



**The Aging Military Aviator:
A Review and Annotated Bibliography**

By

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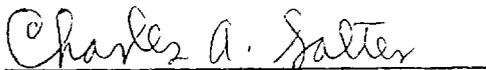
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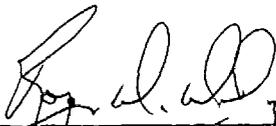
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<p>Studies suggest that aging is another factor which may affect performance of military pilots. Although these aviators generally are better-educated and healthier than their age peers in the general population, they, too, are subject to insidiously deteriorating physiological and sensory systems, a slowly increasing likelihood of acute pathologies, and a general slowing with age--all within the age range of military pilots. Reductions in some parameters might be offset to some degree by experience and maturity; however, age-related changes and the effects therefrom vary more between individuals in any age group than between the groups themselves. The real problem, though, is that we still do not know what effect, if any, age-related changes have on performance of military aviators. Neither is there a concerted effort to provide the aging pilot with a coping strategy for the approaching situation.</p>			
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Introduction

Historically, the U.S. Army Aeromedical Research Laboratory has focused on biomedical factors affecting the performance and well-being of Army aviators. Some of the factors include vibration, fatigue, noise, heat, sleep deprivation, protective equipment, use of night vision devices, and various drugs. Studies done elsewhere suggest that aging is another factor which may affect performance of military aviators.

Statement of the problem

Much human research confirms an association between aging and both physiological and psychological changes; but, there is considerable controversy over the influence these changes have and when they take affect. In 1959 the FAA established a policy setting age 60 as the age beyond which certain commercial pilots may no longer fly as such. While the military has no "age 60" rule, research has shown that some of age-related changes begin as early as age 35, well within the range of military aviators.

Equally well established, and perhaps of greater concern from the standpoint of predictability, is the finding that the pattern of age-related changes varies greatly from one person to another. That is to say, the particular physiological and/or psychological function affected, the age of onset, and the amount and rate of change differ tremendously between individuals. The question is: How do the changes affect the performance of military aviators?

Background

One does not have to dig deeply into the literature to find numerous references documenting various effects of aging in the general population (e.g., Fozard et al., 1990); but, most of the works look at people considerably older than most of the pilots for whom this paper is intended. Also, while there are many inquiries being called "aviator studies," there are surprisingly few of them using pilots as subjects, and even fewer comparing younger and older military pilots. Those that do suggest the differences between the age groups in the range of our consideration, while observable, may not be all that important.

Studies on aging in general

Aging, in general, has been a subject of research interest for a long time. Many inquiries have been made into its various aspects. Fozard and Fisk (1988) summarized some of them with this statement:

One of the most reliable findings in aging research is the general slowing of behavior as a function of age. For tasks requiring information processing (memory scanning, mental rotation, etc.), many studies find that performance speeds of young and old adults are linearly related, with performance of adults in their 60s being about 1.5 to 2.0 times slower than that of adults in their 20s. These kinds of data have implications for the design of tasks requiring highly paced responses such as those found in computerized office environments that control the flow of information (pp. 1-2).

Most readers will note two dubious points right away, the mention of "office environments" and "adults in their 60s."

On the first of these points, while perhaps not an "office" in the usual context of the word, certainly the modern aircraft cockpit easily qualifies as one of "the computerized environments that control the flow of information." With respect to the other point, it may be true that few military aviators are even approaching 60; however, the same referenced "many studies" show evidence of age-related effects well before age 60. Also, because aviators may not be representative of the general population (e.g., Economos and Miquel, 1979, and Tsang, 1989) does not mean they are not susceptible to the effects of aging.

Gerathewohl (1978a) wrote:

Some specific human capabilities depend on talent, reasoning, judgment, and experience which are retained for relatively long periods of time and may even improve with age.... These underlying or constituent functions are operating from early maturity until some ill-defined maximum or state of decline is reached. In contrast, the ability to perform highly skilled tasks rapidly, to adapt swiftly to new and fast changing conditions, to process incoming information, to resist fatigue, to maintain physical stamina, and to perform efficiently in a complex and stressful environment, begins to decline, on the average, in early middle life and from thereon deteriorates in a more or less steady fashion. In addition, although experience, judgment and reasoning may be well preserved and compensate for some of the other functional losses, the

ability to apply them, especially in non-routine or emergency situations, is progressively lost with age at a rate comparable to the loss of rapid performance of highly skilled tasks (p. 3).

Here, the ambiguous phrase "in early middle life" stands out. A review of some pertinent samples of the literature helps to clarify the reason for the ambiguity.

Several researchers pursued the subject of aging from the standpoint of information processing and came away with different conclusions. Salthouse and Somberg (1982) looked at the results of a digit recall reaction time exercise using 13 males and 11 females between 18 and 28 in one group and 12 each between 64 and 71 in another. These investigators found an age effect in each of the three stages they were examining (encoding, or input; comparison; and response, or output) and concluded that the slowing evident in the older group was not related to any one or two stages, but was generalized and possibly produced by a speed reduction in all central processing activity.

At about the same time, Moraal (1982) investigated the same characteristics of information processing using a choice reaction task as the vehicle. Twelve subjects in each of two age groups (20-30 years old in one and 60-70 in the other) operated a device which measured their response times and movement times. Moraal was able to confirm the slower movement times of the elderly, but could not make any conclusions about the encoding stage.

Diggles-Buckles and Vercruyssen (1990) looked at several processing stages in a four-choice stimulus response paradigm. They used 12 college students (16-35 years) and 12 elderly subjects (64-80) from a separate investigation underway at the time. They also found a significant difference between age groups, and concluded the slowing arises from the response selection and response generation stages and not from the encoding stage; hence, the slowing was not generalized as in Salthouse and Somberg (1982) above.

Fozard, et al. (1990) analyzed auditory reaction time data from 865 male and 453 female volunteers aged 20-96 years from the Baltimore Longitudinal Study on Aging, ongoing since 1959. Most of these people were from the upper-middle socioeconomic level of the Baltimore area (70 percent were college graduates and 40 percent had advanced degrees). The investigators found evidence to support the generalized slowing of central nervous system function over age. In addition, they found that age disrupted decision making processes and higher cortical functions. They did not find any particular age at which this problem became manifest.

Investigations concerning aviation

The "age 60" rule

Aviation is one of the few fields to have a single event (what came to be known as the "age 60" rule) so far-reaching as to demand consideration in any review of that industry. Before getting into aviation-centered research, it would be appropriate to discuss briefly the issue that gave rise to much of what follows.

In December 1959, the Federal Aviation Administration (FAA) amended Part 121 to its Civil Air Regulation 40-22 to bar certification to pilots who fly large commercial aircraft once those pilots reach their 60th birthday. ("Large commercial aircraft" in this context are defined as those designed to carry more than 30 passengers.) The policy did not apply to pilots of smaller commercial aircraft (Part 135) nor to general aviation pilots. Very shortly thereafter, the International Civil Aviation Organization (ICAO) issued a similar policy affecting its member countries. The so-called "age 60" rule has been an issue of international controversy ever since.

It would be informative at this point to survey the research the FAA used to formulate its position on this issue; however, the original justifying records for adopting the "age 60" rule appear to have been lost (Coomes, 1973). Even so, it is reasonable to assume the decision was predicated on the increasing complexity of aircraft technology and fears stemming from the state of gerontological knowledge of the day. While it is speculative on our part now, probably it was argued that older people experienced more health problems, to include acute cardiac pathologies. That position is supported by a report written by the director of the Georgetown Clinical Research Institute (then the FAA's aeromedical research laboratory) in which he describes the work being done at the FAA Office of Aviation Medicine at the time (Wentz, 1964). More important to the immediate purpose, though, it contains a statement of the FAA philosophy with regard to the problem of the aging aviator that FAA holds to this day: "...[N]o medical methods exist for evaluating [a specific] adult human being in terms that will provide a useful estimate of his overall status as an aging individual" (p. 1). Very likely, there was some evidence (as there is now) that the probability of incidents of incapacitating illness such as acute cardiac pathologies increases with age. On the basis of that evidence, the FAA probably chose age 60 as the cutoff, sure they were doing the flying public a service by excluding this higher risk group from the cockpit.

For years afterward, aviation-oriented groups such as the Air Line Pilots Association (ALPA) and the Aerospace Medical Association (ASMA) wrangled with the FAA over the "age 60" rule. Even

nonaviation-oriented groups such as the American Association of Retired Persons (AARP) expressed their concern.

Some of these efforts appeared to pay off when in 1967 Congress passed the Age Discrimination in Employment Act prohibiting the use of age as a limiting factor in employment. While that stilled the debate in nonflying circles, it proved to be a disappointment to many opponents of the FAA's "age 60" rule because, whatever other effect that law may have had on national employment practices, it did not affect the "age 60" rule. It did serve to spur research on effects of aging, though.

Gerathewohl (1977) researched extensively to find basis for a functional age index rather than a test based solely on chronological age. He reviewed studies involving pilots and nonpilots. All he found indicated such a series of measures did not yet exist. Soon, he came up with a list of 14 unweighted factors (Gerathewohl, 1978a) he deemed essential for successful pilot performance. In a subsequent report (Gerathewohl, 1978b), he described a selection of technical devices available to measure many of the operational factors needed to establish a functional age index for pilots. However, he pointed out that the verification of the concept was yet to be confirmed.

In 1979, Congress enacted a law (PL 96-171) requiring the Director of the National Institutes of Health (NIH) to conduct a study of the desirability of mandatory age retirement for certain pilots. Subsequently, the National Institute on Aging (NIA) of NIH awarded a contract to the National Academy of Sciences (NAS) to conduct a more objective investigation. The Academy's Institute of Medicine (IOM) did the actual work and rendered the report (IOM, 1981) to NIA.

In the end, the NIA group, by then called the Panel on the Experienced Pilot Study, used the IOM report as a basic reference and found "that age-related changes in health and performance influence adversely the ability of increasing numbers of individuals to perform as pilots with the highest level of safety and, consequently, endanger the safety of the aviation system as a whole. Moreover," it continued, "the Panel could not identify the existence of a medical or performance appraisal system that can single out those pilots who would pose the greatest hazard because of early, or impending, deterioration in health or performance" (NIA, 1981, p. 3). This tended to reinforce the FAA position Wentz (1964) had described. On the basis of its findings, the panel recommended the "age 60" rule be retained and that it be extended to cover all pilots engaged in carrying passengers for hire, including operations under Part 135 (specifically excluded by the original rule). In addition, it recommended establishment of a systematic program to collect the medical and performance data necessary to consider relaxation of the current "age 60" rule.

It was against this backdrop that Mohler (1981), writing in opposition to the "age 60" rule, listed several pages of reasons for eliminating the restriction on airline pilots. In the same article he said:

There is wide individual variation in changes with age at all age groups. This is one of the primary findings in the longitudinal age study conducted ... in Baltimore [since 1959]. Although certain physiologic functions based on population averages show a change toward less capacity in older age groups, the important factor is that there is a tremendous variation among individual capabilities in a given age group. ... There are healthy 70-year-olds (and older) who outperform others in this respect in their 30s.... Present capacity to perform by an individual is the significant point, not the chronological age (p. 447).

There is no evidence that FAA officials were even aware of Mohler's arguments, in that there is no record of a rebuttal and the "age 60" rule did not change.

Boone (1982) thought he had an improvement on Gerathewohl's (1977) functional index plan. He further proposed a numbering scheme to be applied to the pilot physical examination data to better identify those with acute pathologies when calculating the functional age index. Assuming a lower index of functional age is better, his scheme would have penalized a pilot with an acute pathology. Additional physical checks then would be imposed on those with a high index before recertification.

However, it would appear the proponents of a functional age index were unable to replace the chronological age criterion with anything better. Avolio, Barrett, and Sterns (1984) explained that functional age (a concept possibly introduced by McFarland as early as 1943) failed as an alternative to chronological age because no one had yet identified the measures by which to assess functional age. The courts, they held, objected on the grounds that functional age measurement had not demonstrated its reliability in employment decision-making, and the lack of suitable alternatives had left the courts no other recourse.

Those judgments aside, Braune and Wickens (1984a, 1984b, 1985) tried again to establish a functional age index. Using 15 paid volunteers (males, but not otherwise identified as pilots) in each of four age groups (20-26, 27-39, 40-52, and 53-60), they administered a computer-based test battery configured to examine three dimensions of human performance: stages of processing (perceptual/central, response), codes of central processing (spatial, verbal), and input modalities (auditory, visual). The results showed a weak association with age on some facets. The important

finding turned out to be a confirmation that the variance within age groups far outweighed the variance between age groups. To date, there is no indication any of the functional age supporters have been any more successful than their predecessors.

Testifying before Congress in 1985, the director of NIA (Williams, 1985) acknowledged that medical science had progressed a great deal since 1981 (he was one of the original IOM consultants). He told the members of the committee, "... recent studies supported by the [NIA] in healthy individuals in whom special care has been taken to exclude diagnosable disease, show that cardiac output ... and mental functioning ... may be maintained at least as late as age 80 in the same ranges as in healthy young persons" (p. 1). He said "age is not a rational nor reliable criterion for determining whether or not a pilot's medical and functional condition are such that he/she should be permitted to continue in service" (p. 3). Although he included a proposed examination protocol for airline pilots age 60 and above, he stopped short of recommending Congress require FAA officials to retract the "age 60" rule.

In his testimony before a subsequent Congressional hearing, Williams (1991), by then a professor at the University of Rochester School of Medicine and Dentistry, stated unequivocally "that there is no medical or scientific basis for the 'age 60' rule, and that there are sound and dependable methods for evaluating the physical and mental competency of pilots to fly commercial airlines" (p. 8). Further, he testified, "It may be noted, as pointed out in the original Institute of Medicine study, that a pilot in his 40s who has high blood pressure and smokes is at several-fold greater risk of having a sudden heart attack as a pilot in his 60s who does not have these risk factors" (p. 8). While the "age 60" rule has had no direct impact on military aviation per se, it has been the driver of much research on aging that has had--and will continue to have--an impact on military aviation.

Nonaccident research

As one might expect, interest in geriatrics and gerontology increased both at home and abroad following adoption of the "age 60" rule in 1959 and in the years following the NIA report in 1981.

Vision. Melton and Wicks (1966) studied eight subjects (no reference to pilot status) in each of two age groups and concluded that the binocular fusion time in 45-60 year-old men was greater than that of 25-30 year-old men. Also, they found when the displacement was to the far right, the older men were so consistently unable to achieve fusion as to suggest it as a test for neuromuscular aging.

Welsh, Vaughan, and Rasmussen (1976) tendered a questionnaire to 50 general aviation pilots (46 male and 4 female) aged 40-73

years (mean 49.2) to gather information about cockpit visual problems the respondents had experienced and what they did about them. While the report alluded to some visual problems among older pilots, it did not break out the findings in terms of age (i.e., there was no way to determine from the data given whether or not younger pilots were having similar problems, which, if true, might suggest cockpit or instrument design problems rather than aging problems).

Larry and Elworth (1979) examined effects of aging on pilots' abilities to focus the eyes at infinity following performance of near vision tasks. Five subjects (no indication they were pilots) in each of seven groups in 5-year increments between 20 and 55 years were tested under 2 light level conditions on an apparatus designed to measure the time needed to refocus a distant object after viewing a simulated instrument panel. These researchers found the ability to focus the eyes at infinity following near use decreased with age, and was especially pronounced after age 35 (a 50-year old required as much as 3 times longer than a 25-year old). Low-level illumination aggravated the situation even more.

Cognition. Mertens, Higgins, and McKenzie (1983) evaluated performance of 45 men (no indication they were pilots) in 3 age groups (20-29, 40-49, and 60-69) on a multiple task performance battery at 2 simulated altitude levels. Altitude simulation was obtained by means of a gas mixture in a breathing mask: 13.5 percent oxygen and 86.5 percent nitrogen for the 12,500-foot level; compressed air for the ground level. Overall performance declined with age, but not with altitude. While performance of the older group was significantly less than either of the younger groups, the difference between the two younger groups was not significant. This is an interesting point for military aviation, since most military aviators fall between those two lower age ranges. Also, there were interactions between age and workload in which increasing age groups saw increasing performance decrements with increasing workload. The same trend, although not significant, was seen in mental arithmetic and problem solving.

Boer (1986) was examining the feasibility of the Dichotic Listening Task (DLT) for use as a test for improving (airline) aviator selection. In that test, a separate message is presented to each ear simultaneously. A tone tells the listener which message to attend. A short while later, another tone tells the subject to switch attention from one ear to the other. There were 143 chance (awaiting routine physical examination) subjects (131 were pilots) divided into 3 arbitrarily defined age categories (17-29, 30-45, and 45(sic)-70). Complete data sets were collected from 82 of the subjects. The results showed a sensitivity to age; that is, a high correlation between age and errors, especially the number of omissions and intrusions (target numbers of the to-be-

ignored message) in DLT. The only positive age effects were higher levels of accuracy for the RT tasks.

Tsang (1989) presented a reappraisal of the aging aviator issue for the Fifth International Symposium on Aviation Psychology at Ohio State University in which she lamented the dearth of studies on aging pilots that used pilots for subjects. Very briefly, she reviewed four cognitive functions considered important for aviator skills: perceptual processing, memory, problem solving and decision making, and psychomotor coordination. Then, she listed some studies relating to age effects on those functions, noting again that several of the studies used subjects other than pilots. As a matter-of-fact, one of her key points was to stress the need for caution in generalizing results obtained from a population to a select part of that population.

Psychology, emotion, and personality. Preston (1968) took on the task of following the histories of 1000 British airline pilots over a period of 12 years (1954-1965) to see what happened to them. While surprised by the low number of groundings due to cardiac problems (8), Preston expressed alarm at the much larger number of groundings due to psychiatric reasons (36). Those psychiatric groundings accounted for 49.5 percent of the medical failures. Twenty-seven subjects died during the period (22 in aircraft accidents, 1 in an auto accident, and 4 due to unspecified medical causes); however, their ages were not shown.

Yerokhin (1970) examined measures of "neuroemotional tension" collected from two groups of pilots during actual takeoffs and landings. One group consisted of 82 pilots aged 25-40; the other group consisted of 83 pilots "41-45 and more." Visual acuity was 0.7-0.9 (correctable to 1.0 with lenses) in 13 percent of the older group and only 2.4 percent of the younger group. This reduction in acuity was not seen to influence the occupational working capacity. Neither was there an important difference in hearing acuity.

There were no essential differences between the two groups in pulse rate and arterial pressure during orthostatic testing of cardiac measures. However, both age groups displayed significantly increased heart rate during takeoffs and landings with subsequent normalization shortly thereafter. The degree of increase depended on the pilot's participation in the immediate maneuver. The heart rates of pilots at the controls, for instance, were faster than for those not actively engaged in the maneuver (copilot, instructor, etc.), and they lingered longer. Agewise, the increases in heart rate in the younger group in "simple meteorological conditions" were greater than in the older group and extended into almost every stage of the flight.

Data also were reported for the senior group under poor weather conditions. The pattern was the same as before regarding whether

or not subjects were on the controls; but, the heart rates in the senior group surpassed those observed under "simple" conditions (their own or those of the younger group). Even so, Yerokhin concluded the pilots of the senior group exhibited much less neuroemotional tension.

Wadhawan (1978) wanted to assess the influence of age on the flying performance of pilots in the age groups between 20 and 40, but eventually admitted he could not do so because of the variation among individuals. However, he did catalog many of the changes and presented them in a graphic description of aging as it applies to aviators. He saw the most important and meaningful changes taking place in the psychological sphere, and most of that he attributed to the increasing vulnerability to stress with aging. Among the stressors almost constantly at work on pilots, he listed high-density oxygen breathing, hypoxia at intermediate and higher altitudes, vibration at low altitude, changes in pressurization as a result of altitude changes, and changing accelerations. He saw the effects of stress so pervasive that he made the sweeping statement: "The older the pilot the less competent will he be as an operational pilot" (p. 32).

Physiology. In summarizing his more-than-20 years experience as a medical consultant for a large European airline, Durrer (1974) presented some interesting points. With respect to the physiological changes in the heart with age, there is an increase in the amount of fibrous tissue. While this does not by itself cause a problem, it tends to decrease the cardiac reserve over time. It also can interfere with the electrical properties of the heart in time. The same can be said for the heart valves. They tend to lose their softness and pliability; but, again, the normal cardiac reserve masks the loss for a long time.

The effects of acute and chronic emotional factors, especially on hypertension, do not differ much as a function of age. They reflect, instead, the situation in which a pilot finds himself. More important, they change as a function of the individual's physical condition. The presence of a disease process--at any age--can significantly alter the effect of age-related change.

Durrer noted that cardiac diseases--to include arrhythmias, conduction disturbances, and coronary heart disease--were more prevalent in "aging" pilots. As a matter-of-fact, he pointed out that coronary heart disease was the major cause for grounding pilots, and it started many years before--"in early youth."

It was interesting to note the abstracts of several presentations at the 1992 Aerospace Medical Association annual scientific meeting (AsMA, 1992). Kohn and Fennell (1992), referring to a population completely different from Durrer's, presented observations very similar to his. The two investigators reviewed medical

records of all pilots since 1972 determined to be totally and permanently disabled while on active (commercial) flight status for one large U.S. airline. "Cardiovascular disease was responsible for the largest number of medical groundings, followed by neurological and psychiatric disease, and malignant neoplasms" (p. 411). They did not elaborate on the ages of the pilots, however.

Several panels (Glazer, 1992; Jones, 1992; McKinnon, 1992; Mohler, 1992; and Stoklosa, 1992) addressed the "age 60" rule and its continued applicability. In each case, they described how medical science has advanced on this subject over the years, and each recommended against the rule. One panel (Della Rocco and Schroeder, 1992) explained that the FAA had three different studies in progress to reexamine the issue. The agency would make another determination at the conclusion of those three studies.

Flight performance. On a different tack, Leirer, Yesavage, and Morrow (1989) examined the combination of marijuana, aging, and task difficulty on pilot performance. Three levels of drug condition were used: 20 mg and 10 mg of delta 9 THC and a placebo. Two groups of nine pilots each (sexes not described), one group aged 18-29, the other 30-48, were studied in a small, fixed-landing-gear, single-engine aircraft flight simulator. Task difficulty was varied by addition of a moderately turbulent weather simulation. The researchers concluded that turbulent weather produced overall lower performance and that older pilots performed less well than younger pilots. Performance was most impaired immediately after taking the drug. Curiously, a dose x age interaction arose because under the 10 mg dose, the performance of the older pilots did not decrease as much as that of the younger pilots.

While these researchers did find an age-related performance decrement, they pointed out that all, save two, subjects were relatively low-experience pilots (excluding the "high-timers": young mean was 218 hours, old mean was 248 hours). That suggested the older pilots had less recent experience than the younger ones. That notwithstanding, these investigators concluded "age becomes a significant factor in at least some complex human/machine interactions earlier than the general public might expect. The average age of 'Old' pilots in our study was 37 and the oldest pilot in this group was 48." (p. 1151.)

Accident research

In aviation, whether civil or military, accidents constitute an important--if not critical--measure of performance. Several studies have looked at aging as a factor in these accidents; however, it takes but little research through the literature to once again come up with controversial findings. For example, Zeller and Moseley (1957), analyzing Air Force accidents for the

last 6 months of 1953 in search of a direction in which to concentrate the Air Force aircraft accident prevention program, found a disproportionately large number of accidents experienced by pilots in the younger age groups. Pilots aged 25 and below represented only 16 percent of the pilot pool, but were responsible for 40 percent of all accidents.

The authors went on to explain it in terms of hours flown as pilot in command, or first pilot. A common basis for this measure is to calculate the number of accidents per 100,000 hours of flying. When considered from that point of view, the younger pilots still had the highest accident rate. The researchers admitted, however, there were still few "older" pilots flying jets at the time; and, depending on one's perspective, that can make a difference. For instance, when they looked at jet aircraft only, there was a tendency for older age (defined there as over 35) to be associated with a higher accident rate. That comment was quickly followed by a warning: "Caution should be taken in interpreting these results, as analysis of jet fighter accidents indicates that jet time is a more pertinent factor in the jet accident rate than total time. Due to the limited length of time that jet aircraft have been in operation, pilots with large amounts of total experience do not, on the whole, have comparatively large amounts of jet pilot experience" (p. 178).

Two years later, Zeller (1959) examined aircraft accidents experienced by the Air Force in the last 6 months of 1955 and the first 6 months of 1956. This time he concentrated on the age of the pilot, type of aircraft flown, type of accident experienced, portion of flight wherein the accident occurred, and types of errors involved. He found, as before, a larger percentage of accidents overall among the "younger" pilots. This may well be because younger pilots had the greater exposure by far.

When looking at the portion of flight during which the accident occurred, a greater percentage of the accidents happened in the landing phase regardless of age. It was there the accidents increased with age. Zeller suggested a possible link between age-related effects and the more focused vision, precision, and decision of the landing phase.

Mohler et al. (1967) reviewed civil aviation aircraft accident data for 1965 to examine the relationship between age (16-29, 30-44, 45-59, and 60 and over) and pilot certification (student, private, commercial, and air transport). Overall, these researchers found no differences between age groups, but found a significant interaction between age and type of certificate. When the student pilots were excluded, for example, the accident record of the two older groups was superior to that of the younger pilot group. In the private pilot group (by far, the largest), age was

not a factor at all. The authors noted, however, that 51 percent of the mishaps that did occur in the older age group occurred in the landing phase--much as Zeller (1959) had found with the Air Force pilots.

In another study, Booze (1977) was interested in the relationship between occupation and age. He examined the records of over 4000 (general aviation) accident-involved airmen for the year 1974 and found an age-related increase in rate per 1000 airmen with a leveling off over the age intervals from 30 to 49. He noted the highest rates for 9 to 14 major occupational categories occurred in the age intervals above 49 years. When viewed from the point of cumulative experience, however, he noted that for the higher cumulative exposure intervals, younger ages have much higher rates. From the standpoint of recent experience (i.e., flight hours in the 6 months preceding the accident), he noted the same trend; that is, for higher exposure intervals, rates were higher in younger ages.

Ambiguity was heightened further when Eyraud and Borowsky (1985) compared flight records of all U.S. Navy pilots from 1977-1982 with records of mishaps for the fighter, attack, and helicopter communities in which the aviator in control of the aircraft was found at fault. Training mishap data were omitted from the analysis. These authors noted helicopter pilot factor mishap rates, for example, did not exhibit a statistically significant relationship with age, although the rates tended to increase with age.

A brief review of aviation accidents among U.S. Army aviators has revealed similar findings. The Army Safety Center database includes the number and ages of Army aviators involved in Class A and B helicopter ground-strike mishaps¹. Sorted by 2-year age increments of the pilots, Figure 1 is a plot of the total number of these mishaps for the calendar years 1986 (the first full year of the Army's Aviation Epidemiology Data Registry (AEDR)) through 1990 (the last full year of Safety Center data currently available). It shows the number of mishaps increased sharply for younger pilots from the start of their careers into their late-20s and decreased the same way for pilots in their early- to mid-30s. The curve flattened out in the mid- to late-30s and declined again in the early-40s. Beyond that, there were few mishaps.

To draw meaningful conclusions from this data, however, one must have some idea of how many pilots were available during the comparable period, their ages, and the numbers of hours flown by

¹A Class A mishap is one in which the loss (including property damage, occupational illness, and/or injury) exceeds \$1,000,000, or in which an injury results in a fatality or permanent total disability. A Class B mishap involves a loss of between \$500,000 and \$1,000,000 without fatality or permanent total disability.

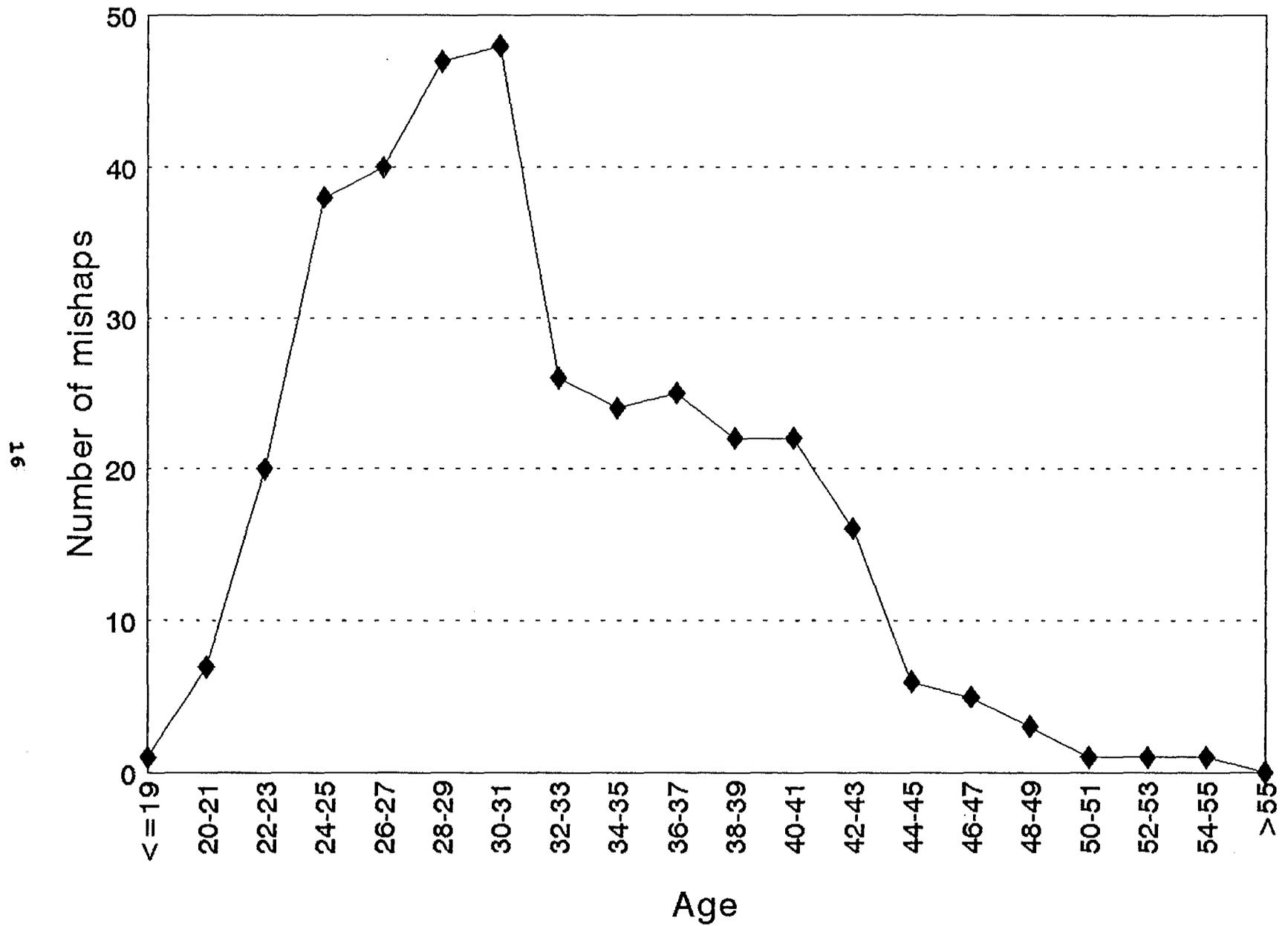


Figure 1. Total Army Class A and B ground-strike mishaps for CYs 1986 through 1990. The first year for the Aviation Epidemiology Data Registry was 1986.

each of those pilots. The number of pilots and their ages can be obtained from the AEDR, which has been tracking all Army pilots through their annual physical examinations since it came on-line in 1986. The hours flown, on the other hand, are not as easily obtained because each aviation unit keeps its own record. The Army does not maintain a central repository for individual flying time. Thus, the numbers of pilots and their ages are readily at hand, but not the hours flown.

While it is true that no final conclusions can be drawn without all three factors, a cautious comparison of aircraft accidents and aviators available can be useful. Figure 2 is a graph of the Army aviator population (active duty, National Guard, and Reserve) by age to match the sources of the ground-strike mishap data in Figure 1. This plot shows a decidedly more bimodal distribution than Figure 1; but, aside from the degree, is remarkably coincident with ages of pilots in the crash data. The number of pilots in the system increased with age to a peak in the late 20s, declined into the mid-30s, increased dramatically into the 40s, fell off just as sharply into the late-40s, and ran out into the 50s. The size of the disparity between these two figures in the second mode deserves further examination.

Figure 3 is included only to show the components of Figure 2 in their relationship to each other. Figures 4, 5, and 6 separate them. In each case, there is an increased number of pilots in the age group from the late 20s to the early 30s and a second group in the late 30s to the early 40s. The younger group peaks at about the same age in each component; the second group, however, has some interesting differences.

The ratio of older pilots to younger ones in the Army Reserve and National Guard (Figures 4 and 5, respectively) is about 2:1. For active duty pilots (Figure 6), it's about 1:1. While the number of older pilots in the Reserve declined slightly over the period, the number in the National Guard was holding. For the active duty component, the reduction in older pilots was dramatic, probably reflecting loss of the Viet Nam era pilots, many of whom would have been reaching retirement about CY86-90. That option would not have been available to most of the Reserve and National Guard pilots.

A comparison of Figures 1 and 2 at this point is informative, but must be approached with caution because it does not include the flying time, as already stated. Figure 7 shows the mishap rate per 1000 Army aviators for the age increments. While the peak at the start may be due to inexperience, it also may reflect a greater exposure (amount of flying time). There may be other explanations as well.

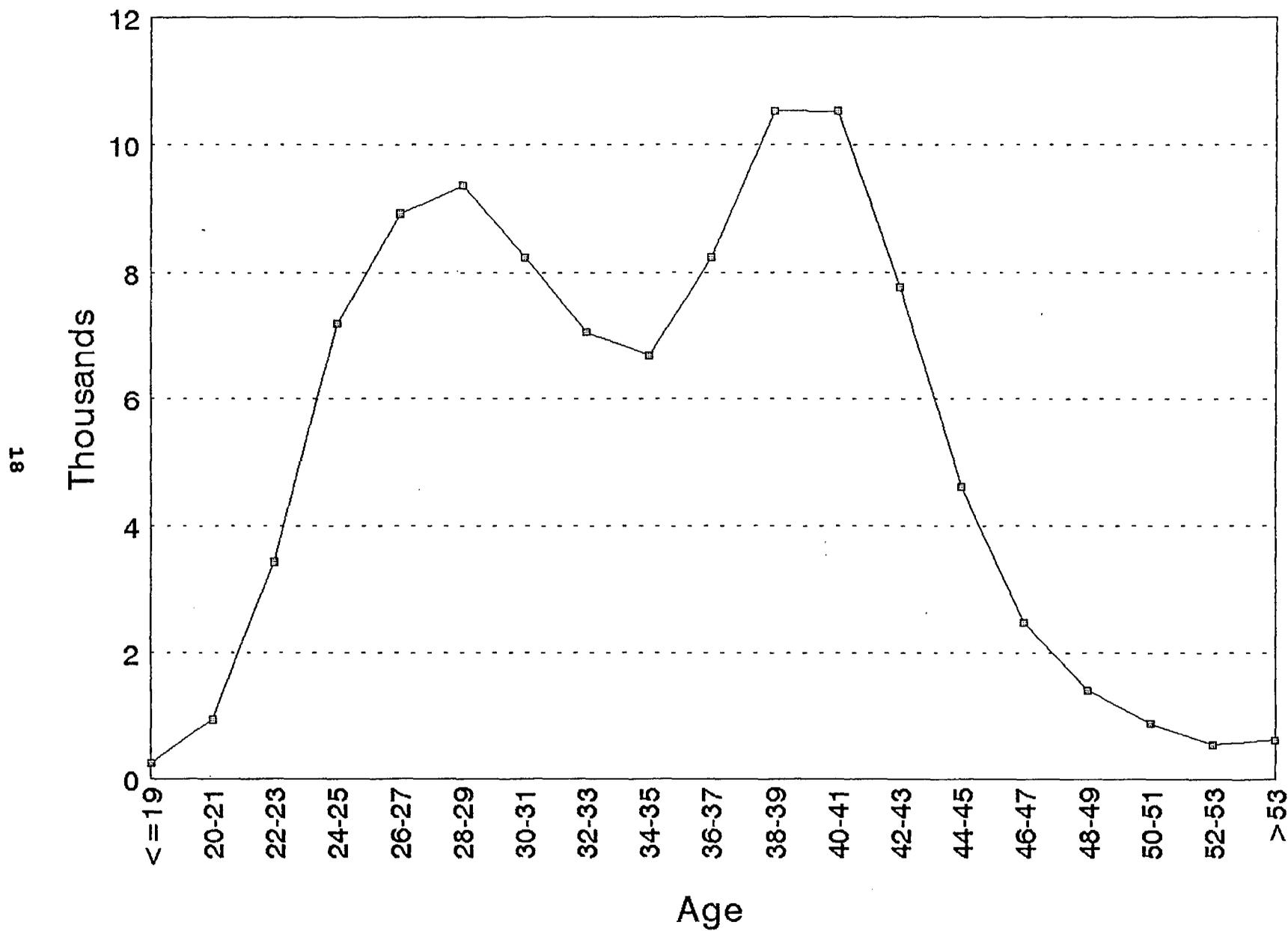


Figure 2. Total Army aviator population for CYs 1986 through 1990. The first year for the Aviation Epidemiology Data Registry was 1986.

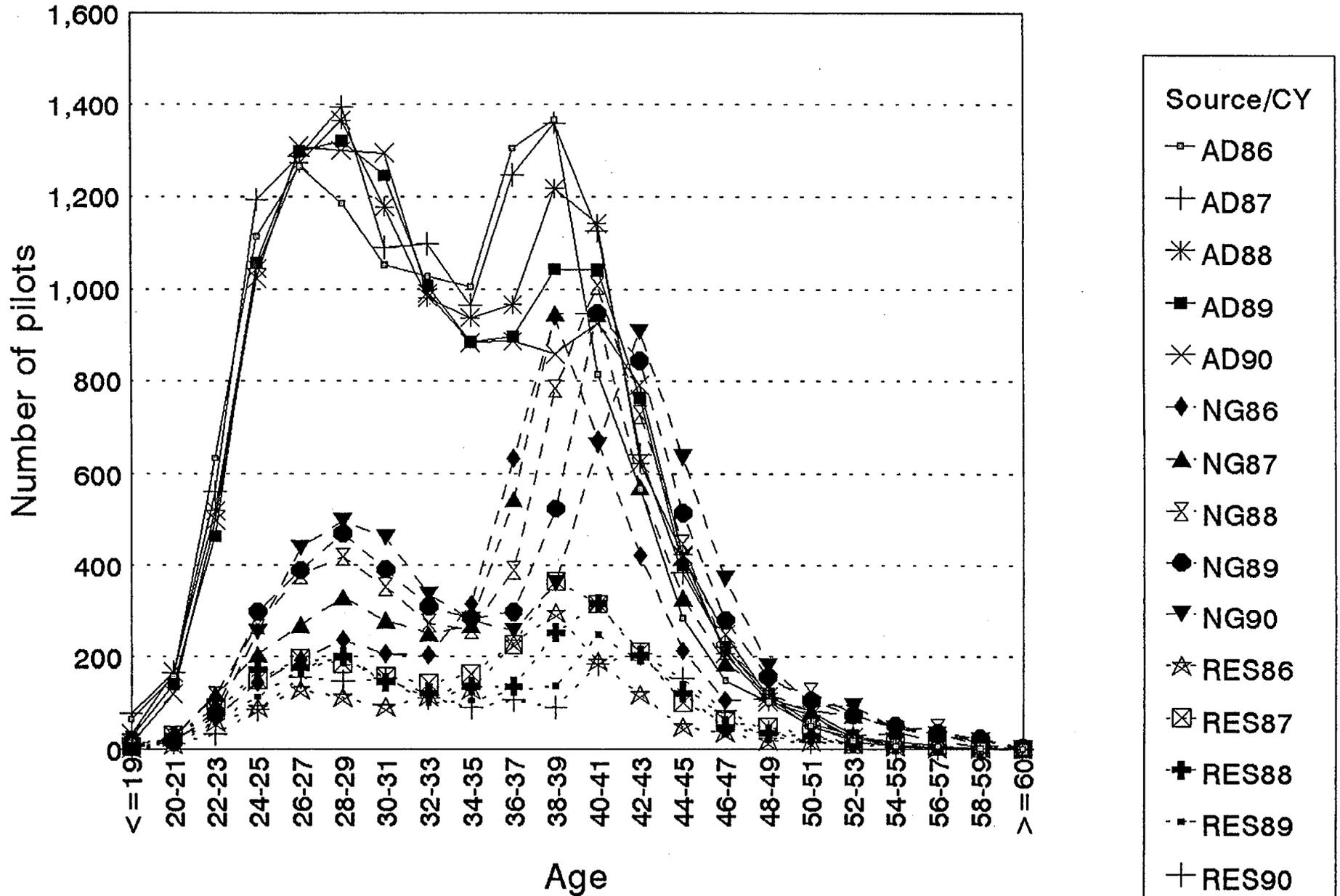


Figure 3. Armywide aviator population for CYs 1986 through 1990. The first year for the Aviation Epidemiology Data Registry was 1986.

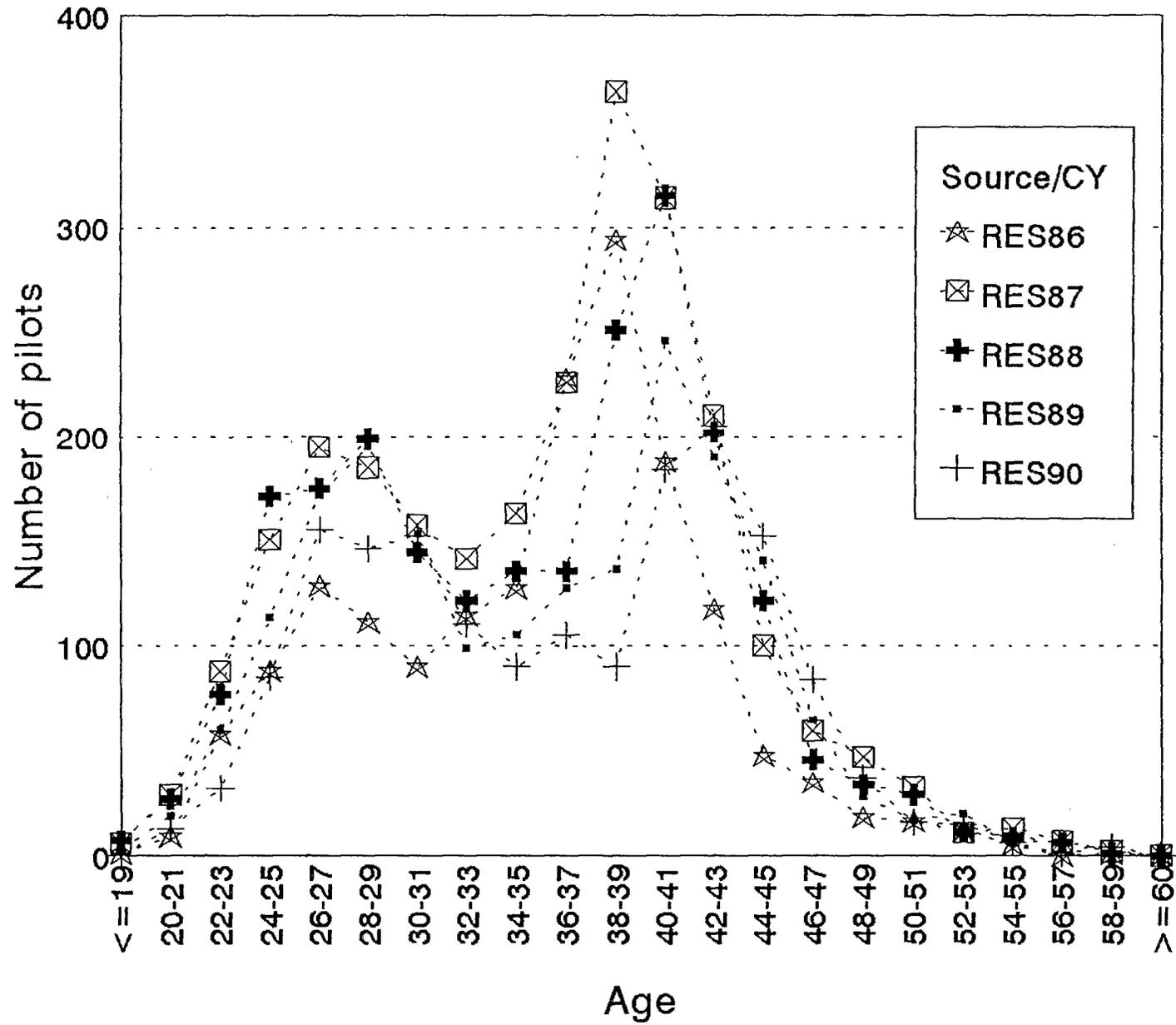


Figure 4. Army Reserve aviator population for CYs 1986 through 1990. The first year for the Aviation Epidemiology Data Registry was 1986.

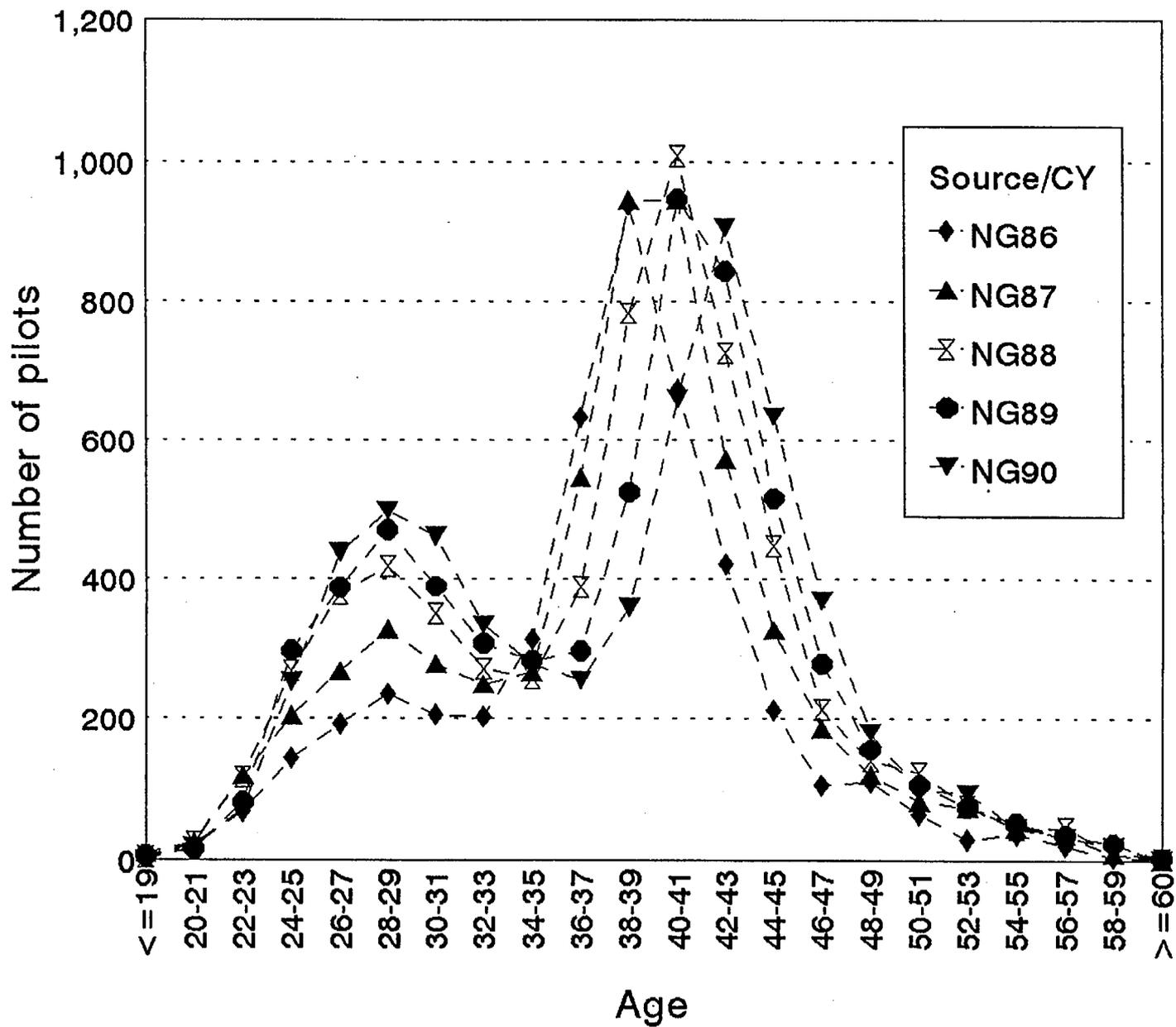


Figure 5. Army National Guard aviator population for CYs 1986 through 1990. The first year for the Aviation Epidemiology Data Registry was 1986.

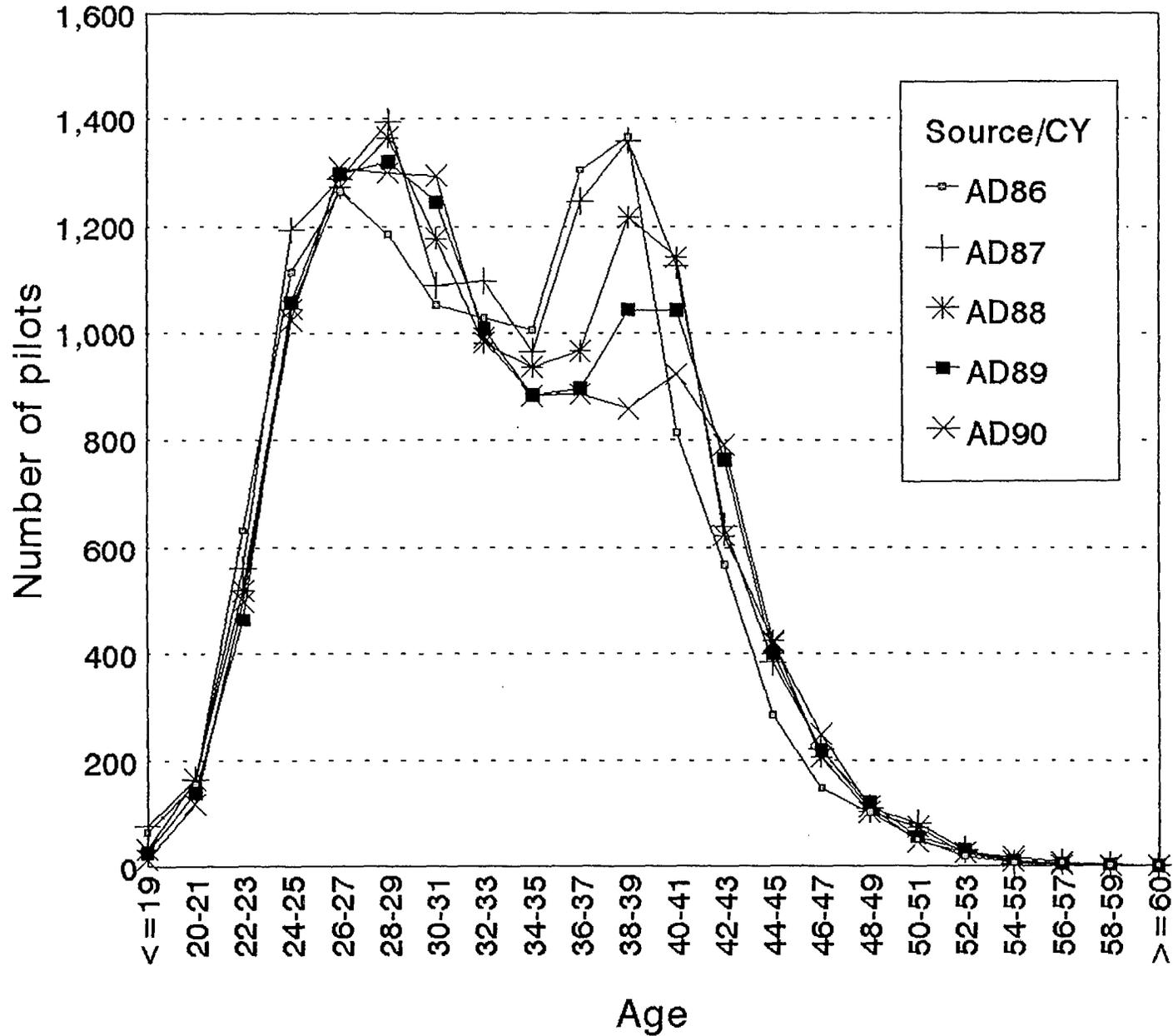


Figure 6. Army active duty aviator population for CYs 1986 through 1990. The first year for the Aviation Epidemiology Data Registry was 1986.

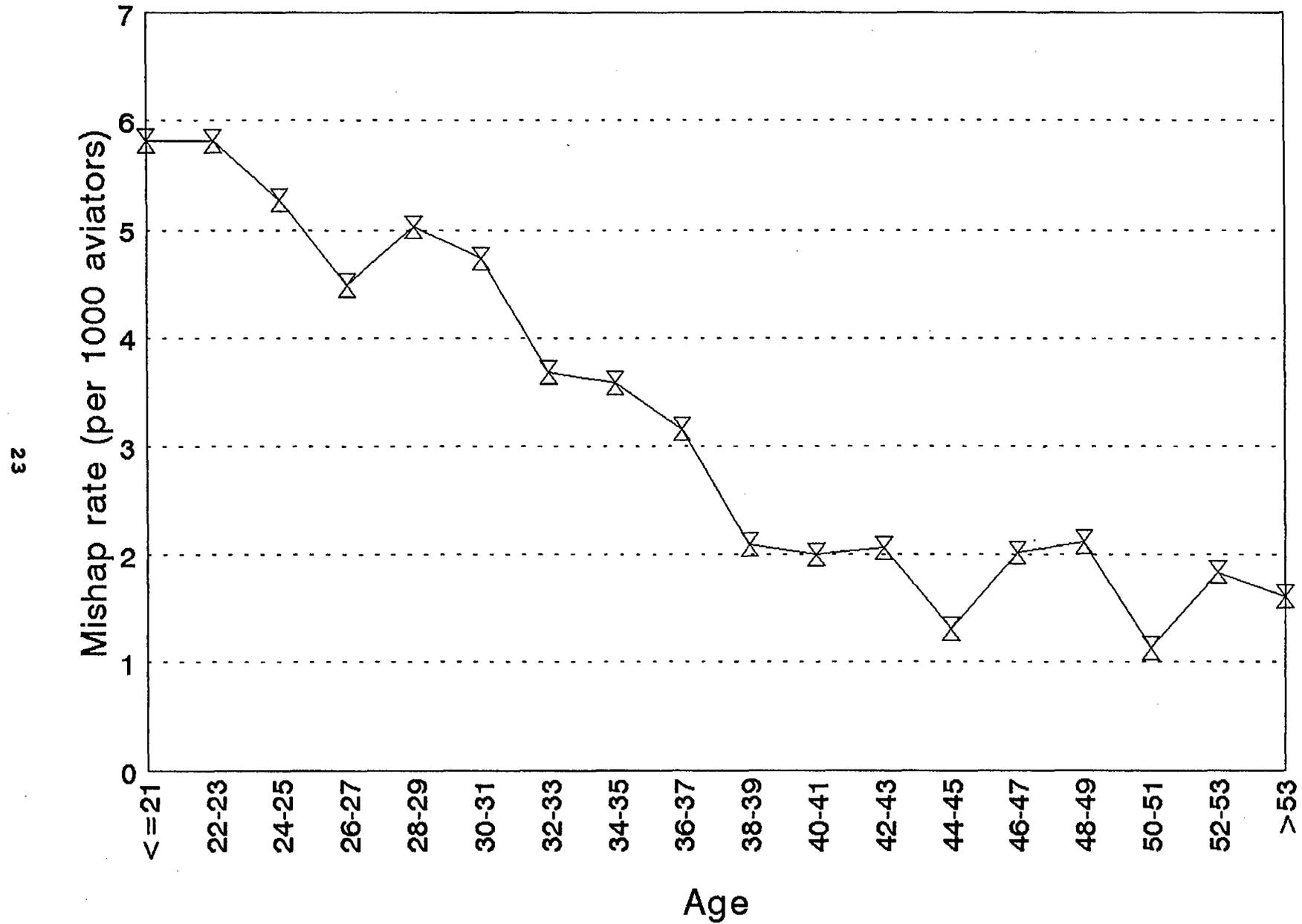


Figure 7. Total Army Class A and B ground-strike mishaps for CYs 1986 through 1990 by age.

What explains the peak at ages 28-29? If the bulk of flying was done by so-called "midcareer" pilots (28-29), that might account for some of the increased accident experience in that cohort. There might be other explanations. Then, too, the difference might simply reflect random variation.

Why does the rate increase from 46-49 among pilots who, presumably, have the most experience and maturity? It could be that the initially lower rate is confounded by reduced exposure. The increase may be not statistically significant at all.

Finally, what explains the increased rate in the older group? Is the increase after age 50 an artifact resulting from a decreased number of pilots and only one accident in each increment? How much is explained by a reduction in exposure? How much of it--if any--is age-related?

It is possible also that age of the pilot interacts with the type of helicopter. Figure 8 illustrates the CY86-90 Army aviation mishap data from the standpoint of the type of helicopter (attack, cargo, scout, or utility) flown. For attack helicopters, 24-25 year-old pilots (about 7 percent of the total available) accounted for about 20 percent of the mishaps. In scout helicopters, 26-31 year-olds (about 26 percent of the total) accounted for about 46 percent of the accidents. With the utility-type helicopters, about half occurred to pilots up to age 31 (38 percent of the total) and half to those above. Almost 60 percent of the cargo accidents, on the other hand, implicated 38-45 year-old pilots, or about a third of the pool. But, and it bears repeating, this picture may be deceiving in that it lacks the exposure information. Anecdotally, one is more likely to find a younger pilot at the controls of an attack or scout helicopter; an older pilot at the controls of a cargo-type helicopter. There is no known support for that statement, however. Certainly, a thorough and well-planned research effort is needed to answer the questions posed.

Military aviators and age-related change

Some physiological and psychological aspects of aging in military aviators have been examined. In 1970, NATO's Advisory Group for Aerospace Research and Development (AGARD) met in Germany for a symposium on "The Aging and Aged Aircrew" (AGARD, 1971). At that meeting, Grunhofer and Gerbert (1971) briefly reviewed some of the research on aging, directing attention to the large variability within age groups and the different demands associated with different tasks. Those two investigators kept returning to the same question: Without considering age, how well can a given pilot perform a given function? To many, the question is still valid.

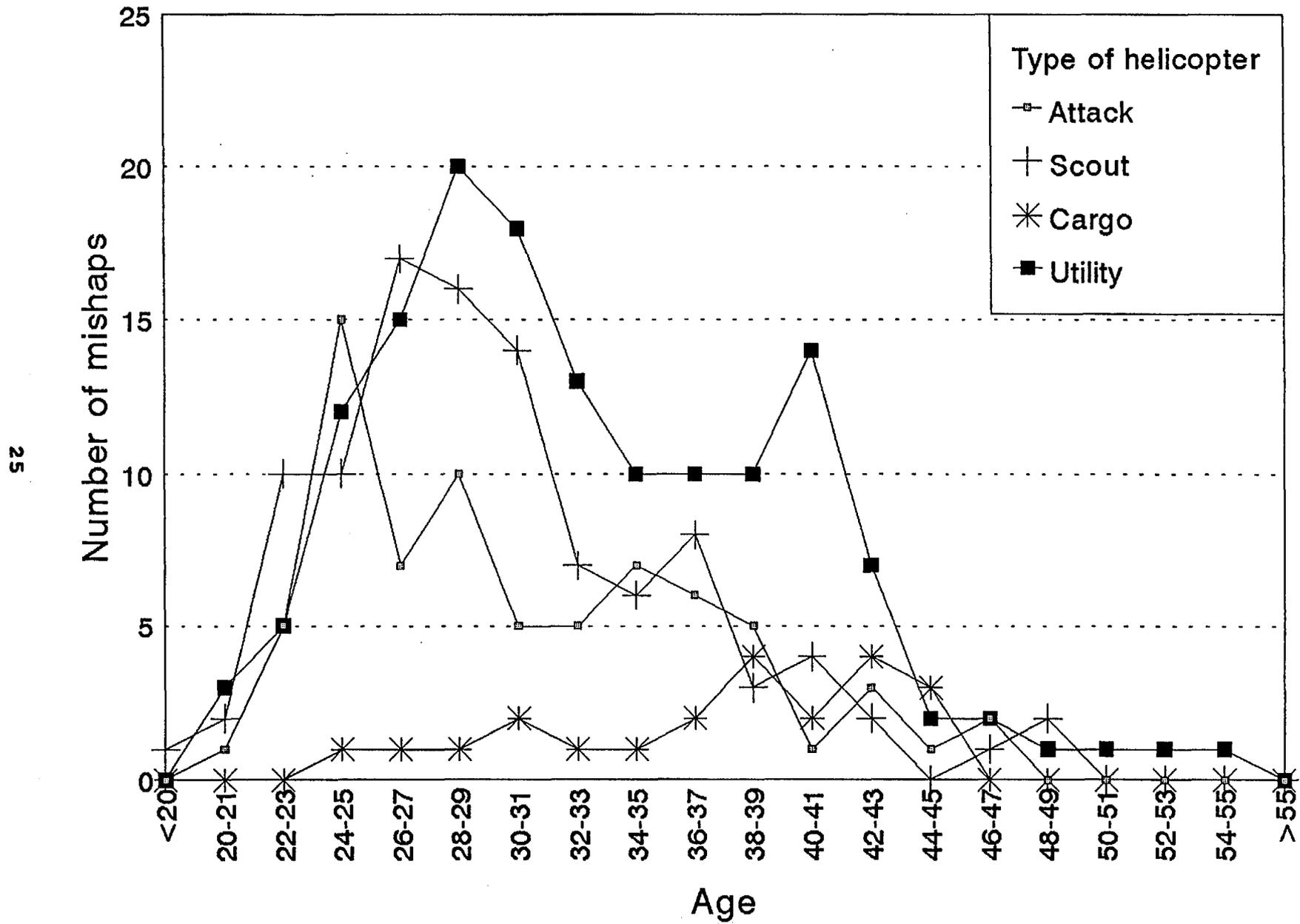


Figure 8. Total Army Class A and B ground-strike mishaps for CYs 1986 through 1990 sorted by type of helicopter and ages of pilots.

Frölich (1971) examined the pure tone audiograms of 1024 German Air Force pilots and noted a marked increase in number and severity of hearing losses with increasing age, especially above 35 years. In practical terms, the level of hearing loss could be expected to interfere with cockpit conversation under normal circumstances. Earphones with good attenuation characteristics and closely fitted earcups would be of considerable value; although he, like Grunhofer and Gerbert (1971), said each pilot must be evaluated on the basis of his hearing ability and the needs of his job.

Goldman (1971) pointed out that because of sophisticated electro-mechanical devices and hydraulic booster systems in modern aircraft, the usual measures of physical fitness--muscular strength, cardio-respiratory capacity, and relative body weight--are of little importance to aircrewmen. More important is the aircrewman's attitude associated with being fit and able to cope with anything.

Mitchell et al. (1971) told the AGARD conferees how some of the data from the "Thousand Aviator Study,"² helped medical science understand more about the electrocardiogram and the meanings of subtle changes seen therein. Also, he told them that increasing blood pressure (a prominent cardiac pathology factor) was found to be correlated with weight gain, especially if the man's parents died in middle age. (That seems to be unrelated to the discussion; but, high blood pressure and weight control associated with aging have been ongoing problems in the military for many years.)

In a longitudinal study not related to AGARD, Saito et al. (1969) observed 485 jet pilots of the Japan Air Self-Defense Force for 6 years. Interestingly, the most remarkable finding in that study was a sharp decrease in accommodation above age 41.

This issue and others came up again when the U.S. Department of the Navy asked the National Research Council (NRC) for information about how aging affected military pilots. Sekuler, Kline, and Dismukes (1982) reviewed existing literature concerning the relationship between aging and visual function on behalf of Working Group 55, Committee on Vision, Assembly of Behavioral and Social Sciences, NRC. They cautioned, however, that their data was based mostly on the general population because there was virtually no data at the time based on military pilots. Further, they said they had insufficient information to determine how these age-related changes might affect performance.

²The Navy began a study of 1056 pilots at Pensacola Naval Air Station in 1940 which eventually became known as the "Thousand Aviator Study." Numerous reports have been spawned by that still-ongoing research effort; however, it was never started as a longitudinal study and was never written up as such.

With that caveat in mind: They found the pupil of the eye shows a reduction in resting diameter in the age range of 35-45 years. This might cause a problem in low-light situations. The lens, too, begins to harden and yellow about the same time, usually resulting in the familiar reduction in accommodation mentioned earlier. Also, it accounts for the impaired discrimination of color perception in the lower frequencies of light often experienced by older people--whether pilot or not. Changes in pupil and lens may be responsible for changes in dark adaptation and acuity with age; but, there was controversy on that issue. Similarly, contrast sensitivity and dynamic visual acuity were not fully understood.

Working Group 55 found changes to some of the other visual processes unclear, too. While visual fields, for example, do diminish with age, the exact cause is not known; and no one had studied the effect on performance. As for depth perception, the authors lamented the lack of general methods of evaluating an individual's monocular depth perception. If binocular vision is so vital to aviation, how does one explain aged pilots with reduced binocular vision, or even monocular vision, accomplishing landings and other tasks requiring depth perception? Quite obviously they are able to use other cues, especially in familiar environments. Thus, the Group found evidence to suggest effects of age and experience on depth perception may be confounded.

Temporal resolution is another potential problem to the older military pilot. According to the research reviewed by the Working Group, pilots over 40 have a tendency to retain an image on the retina longer. This could be a problem, for instance, in recovering from light flashes in combat. There is no known research on age-related effects with night vision devices.

As mentioned earlier (e.g., Fozard and Fisk, 1988, and others), the decline of processing speed by older people also is a potential factor here. Sekuler and his colleagues found studies to suggest "conditions that permit efficient performance by a 25-year-old...-aviator may not be adequate for his 45-55 year-old counterpart...." In the same search, they found information which indicates pilots are less prone to this age-related slowing, thus clouding that issue even more.

Another area of potential difficulty involves pilots' abilities to perceive incomplete targets. The evidence at hand indicated to the Group that pilots in their fifties make less efficient use of partial information. And, once a perception has been established, older persons may be less likely to modify that perception--even in light of additional evidence. Once again, the effect on pilot performance is not known.

Much of the uncertainty in the NRC review described arises from the relatively large number of studies undertaken to predict

behavioral changes in aging pilots, although few of those studies used pilots for subjects. Of course, a major question arises immediately: Are findings based on data from a general population generalizable to a select portion of that population? The answer has to be: Only with great caution. And there is even greater danger when one considers a third level of generalization: Are the findings supposedly relevant to a general aviator population also relevant to a military aviator population? Tsang (1989) and Sekuler, Kline, and Dismukes (1982) say not. Economos and Miguel (1979), looking at population dynamics, are not so sure. They believe mortality, for instance, starts later in the pilot population, but proceeds at a steeper rate once underway, thus ending in about the same place.

It is noteworthy to point out that there are very good reasons for advocating the use of pilots (military pilots, where appropriate) as subjects in such investigations. Besides the obvious screening as a result of physical (and sometimes educational) examination requirements, there are psychological factors which allow general aviation pilots to accept the risks involved in aviation itself. To this mix one might reasonably add the challenge of the military aviator who must keep himself ready to stalk, intercept, and neutralize (kill, if necessary) an opponent before that opponent has a chance to do the same to him. Provocation and simple survival are factors not normally encountered in civil or commercial aviation. Do these differences make military aviators unique? Does it make them a special subgroup? At the risk of repeating the theme of this paper, how do age-related changes affect military aviator performance?

Unrelated to the "Thousand Aviator Study," but related to each other, two more studies examined hospitalization rates of a large number of male U.S. Navy pilots. In the first survey, Hoiberg and Blood (1983) compared by age (3-year intervals from 21 through 53) the hospitalization rates (per 10,000 strength) for 22,417 pilots with rates for 3 control groups: nonpilot aircrew officers, unrestricted line officers, and staff officers. While young pilots were more prone to dental-related problems and accidental injuries (primarily sports-related), older pilots (especially in the 39-41 age range) were prone to circulatory diseases. The researchers found all groups were generally healthier than equivalent civilian samples.

In the second review, Hoiberg and Burr (1984) examined the hospitalization records of 22,245 male U.S. Navy pilots to see if any "ill health effects" could be associated with any type aircraft. While not specifically addressed in the objectives, they looked at an age factor also. The number of hospitalizations for each diagnosis was listed by the pilot's age category ("under 36", or "over 35") within the primary type of aircraft flown (fighter, attack, electronic, helicopter, patrol/antisubmarine, cargo trans-

port, reconnaissance, and trainer/other). They were not able to find any relationship pertinent to this review.

In view of the physiological deterioration so far described, how then does the aging aviator compensate to maintain--if not improve--his pilot skills? Wadhawan (1978) suggests that experience and maturity gained from accumulated flying time makes the difference. His question was, "Up to what extent is the balance maintained and when does it break down...?" (p. 33.)

Gubser (1983) describes a change from the young pilot "unconcerned about the risks of his work" to the older aviator who slowly becomes more cautious, even anxious at times. As the pilot matures "he will be able to equally estimate risk and pleasure, then balance between temperament and cautiousness." Gubser also suggests that younger pilots with their "trigger-quick reflexes have been known to get a young man into trouble he can't get out of." By the same token, experience and maturity may preclude the older pilot from getting into the same situation. Indeed, it may be that those who do not recognize--and respect--age-related changes are less likely to survive. Hence, the sage reflection, "There are old pilots and bold pilots, but very few old, bold pilots."

With respect to military aviators in the U.S., age has never really surfaced as a serious issue--possibly because most military aviators who retire in service do so long before what has become the "age of concern." The statutes governing mandatory retirement are sometimes complex, depending on branch of service, rank, and exigencies of the military. While an Army warrant officer aviator starting a career early, for example, would usually be forced to retire about age 48-50, it is possible for the same person, say, in a Reserve or National Guard capacity, to retire 61 days after reaching the age of 62. Under certain very stringent conditions, retirement could go even beyond age 62; but, such cases are extremely rare. The point is: Any retirement would be based on a statutory requirement for that rank, etc. The U.S. Department of Defense has no upper chronological age limit for its aviators. Some people see this as a moot point since it is very unlikely anyone would survive the various separation options to reach the statutory limitations in question. Most military aviators retire after 20 years active duty (about 40 years old), while some continue to 30 years. Very few stay on to encounter mandatory retirement--and rarely do any of those serve in a combat role.

As already noted, however, the mechanics of the human system have been studied extensively. Age-related changes start long before age 60. Some of those studies (e.g., Wadhawan, 1978; Gubser, 1983) have tried to relate the changes to various elements of military aviation; but, few studies have sought to check the effects on performance. Inevitably, the essential question still

has to be answered: "How does aging affect the performance of military aviators?"

Cockpits and aviation-related systems are becoming more and more complex. In terms of expense, the cost of even one lost aircraft is large and increasing. The additional cost in terms of injury and loss of life--not to mention the potential for liability--cannot even be estimated. We already have established that the effects of aging vary tremendously between individuals. Also, they are frequently insidious, sometimes taking years to become manifest. How, then, does one predict the point at which age-related physiological and psychological changes in any one military aviator overcome the compensating mechanisms of maturity and experience? Or, said another way: How does one predict the point at which maturity and experience no longer compensate for age-related changes in any one military aviator? There seems to be little research bearing directly on that question.

Discussion

There can be no doubt that military pilots, like other people, are subject to functional declines which accompany aging. Changes in the quality of vision and hearing are well-documented. Disease processes are more frequent in people as they age, even though there is evidence to suggest that, on the average, the rate of deterioration of any one pilot may be significantly slower than that of his nonpilot counterpart in the general population. Also, there is some suggestion that the postdecline period is more rapid, thus ending in about the same place.

What about some of the other factors mentioned in the introduction to this paper? Is there a synergistic effect between aging and vibration? Fatigue? Temperature extremes? Sleep deprivation and/or irregular work schedules? Physicians already know something about how drug effects differ as a result of older age. Does that knowledge apply to people in the age range of military aviators? For example, should age be considered in taking atropine as an antidote to toxic agents likely to be encountered on any future battlefield?

Of course, all of these arguments beg the question: What effect does it have on performance during the years on active duty (and following, if the pilots transfer to the Reserve or National Guard)? As age-related declines occur, some evidence suggests evolving experience and maturity enable a balance for some time. But, there is not sufficient evidence to suggest how one determines--predicts--the point at which that balance is lost.

On the subject of Army Reserve and/or National Guard pilots, many of these men and women are in their 40s and 50s and have not kept up with changes of aviation inventory. Many have not had combat-related experience in a long time. Have the few weeks a year of active duty enabled them to maintain their skills? If they are called to active duty in times of national crisis, can they be retrained quickly into new and sometimes radically different technology? Are the techniques available for such an undertaking the same for older pilots as for younger pilots?

This is not to suggest a system failure. It is to ask: Is there sufficient evidence to determine when the performance of older pilots, whatever their component, is no longer adequate for the formidable tasks they are sent to accomplish--especially when one considers that the opposition may be a younger pilot with the same level of training?

The AEDR shows a large contingent of older pilots now on active duty. Hence, the problem may be more noticeable now simply because of numbers. Even with reductions due to normal attrition, however, the current younger aviators will eventually age, even though replaced by other younger pilots. If there is another national crisis, many of the older Reserve and National Guard pilots will be brought into active service along with the younger ones. The problem is not likely to go away.

There is another important question: "Could pilots in the 'middle ground,' so to speak, be trained in a nonthreatening environment to watch for signs of aging and be taught a 'coping strategy' to avoid having to learn the lesson the hard way--by trial-and-error?" For that matter, are the differences in performance over the likely period of military service such as to be of no concern at all? The literature now available simply does not permit a definitive answer to those questions. Eventually, it must.

Conclusion

The picture of an aging military pilot as projected by the information at hand would not be clearly in focus. While much is known about age-related effects in the general population and, by inference, in the aviator population, little is known about the effects those changes have on the performance of military aviators. The picture would show a person (probably male, but female is not ruled out) who is better-educated and healthier than his age peers in the general population. Even so, he is subject to insidiously deteriorating physiological and sensory systems (usually occurring over a period of years), a slowly increasing likelihood of acute pathologies, and a general slowing down. Reductions in hearing, central processing speed, and some vision parameters would be

offset to some degree by experience and a possible tendency to avoid those situations which would unnecessarily challenge his skills in the first place. As far as age-related changes in any one aviator are concerned, we would expect to see more variance between individuals in any age group than between the groups themselves. But we would still not know what affect, if any, age-related changes have on performance. Neither would we see a concerted effort to educate the aging pilot on the approaching situation.

Therein lies the challenge to research: What is the effect on performance of age-related changes in military aviators? Can military aviators be taught to cope with these age-related declines before the effects become manifest? Wadhawan (1978); Sekuler, Kline, and Dismukes (1982); and Gubser (1983) provide a good platform from which to start because each of these studies described potential effects on performance.

Bibliography

Aerospace Medical Association. 1992. Aviation, space, and environmental medicine. 63: 411-428.

AGARD. 1971. Physical fitness in flying including the aging and aged aircrew. London: AGARD conference proceedings no. 81. AGARD-CP-81-71.

[Contains the papers presented at a symposium in Garmisch-Partenkirchen, Germany September 1970 on the subject of physical fitness in flying. A second (proposed) symposium on the subject of age and physical fitness was so closely related, it was decided to combine the two symposia into one.]

Avolio, B. J., Barrett, G. V., and Sterns, H. L. 1984. Alternatives to age for assessing occupational performance capacity. Experimental aging research. 10: 101-105.

[Points out that functional age has failed as an alternative to chronological age primarily because the attempts to identify measures of functional age have not been successful.]

Boer, L. C. 1986. Attention tasks and their relation to aging and flight experience. Soesterberg, The Netherlands: TNO Institute for Perception. Report no. IZF 1986-4.

[Discusses the results of several tests given to pilots of different age groups and flight experience. Listening and reaction time (RT) were primary in the experience groups; but, age effected all of the tests.]

Boone, J. O. 1982. Functional aging in pilots: An examination of a mathematical model based on medical data on general aviation pilots. Oklahoma City, OK: Federal Aviation Administration, Civil Aeromedical Institute. Report no. FAA-AM-82-18.

[Describes an attempt to construct a numerical index intended to determine whether or not a person should be certified for aviation license as a function of age.]

Booze, C. F., Jr. 1977. Epidemiologic investigation of occupation, age, and exposure in general aviation accidents. Aviation, space, and environmental medicine. 48: 1081-1091.

[Examines the general aviation accidents for 1974 to obtain relevant occupation, exposure, and other descriptive epidemiologic profile information.]

Braune, R., and Wickens, C. D. 1984a. Individual differences and age-related performance assessment in naval aviators. Part 1. Battery development and assessment. (Final technical report for the period 1 Aug 82 - 1 Nov 83.) Champagne-Urbana, IL: University of Illinois Engineering-Psychology Research Laboratory. Report no. EPL-83-4/NAMRL-83-1. (AD-A175 022/3/XAB)

[Describes an attempt to revive the functional age concept of Gerathewohl (1978).]

Braune, R., and Wickens, C. D. 1984b. Initial validation of a functional age profile for aviators. In Proceedings of the symposium: Psychology in the Department of Defense held at Colorado Springs, CO 18-20 April. (AD-P003 271/4)

Braune, R., and Wickens, C. D. 1985. The functional age profile: An objective decision criterion for the assessment of pilot performance capacities and capabilities. Human factors. Santa Monica, CA: Human Factors Society. 27: 681-693.

[Argues for a functional rather than chronological age distinction in limiting the operational careers of pilots.]

Castelo-Branco, A., Cabral-Sà, A., and Coelho-Borges, J. 1985. Comparative study of physical and mental incapacities among Portuguese airline pilots under and over age 60. Aviation, space, and environmental medicine. 56: 752-757. (A85-43103)

[Indicates the U.S. was not the only country to adopt the "age 60" rule for its commercial airline pilots. Presents evidence to refute the practice and suggests an alternative.]

Coomes, L. 1973. Missing regulatory dockets 40, 41, and 42 (Pilot age 60 rule), Memorandum to Associate General Counsel (dated 11 July). Washington, DC: Regulations and Codification Division, FAA.

Della Rocco, P. S., and Schroeder, D. S. 1992. Panel presentation at the 1992 Aerospace Medical Association annual scientific meeting in Miami Beach, FL, 10-14 May. (AsMA reference #501.)

[Says FAA has three different studies in progress to reexamine the issue and that the agency plans to reassess the status of the "age 60" rule.]

Diggles-Buckles, V., and Vercruyssen, M. 1990. Age-related slowing, S-R compatibility, and stages of information processing. Proceedings of the Human Factors Society 34th annual meeting, Volume 1. Santa Monica, CA: Human Factors Society. 154-157.

[Examines the locus of age-related slowing within the information processing system to find it involving the response selection and response generation and programming stages.]

Durrer, D. 1974. Cardiological aspects of the aging pilot. Aero-space medicine. 45: 438-442.
(A74-27242)

[Addresses some of the many physiological problems (especially those related to the heart) associated with aging and flying.]

Economos, A. C., and Miquel, J. 1979. Analysis of population mortality kinetics with application to the longevity followup of the Navy's "1000 aviators." Aviation, space, and environmental medicine. 50: 697-701.

[Suggests some factors which may account for the results seen in the studies examined.]

Eyraud, M. Y., and Borowsky, B. S. 1985. Age and pilot performance. Aviation, space, and environmental medicine. 56: 553-558.
(85251444)

[Adds yet another voice to the functional side of the functional versus chronological age controversy.]

Fozard, J. L., and Fisk, A. D. 1988. Human factors and the aging population. Human Factors Society bulletin, 31 (November): 1-2.

[Suggests the directions of progress for age-related research in the coming century.]

Fozard, J. L., Vercruyssen, M., Reynolds, S. L., and Hancock, P. A. 1990. Longitudinal analysis of age-related slowing: BLSA reaction time data. Proceedings of the Human Factors Society 34th annual meeting, Volume 1. Santa Monica, CA: Human Factors Society. 163-167.

[Reports on some findings of the Baltimore Longitudinal Study on Aging (BLSA) which has been ongoing since 1959.]

Frölich, G. R. 1971. Hearing acuity in relation to age and flying time. In Physical fitness in flying including the aging and aged aircrew (AD-721 831). London: AGARD conference proceedings no. 81. AGARD-CP-81-71.

[Shows "a marked increase in number and severity of hearing losses with increasing age, especially above 35 years."]

Gerathewohl, S. J. 1977. Psychophysiological effects of aging - Developing a functional age index for pilots: I. A survey of the pertinent literature. Washington, DC: Federal Aviation Administration. Report no. FAA-AM-77-6. (AD-A040 322/0)

[Surveys selected materials useful to the author in arguing for his concept of a functional age index. This is the first of a three-part series on this index.]

Gerathewohl, S. J. 1978a. Psychophysiological effects of aging - Developing a functional age index for pilots: II. Taxonomy of psychological factors. Washington, DC: Federal Aviation Administration. Report no. FAA-AM-78-16. (AD-A054 356/1)

[Proposes a set of variables intended to predict the point at which the flying proficiency of an aviator falls below an unacceptable level primarily because of aging. The premise is that such a set of elements could identify a functional age beyond which a pilot unacceptably increases the risk of an accident.]

Gerathewohl, S. J. 1978b. Psychophysiological effects of aging - Developing a functional age index for pilots: III. Measurement of pilot performance. Washington, DC: Federal Aviation Administration. Report no. FAA-AM-78-27. (AD-A062 501/2)

[Discusses measurement of the elements described in Part II of this series.]

Glazer, I. 1992. Pilot aging policies in international airlines. Panel presentation at the 1992 Aerospace Medical Association annual scientific meeting in Miami Beach, FL, 10-14 May. (AsMA reference #505.)

[Advocates emphasis on the medical-physiological criteria instead of an arbitrary chronological limit to determine when a pilot should be permanently grounded. New and improved diagnostic techniques assure reasonable confidence in detecting incapacitating illnesses.]

Goldman, R. F. 1971. Physical fitness, flight requirements and age. In Physical fitness in flying including the aging and aged aircrew (AD-721 831). London: AGARD conference proceedings no. 81. AGARD-CP-81-71.

[Proposes that the standard measures of physical fitness (muscular strength, cardio-respiratory capacity, and relative body weight) are of little importance to pilots. Other, less easily measured aspects of physical fitness, however, may be more essential.]

Grunhofer, H. J., and Gerbert, K. 1971. Psychophysiological processes of aging. In Physical fitness in flying including the aging and aged aircrew (AD-721 831). London: AGARD conference proceedings no. 81. AGARD-CP-81-71.

[Recaps much of what was then known about aging and its effect on pilots.]

Gubser, A. W. 1983. Aging problems and their impact on pilot performance. In Cockpit. Dübendorf, Switzerland: SAF Institute of Aviation Medicine. 18(5): 4-8. (A84-21675)

[The title is very descriptive.]

Hickman, J. R., Triebwasser, J. H., and Lancaster, M. C. 1980. Physical standards for high-performance fighter aircraft pilots. Aviation, space, and environmental medicine. 51: 1052-1056.

[Discusses possible short-comings in current physical examination standards for selecting and retaining pilots to fly high-performance aircraft. Centers mostly around coronary artery diseases.]

Hoiberg, A., and Blood, C. 1983. Age-specific morbidity among Navy pilots. San Diego: Naval Health Research Center. Report no. 82-31 (interim).

[Compares morbidity (hospitalization) rates by age for male Navy pilots with rates for 3 control populations: aircrew officers (nonpilots), unrestricted line officers, and staff officers.]

Hoiberg, A., and Burr, R. G. 1984. Health risks associated with aircraft model type among U.S. Navy pilots. In Proceedings of the symposium: Psychology in the Department of Defense held at Colorado Springs, CO 18-20 April.

[Examines from a different perspective the same data as Hoiberg and Blood (1983).]

Holley, D. C., Winget, C. M., DeRoshia, C. W., Heinold, M. P., Edgar, D. M., Kinney, N. E., Langston, S. E., Markley, C. L., and Anthony, J. A. 1981. Effects of circadian rhythm phase alteration on physiological and psychological variables: Implications to pilot performance (including a partial bibliography). Moffett Field, CA: Ames Research Center. NASA technical memorandum 81277.

[Interesting work in itself, but has only vague and indirect application to the subject of aging.]

Hull, D. H., Wolthuis, R. A., Gillingham, K. K., and Triebwasser, J. H. 1978. Relaxed +G_z tolerance in healthy men: Effect of age. Journal of applied physiology: Respiratory, environmental, and exercise physiology. 45:626-629.
(AD-A062 326)

[Reports on the results of an AF centrifuge study to test for the effects of age on relaxed +G_z tolerance in AF aircrewmembers.]

Institute of Medicine. 1981. Airline pilot age, health, and performance: Scientific and medical considerations. Washington, DC: Sponsored by the National Institute on Aging, Bethesda, MD. Report no. ISBN-0-309-03176-1.
(PB82-161506)

[Reports on the findings of the study requested by NIA/NIH in response to Public Law 96-171. See NIA below.]

Jones, D. R. 1992. Mental health aspects of the aging flyer. Panel presentation at the 1992 Aerospace Medical Association annual scientific meeting in Miami Beach, FL, 10-14 May. (ASMA reference #504.)

[Cautions physicians and other practitioners to watch for signs of psychological distress and explains some warning signs.]

Kamenskiy, Y. N., and Sokolova, Y. A. 1979. Age-related distinctions of changes in psychophysiological functions of pilots in the civil aviation under the influence of vibration and noise. Space biology and aerospace medicine. Arlington, VA: Joint Publications Research Service. 13(5): 30-34. (Translated into English from Russian. Moscow: Kosm. biol. i aviakosm. med. 13(5): 21-24.)

Kirchhoff, H. W. 1971. Physical activity and aging. In Physical fitness in flying including the aging and aged aircrew (AD-721 831). London: AGARD conference proceedings no. 81. AGARD-CP-81-71.

[Addresses the effects of exercise on the cardiovascular function of aging pilots.]

Kohn, G. M., and Fennell, R. G. 1992. Permanent grounding of a commercial airline's pilots: A 20-year review. Panel presentation at the 1992 Aerospace Medical Association annual scientific meeting in Miami Beach, FL, 10-14 May. (ASMA reference #157.)

Lancaster, M. C., and Ord, J. W. 1971. A comparison of the effects of early cardiovascular disease and aging upon maximal exercise performance in the USAF aircrew population. In Physical fitness in flying including the aging and aged aircrew (AD-721 831). London: AGARD conference proceedings no. 81. AGARD-CP-81-71.

[Shows that early cardiovascular disease exerts an effect (on treadmill testing) over and above that expected with age.]

Larry, C., and Elworth, C. 1979. The effects of pilot age, lighting, and head-down time on visual accommodation. Seattle, WA: Boeing Co. Report no. D162-10378-1-TN. (AD-A064 912/9)

[Suggests, though not conclusively, "...the ability to focus the eyes at infinity following performance of near vision tasks decreases with age..."]

Leirer, V. O., Yesavage, J. A., and Morrow, D. G. 1989. Marijuana, aging, and task difficulty effects on pilot performance. Aviation, space, and environmental medicine. 60: 1145-1152. (A90-17514)

[Contains some background information on aging as well as the other.]

McFarland, R. A. 1943. The older worker in industry. Harvard business review. 21(4): 505-520.

McKinnon, B. J. 1992. Physiologic "age" versus chronologic age in pilot medical standards. Panel presentation at the 1992 Aerospace Medical Association annual scientific meeting in Miami Beach, FL, 10-14 May. (ASMA reference #502.)

[Proposes to use the "Thousand Aviator Study" data to determine if a physiologic standard can be derived from existing data to replace the current chronologic standard.]

Melton, C. E., Jr., and Wicks, M. 1966. Pilot vision considerations: The effect of age on binocular fusion time. Oklahoma City, OK: Civil Aeromedical Institute. Report no. AM-66-35. (AD-645 495)

[Provides data regarding the relationship between vision performance and age of the individual.]

Mertens, H. W., Higgins, E. A., and McKenzie, J. M. 1983. Age, altitude, and workload effects on complex performance. Washington, DC: Federal Aviation Agency. Report no. FAA-AM-83-15.

(AD-A134 508/1)

[Looks at age differences using a gas mixture in a face mask to simulate altitude. Age differences did show up, but not as a function of altitude.]

Mitchell, R. E., Graybiel, A., Oberman, A., and Harlan, W. R. 1971. The thousand aviators - A thirty year follow up. In Physical fitness in flying including the aging and aged aircrew (AD-721 831). London: AGARD conference proceedings no. 81. AGARD-CP-81-71.

[Discusses the electrocardiographic and blood pressure findings (to date) of a study of 1056 (U.S. Navy) flight students and related personnel begun in 1940.]

Mohler, S. R. 1981. Reasons for eliminating the "age 60" regulation for airline pilots. Aviation, space, and environmental medicine. 52: 445-454.

(A81-43369)

[Presents a veritable "laundry list" of arguments against the "age 60" rule. The logic was unsuccessful, however; 10 years later the rule is still in force.]

Mohler, S. R. 1984. Aircrew physical status and career longevity. In Human factors bulletin. Arlington, VA: Flight Safety Foundation, Inc. 31(1).

[Concerns medical aspects of pilot certification by age groups. While the "age 60" rule is not mentioned, the article is clearly from the opposition camp.]

Mohler, S. R. 1992. The aging pilot question: History and technology status. Panel presentation at the 1992 Aerospace Medical Association annual scientific meeting in Miami Beach, FL, 10-14 May. (AsMA reference #503.)

[Recites historical background for the "age 60" rule and says things have changed--for the better. Because of modern medical diagnostic and treatment technology and improved performance assessments, the rule is no longer needed.]

Mohler, S. R., Bedell, R. H. S., Ross, A., and Veregge, E. J. 1967. Aircraft accidents by older persons. Washington, DC: Federal Aviation Administration. Report no. FAA-AM-67-22.

[Uses 1965 civil general aviation accident data to show differences between age groups and pilot certification. The "older persons" here are 60 and over.]

Moraal, J. 1982. Age and information processing: An application of Sternberg's additive factor method. Soesterberg, The Netherlands: Institute for Perception, TNO. Report no. IZF 1982-18.

[Seeks to confirm the stage of information processing responsible for the differences in choice reaction time observed between younger and older subjects.]

National Institute on Aging. 1981. Report of the National Institute on Aging panel on the experienced pilots study. Bethesda, MD: U.S. Department of Health and Human Services, Public Health Service, National Institutes of Health.

[Combines the Institute of Medicine report (1981) with other information to make the NIH response to Congress required by PL 96-171.]

Ord, J. W., and Lancaster, M. C. 1971. The effects of aging on body composition and exercise performance in the USAF aircrew population. In Physical fitness in flying including the aging and aged aircrew (AD-721 831). London: AGARD conference proceedings no. 81. AGARD-CP-81-71.

[The "aging" here involved a group of pilots from 25 to 49 years old who were compared against a "special projects" group (including astronauts).]

Preston, F. S. 1968. Twelve year survey of airline pilots. Aerospace medicine. 39: 312-314.
(A68-23714)

[Examines the histories of 1000 airline pilots in the United Kingdom and discusses what happened to them.]

Proper, R. 1969. Preliminary impressions of cardiovascular function in the study of physiologic and psychologic aging in professional pilots. Aerospace medicine. 40: 557-560.
(A69-29309)

[Presents findings almost identical to the Proper and Masters article below. No particularly meaningful conclusions are given.]

Proper, R., and Masters, R. L. 1969. Cardiovascular aging and aeromedical maintenance programs in professional test pilots. Technical review. Beverly Hills, CA: Society of Experimental Test Pilots. 9(4):217-236.
(A70-21739)

[Reports on a longitudinal program which follows the physiological aging of test pilots by gathering and maintaining some 800 pieces of information on each subject.]

Saito, I., Yagura, S., Kurihara, Y., and Ishido, N. 1969. The results of physical examination on pilots. (1) Alteration of physical function through aging. In Reports. Tachikawa, Japan: Japan Air Self-Defense Force Aeromedical Laboratory. 10: 134-141.
(A70-42878)

[Presents findings from a number of measures followed over a period of 6 years. Accommodation was the most remarkable change. (Abstract in English.)]

Salthouse, T. A., and Somberg, B. L. 1982. Isolating the age deficit in speeded performance. Journal of gerontology, 37: 59-63.

[Uses the Sternberg (1969) methodology to show that age-related slowing is general rather than specific.]

Schur, W. 1974. Pilots: Middle-age; physical fitness. In Translations on Eastern Europe: Scientific affairs no. 409. Arlington, VA: Joint Publications Research Service. (Translated into English from German out of Berlin, German Democratic Republic: Z. militaermed.) 28-36.

Sekuler, R., Kline, D., and Dismukes, K., eds. 1982. Aging and visual function of military pilots: A review. Aviation, space, and environmental medicine. 53: 747-758. (AD-A120 529/3)

[Reviews (then) current knowledge "about the effects of age on visual function and discusses the implications of age-related changes in vision for the flying performance of military pilots."]

Smith, R. L. 1984. Age and aviator performance: An annotated bibliography (1953 - 1983). Fort Rucker, AL: Army Research Institute Field Unit. Draft (Paper was never published).

[Reviews many of the pertinent publications on the subject. Could not find out why it wasn't followed through; but, the information is still good.]

Sternberg, S. 1969. The discovery of processing stages: Extension of Donders' method. Acta psychologica, 30: 276-315.

[Describes a research methodology used by Salthouse, et al. to support a general deficiency thesis as opposed to several specific ones.]

Stevenson, W. J. C. 1971. Morbidity of aircrew in the Canadian Forces in relation to age. In Physical fitness in flying including the aging and aged aircrew (AD-721 831). London: AGARD conference proceedings no. 81. AGARD-CP-81-71.

["...Indicates that diseases of the circulatory system was cause for removal from flying duties of the largest number of older aircrew, while psychiatric disorders resulted in the greatest number of groundings in the younger group."]

Stoklosa, J. H. 1992. Review of performance, medical, and operational data on pilot aging issues. Panel presentation at the 1992 Aerospace Medical Association annual scientific meeting in Miami Beach, FL, 10-14 May. (AsMA reference #506.)

[Shows how recent improvements in medical diagnostic and treatment technology have made it possible to single out pilots developing sudden incapacitating illnesses. Advocates abolition of the "age 60" rule.]

Szafran, J. 1968. "Neural noise" as a factor limiting "channel capacity." Proceedings of 5th national biomedical sciences instrumentation symposium. Albuquerque, NM: Instrument Society of America. 81-88.
(A68-31852)

[Sketches a profile of aging professional pilots' capacities from standpoint of cardiovascular and pulmonary physiology and experimental psychology, discussing the effect of aging on the nerve pathways.]

Szafran, J. 1969. Psychological studies of aging in pilots. Aerospace medicine, 40: 543-553.

[Presents more of the Lovelace Foundation findings a la Proper and Masters (1969).]

Tsang, P. S. 1989. A reappraisal of aging and pilot performance. In Proceedings of the 5th international symposium on aviation psychology (A90-26176 10-53). Columbus, OH: Ohio State University. 521-526.
(A90-26246)

[Summarizes age-related research both within and without the aviation community, but concludes that age-related research on the general population is not necessarily generalizable to the aviation community. Aviation research must use aviators for subjects.]

Wadhawan, M. L. 1978. Ageing and flying fitness. Aviation medicine. 22: 31-33.
(A79-33190)

[Relates the effects of aging to the aviator's performance of normal duties. The author goes so far as to say, "...older the pilot less competent will he be as an operational pilot."]

Welsh, K. W., Vaughan, J. A., and Rasmussen, P. G. 1976. Survey of cockpit visual problems of senior pilots. Oklahoma City, OK: Federal Aviation Administration, Civil Aeromedical Institute. Report no. FAA-AM-77-2.

[Summarizes the results of a questionnaire in which 50 pilots (40-73 years of age) answered questions about visual problems they experienced and what they did about them.]

Wentz, A. E. 1964. Studies on aging in aviation personnel. Washington, DC: Georgetown Clinical Research Institute. Report no. AM-64-1.
(AD 456 652)

[Describes the work being done at the FAA Office of Aviation Medicine research at the time; but, more importantly, contains a statement of the FAA philosophy with regard to the problem of the aging aviator that FAA holds to this day: "...[N]o medical methods exist for evaluating [a specific] adult human being in terms that will provide a useful estimate of his overall status as an aging individual."]

Williams, T. F. 1985. Statement by T. Franklin Williams, Director, before the House Select Committee on Aging, 17 Oct. Washington, DC: National Institute on Aging of National Institutes of Health.

[Restates the findings of the earlier panel (NIA, 1981) with perhaps a little more emphasis on the lack of support for the "age 60" rule.]

Williams, T. F. 1991. Testimony [of Williams] to a Joint Hearing of the House Select Committee on Aging and the Education and Labor Subcommittee on Employment Opportunities on the problem of age discrimination in employment, Tuesday, 24 September. Washington, DC.

[Expresses adamant opposition to the "age 60" rule and points outs that there are a number of tests that could be applied to pilots over 60 in the same way they are used with pilots under 60.]

Yerokhin, V. P. 1970. Age restrictions in civil aviation. In Komendantov, G. L., (ed.) Problems in aviation medicine. Moscow: Moscow Central Order of Lenin Institute for Advanced Training of Physicians. 143: 126-141. (1973 translation by Techtran Corporation, Glen Burnie, MD. NASA publication no. TT F-687: 139-156).

[Describes a study of some physiological reactions of two age groups of pilots during takeoff, climbout, and landing phases of flight.]

Zeller, A. F. 1959. Age, experience and aircraft accidents. Aerospace medicine, 30: 736-750.

[Examines previous information (e.g., Zeller and Moseley, 1957) in greater detail concentrating on age of the pilots, type aircraft flown, type of accident experienced, portion of flight wherein the accident occurred, and types of errors involved (poor technique, faulty operation, etc.)]

Zeller, A. F., and Moseley, H. G. 1957. Aircraft accidents as related to pilot age and experience. Aviation medicine, 28: 171-179.

[Looks at the accident data for the Air Force in the last 6 months of 1953 to determine there was an increase in jet fighter accidents as the result of the younger pilots. It goes on to look at other areas as well.]