problems. Expertise comprehension benefits were similar for older and younger pilots. Older experts were especially likely to elaborate the problem compared to younger experts. Older novices were less likely to elaborate the problem and to identify appropriate solutions compared to their younger counterparts. The study's findings suggest age invariance in knowledge-based comprehension relevant to pilot decision making.

21. Morrow, Daniel G., Heather E. Ridolfo, William E. Menard, Adam Sanborn, Elizabeth A.L. Stine-Morrow, Cliff Magnor, Larry Herman, Thomas Teller and David Bryant. Environmental support promotes expertise-based mitigation of age differences on pilot communication tasks. *Psychology and Aging*, 2003; 18(2): 268-284.

Investigated whether expertise is more likely to mitigate age declines when experts rely on environmental support in a pilot/air traffic control communication task. Pilots and nonpilots listened to ATC messages that described a route through airspace, while they referred to a chart of that airspace. They read back each message and answered a question about

the route. In one experiment, note-taking was allowed while in another experiment, note-taking was manipulated. Note-taking determined when expertise mitigated age differences. With note-taking, read-back accuracy declined with age for nonpilots but not for pilots. Without note-taking, similar age-related declines occurred for pilots and nonpilots. The authors state that findings suggest that older adults take advantage of environmental support (note-taking) to maintain performance on some complex tasks despite typical age-related declines in cognitive ability.

22. Morrow, Daniel G., William E. Menard, Heather E. Ridolfo, Elizabeth A.L. Stine-Morrow, Thomas Teller and David Bryant. Expertise, cognitive ability, and age effects on pilot communication. *The International Journal of Aviation Psychology*, 2003; 13(4): 345-371.

Investigated whether expertise reduced age-related declines in pilot communication. Young, middle-aged, and older pilots and nonpilots listened to air traffic control messages that described an aircraft's route through an airspace, while they referred to a chart of the airspace route. Pilots read back messages more accurately than nonpilots, and younger participants were more accurate than older participants. Expertise and aging had similar effects on the questions task. Expertise did not moderate age-related declines on the aviation tasks studied here. However, some evidence shows that more flying experience amongst older pilots helped buffer the age-related declines in cognitive abilities.

23. Taylor, Joy L., Martin S. Mementhaler, Ruth O'Hara, and Jerome A. Yesavage. Assessments of expertise and working memory in predicting older pilots' performance of a simulated ATC communication task. *Proceedings of the Twelfth International Symposium on Aviation Psychology*, April 14-17, 2003, Dayton, Ohio. Pages 1155-1160.

Examined variables likely to predict older aircraft pilots' memory for air traffic controller communications. Ninety-seven pilots ranging in age from 45 to 69 years old were grouped into one of three expertise levels: VFR, IFR, or IFR and ATP rating. Pilots listened to tape-recorded ATC messages while they flew six flights in a single engine flight simulator. They were told to repeat the ATC message and then execute the instructions. Results showed the oldest

pilots were less accurate on average whereas the most expert pilots were most accurate on average. Expertise effects were mediated more by training and experience than by basic cognitive ability. IFR rated pilots excelled at the ATC task but they performed no better than VFR rated pilots on the general working memory tasks. While age differences in ATC communication performance may largely reflect age-related decreases in working memory, expert knowledge may at least partially offset the effect of a decrease.

24. Taylor, Joy L., Jerome A. Yesavage, Daniel G. Morrow, Nancy Colhert, John O. Brooks, III and Leonard W. Poon. The effects of information load and speech rate on younger and older aircraft pilots' ability to execute simulated air-traffic controller instructions. *Journal of Gerontology*, 1994; 49(5): 191-200.

Younger and older pilots heard recorded air traffic controller messages and flew six simulated flights. The ATC messages varied in length (three or four items), speech rates (235 vs 365 wpm) and type of command (course, headings, altitudes, radio frequencies, and transponder codes.) Older pilots made more execution errors on average and the age difference was greater for the radio/transponder commands, which contained more unique digits than the course commands. Longer message lengths and faster speech rates led to higher error rates although the increases were not more marked in the older pilots group.

25. Tsang, Pamela S. Age and pilot performance. In *Aviation Training: Learners, Instruction and Organization*, edited by Ross A. Telfer and Phillip J. Moore. Aldershot: Avebury Aviation, 1997. Pages 21-39.

Reviews some of the known age effects on cognitive functions that have been identified to be essential to piloting. Some of these cognitive functions are: perceptual processing, memory, problem solving, decision making, psychomotor coordination, and time-sharing performance. In summary, the author states that it has not been easy to detect how age affects pilot

performance. Not only does age affect the different cognitive functions to different degrees, the time of onset of significant age effects also differ across cognitive functions.

26. Tsang, Pamela S. and Tonya L. Shaner. Age, attention, expertise, and time-sharing performance. *Psychology and Aging*, 1998; 13(2): 323-247.

Examined time-sharing (performing more than one task simultaneously), efficiency and resource allocation in a group of pilots and nonpilots aged 20 to 79 years. The participants performed five dual tasks that represented different degrees of structural similarity. Age, expertise, and structural similarity were found to interactively affect time-sharing performance through attentional resources. Age-related deficits in time-sharing were evident under conditions of intense attentional demands and when precise control was required. Some modulation of the age effects is likely with modest expertise.

## PHYSICAL HEALTH

27. Booze, Charles F. Jr. Sudden in-flight incapacitation in general aviation. Technical Report DOT/FAA/AM/87/7. FAA Civil Aeromedical Institute, Oklahoma City, Oklahoma. August 1987.

Considered NTSB data and post-crash medical data to estimate the probability of in-flight incapacitation in general aviation. Data indicated that approximately three accidents per thousand are known to result from pilot incapacitation. There were suggestions that the likelihood of incapacitation increases with age.



28. Froom, Paul. The risks of piloting with advancing age: commentary. *Journal of Community Health*, 1994; 19(2): 71-73.

Argued against the proposal that pilots over 60 should have more frequent physical examinations. A primary problem with determining whether a pilot is fit to fly is that there is no existing definition of acceptable risk. Some have supported a 1% rule. This refers to a 1 percent chance of sudden incapacitation during the course of a single year, or one in 864,000 hours. In discussing a proposal for the development of a multivariate logistic function to predict 60 year old pilots who have a greater risk for sudden incapacitation, the author feels that a problem with this approach is that above age 55 the risk factors are no longer good predictors of future morbidity or mortality. The author recommends that evaluations of pilots over 60 be based on actual performance rather than more frequent medical examinations.

29. Rebok, George W., Yandong Qiang, Susan P. Baker and Guohua Li. Age-related vision problems in commuter and air taxi pilots: a study of 3019 pilots, 1987-1997. *Aviation, Space, and Environmental Medicine*, 2007; 78(7): 706-711.

Examined the incidence of age-related vision problems in a fixed group of 3,019 commuter air carrier and air taxi pilots. The study period accumulated 419 incident cases of vision problems, with the three most prevalent types of visual problems being corneal problems, glaucoma, and cataracts. A baseline history of eye problems and older age were each significantly associated with an increased incidence of vision problems. The authors conclude that with the increasing maturity of the pilot population, it is essential that appropriate visual screening and correction be emphasized for specific age-related ophthalmic conditions.

30. Taneja, Narinder and Dougl A. Wiegmann. Prevalence of cardiovascular abnormalities in pilots involved in fatal general aviation airplane accidents. Aviation, Space, and Environmental Medicine, 2002;73(10):1025-1030.

Analyzed the cardiovascular abnormalities in pilots involved in fatal general aviation airplane accidents. A comprehensive review was conducted on pilots involved in fatal fixed-wing general aviation aircraft accidents in the U.S. from 1996 to 1999. The analysis revealed the presence of cardiovascular abnormalities in 43.82 percent of the pilots. Coronary stenosis had a prevalence rate of 37.4 percent. There were 41 pilots who had evidence of severe atherosclerosis of the left coronary artery. There was a statistically significant relation between coronary atherosclerosis and advancing age. The findings have implication for aircrew health education and primary prevention programs.



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