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Low-Airspeed Protection for Small to Medium-Sized Commercial Airplanes: an Important Safety Gap

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LOW-AIRSPEED PROTECTION FOR SMALL TO MEDIUM-SIZED COMMERCIAL AIRPLANES: AN IMPORTANT SAFETY GAP

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In November 2003, the National Transportation Safety Board recommended that the Federal Aviation Administration (FAA) convene a panel of aircraft design, operations, and human factors specialists to examine the feasibility of requiring the installation of low airspeed alerting devices on airplanes operating commercially under 14 C.F.R. Parts 121 and 135. The Board further recommended that if the panel determined such a requirement to be feasible, the FAA should establish requirements for low-airspeed alert systems. This paper discusses the reasoning behind these recommendations, explores relevant accident history from the Safety Board's investigative records, and discusses shortcomings of an approach to cockpit design that relies on flight crew monitoring and artificial stall warnings for avoidance of low airspeed related accidents. Potential benefits and concerns associated with the installation of a new kind of low airspeed alerting device are also addressed.

Introduction

On October 25, 2002, a Raytheon King Air A100 on a non-scheduled Part 135 flight crashed 1.8 miles short of the runway threshold during a VOR approach to the Eveleth-Virginia Municipal Airport, Eveleth, Minnesota. Radar and weather data indicated that the flight crew experienced difficulty intercepting the approach course and performed a steep, fast approach, which probably required them to reduce engine power to very low levels. As the crew descended, their airspeed slowly and steadily decreased until it fell below recommended approach speed. Airspeed continued to decrease at a rate of approximately 1 knot per second for the last 48 seconds of flight. As the airplane reached the minimum descent altitude in the landing configuration, with its airspeed having decreased to near the calculated stall speed, the airplane suddenly rolled left, descended steeply, and impacted terrain. All occupants were killed, including the late U.S. Senator Paul Wellstone. The Safety Board found that icing was not a factor, and determined that the probable cause of this accident was "the flight crew's failure to maintain adequate airspeed, which led to an aerodynamic stall from which they did not recover" (National Transportation Safety Board, 2003).

In its final report on this accident, adopted on November 18, 2003, the Safety Board urged the FAA to convene a panel of aircraft design, aviation operations, and aviation human factors specialists, including representatives from the National Air and Space Administration to determine whether a requirement for the installation of low airspeed alert systems in airplanes engaged in commercial operations under 14 Code of Federal Regulations Parts 121 and 135 would be feasible (NTSB Recommendation No. A-03-53). The Board further recommended that if the panel determined such a requirement to be feasible, the FAA should establish requirements for low-airspeed alert systems (NTSB Recommendation No. A-03-54). This paper discusses the reasoning behind the Safety Board's recommendations, explores relevant accident history from the Board's investigative records, and discusses shortcomings of the current cockpit design philosophy relying on flight crew monitoring and artificial stall warnings to avoid low airspeed related accidents. Potential benefits and concerns associated with the installation of a new kind of low airspeed alerting device are also addressed.

Background

Airspeed is a basic measure of airplane performance monitored by flight crews. Angle of attack is the angle between the chord line of an airplane's wings and the oncoming relative wind. All other things held constant, when airspeed decreases, angle of

[1] The opinions expressed in this paper are those of the authors and do not necessarily reflect the official views and opinions of the U.S. National Transportation Safety Board.

attack must be increased to maintain lift. However, if angle of attack is increased too much, critical angle of attack can be exceeded, smooth airflow over the wing will be disrupted, and an aerodynamic stall results. A stall can occur at any airspeed, attitude, or power setting, however, if airspeed is allowed to decrease too much, a stall will reliably be produced.

Practicing aerodynamic stalls, and their recovery, is a routine part of pilot training. However, inadvertent stalls can be dangerous. This is especially true during the takeoff, climb, approach, and landing phases of flight. Inadvertent stalls are more likely during these phases because operating airspeeds are lower and stall speed margins are reduced. In addition, lower altitudes make stall recovery less certain. Flight crew airspeed monitoring is the first line of defense against inadvertent stalls. To guard against them, flight crews are trained to monitor airspeed instruments and to maintain target airspeeds.

Stall warnings provide a second line of defense against inadvertent stalls, serving as a backup to crew monitoring. Federal airworthiness standards (14 C.F.R. Parts 23 and 25) require the presence of a clear and distinctive warning capable of alerting the crew of an impending stall. This warning cannot require the crew's visual attention inside the cockpit, and must begin 5 or more knots above stalling speed for normal and commuter category airplanes. For transport category airplanes, it must begin at least 5 knots or 5 percent above stalling speed (whichever value is greater).[2] If the aerodynamic qualities of an aircraft (e.g., buffeting) do not provide a clear and distinctive warning meeting these requirements, an artificial stall warning must be installed. Flight crews are trained to begin stall recovery procedures if a stall warning occurs during normal flight operations.

The widespread introduction of swept-wing jet aircraft in commercial aviation in the 1960s brought an increased emphasis on stall avoidance, because stall recovery in such aircraft can be difficult or impossible (Federal Aviation Administration, 2004). Stick "pushers" installed on such airplanes were designed to lower the nose before critical angle of attack was exceeded, and artificial stall warning systems were required to be calibrated to activate at least five knots above stick pusher activation thresholds. Additional stall protection measures were developed in the late 20th century as manufacturers of fly-by-wire transport category airplanes with integrated autoflight systems developed flight envelope protection systems to prevent airplanes from exceeding high or low airspeed limitations. Full authority envelope protection systems, such as those installed on the Airbus A320, were made capable of increasing engine power and even modulating the effects of pilot control inputs to prevent exceedence of the critical angle of attack (Vakil, 2000).

The Safety Gap

Despite advances in the state of the art in stall avoidance and protection systems, many small to medium-sized commercial turboprop and turbine engine airplanes in use today still rely solely on flight crew monitoring and artificial stall warnings to avoid low airspeed-related accidents. This approach is problematic for two reasons. First, flying involves the time-sharing of multiple concurrent tasks, many of which require flight crews to monitor multiple displays. These tasks cannot always be performed simultaneously. For this reason, successful flying depends on effective prioritization and visual scanning strategies (Wickens, 2003). The process by which flight crews allocate their attentional resources among concurrent flying tasks has been called "cockpit task management" (Funk, 1991). Crews must ensure that important flying tasks, such as airspeed monitoring, receive adequate attention at appropriate times and are not pre-empted by lower priority tasks. Research has shown that pilots are generally good at doing this. However, a variety of evidence indicates that suboptimal cockpit task management does sometimes occur and can have a negative impact on safety (Wickens, 2003). Of interest to the topic at hand, the authors of one early study of flight crew performance in a full mission flight simulation cited violations of airspeed limitations (both high and low) as one of the most common types of flying errors made by three-pilot airline crews (Ruffel Smith, 1979).

A second problem with relying on pilot monitoring and stall warnings for stall avoidance has to do with characteristics of the stall warning itself. In theory, stall warnings are designed so that flight crews can prevent a stall by responding quickly to the occurrence of a stall warning. Current airworthiness requirements for transport category airplanes even state that it must be possible for a test pilot to prevent a stall during powered 1.5 G banked turns when stall recovery is delayed for at least one second after the onset of a stall warning. However, certain combinations of power changes and abrupt maneuvering (such as a level-off at MDA with or without structural icing) could reduce this margin of

[2] This requirement is reduced to 3 knots or 3 percent above stall speed when flying straight and level at idle power.

warning. Moreover, stall warnings can be unreliable because of ice accumulation, which raises stall speed and can degrade warning margins to the point where little or no warning is provided. This phenomenon was noted during the investigation of a 1997 accident near Monroe, Michigan that caused the deaths of 29 people, and led the Safety Board to recommend that the FAA apply more stringent certification requirements to airplanes certified for operation in icing conditions (National Transportation Safety Board, 1998).

Low Airspeed / Stall Events

In light of known human monitoring weaknesses and the potential inadequacy of artificial stall warnings, it should come as no surprise that the Safety Board has investigated numerous accidents and incidents involving flight crew failure to monitor and maintain airspeed. In some cases, loss of airspeed / stall events have been preceded by aggravating factors such as aircraft equipment or system failures that made airspeed monitoring and maintenance more difficult. Weather has also been an important contributing factor for low-airspeed related events. Aerodynamic stalls have occurred following encounters with wind, turbulence, and convective phenomena such as wind shear or microburst. However, structural icing may be the most common contributing factor.

Events involving flight crew failures to monitor airspeed can occur during any phase of flight, as the following example attests. On June 4, 2002, a Spirit Airlines McDonnell Douglas MD-82 on a scheduled Part 121 flight from Denver, Colorado to Ft. Lauderdale, Florida experienced an aerodynamic stall while cruising at 33,000 feet on autopilot. Fifteen minutes into the cruise phase of flight, the crew felt a sudden vibration, heard the stick shaker and stall warning activate, noticed that their airspeed was low and their engines were operating at a very low power setting. They also noticed that one engine's temperature was too high. The captain took manual control of the airplane and shut down the hot engine. Shortly thereafter, power rolled back on the good engine as well. The flight crew managed to restore power to both engines at 17,000 feet, and made a precautionary landing. The Safety Board found that the airplane's engine inlet probes had become blocked by ice crystals resulting in a false engine pressure ratio indication and subsequent retarding of the throttles by the auto throttle system. The Board attributed the probable cause of this incident to the flight crew's failure to verify the engine instrument indications and power plant controls while on autopilot with the auto throttles engaged, and their failure to recognize the drop in airspeed which led to an aerodynamic stall associated with the reduction in engine power (Safety Board No. CHI02IA151).

The authors searched records contained in the Safety Board's Aviation Accident/Incident Database, looking specifically for low-airspeed events in the approach and landing phases of flight where equipment failure was not cited as a contributing factor. This search identified 40 low airspeed-related events since 1982. It is likely that additional cases of hard landings and tail strikes have occurred but gone unreported because they did not result in substantial damage. The events identified were categorized by type of operation (Part 121 versus Part 135) and by involvement of structural icing (icing versus non-icing). The results of this categorization are shown in Figure 1. This categorization indicates that low-airspeed events during approach and landing occurred more often during Part 135 than Part 121 flight operations. The results also underscore the prevalence of structural icing in such events. However, that at least 19 of the low-airspeed related accidents and incidents identified did not involve icing or equipment failure.

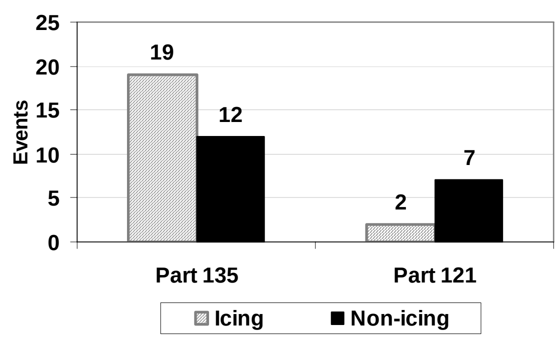

Figure 1. *Accidents and incidents during approach or landing citing low airspeed, 1982-2004.*

Most of the low-airspeed related non-icing events involving Part 121 flight operations resulted in hard landings and/or tail strikes causing substantial aircraft damage, and none resulted in serious injuries. During one typical incident, reported in 1996, the Part 121 airline captain of a McDonnell-Douglas MD-88 said he flew a normal, stabilized approach, using normal flaps and a landing reference speed of 133 knots plus 5 knots. He reported flaring the airplane over the runway and realizing that the sink rate was not being arrested as desired. The captain said he made a more "aggressive" pull on the control yoke while advancing the thrust levers. The airplane landed hard, sustaining substantial damage. Digital flight data recorder readout disclosed that airspeed remained above 138 knots until, at an absolute altitude of 238 feet, airspeed began steadily decreasing below that speed. When the airplane touched down on the runway, airspeed was 125 knots and pitch attitude was 10.6 degrees nose up. There was a +5.5 G vertical acceleration spike at touchdown (Safety Board No. FTW96LA111).

By contrast, low-airspeed related non-icing events involving Part 135 flight operations resulted in more severe outcomes. Records of the investigations of these events indicate that fatal injuries occurred in approximately 1 out of every 4 cases. Part 135 flight operations typically utilize smaller aircraft with less sophisticated autoflight systems. They are less likely to be equipped with auto throttles or sophisticated envelope protection systems. Also, Part 135 flight crews are often less experienced than Part 121 flight crews, and Part 135 flight operations have less stringent flight crew training requirements. These factors could explain the higher prevalence of such events in Part 135 flight operations, and the relative severity of their outcomes.

The Safety Board investigated an accident in 1994, involving a Jetstream 41 on a scheduled Part 135 commuter flight, which crashed 1.2 nautical miles short of the runway during an ILS approach to the Port Columbus International Airport, Columbus Ohio, killing 5 and injuring 2 on board. The flight crew initiated the landing checklist late in the approach. The delay caused distractions to both pilots, and the approach was unstabilized. The autopilot was engaged during the approach, and it kept the airplane on the localizer and glide slope. However, power was set too low to maintain airspeed. This airplane was not equipped with autothrottles. The flight crew did not adequately monitor airspeed indications, and the airplane decelerated until it stalled. Although a stall warning was heard, the captain failed to execute appropriate stall recovery procedures, and the airplane descended steeply, impacting a building. Icing was found not to have been a factor in the accident. The Board found the probable cause of this accident to be, in part, "an aerodynamic stall that occurred when the flight crew allowed the airspeed to decay to stall speed following a very poorly planned and executed approach characterized by an absence of procedural discipline" (National Transportation Safety Board, 1994).

A Change in Design Philosophy

The introduction of a new kind of low-airspeed alert associated with the minimum operationally acceptable speed for a particular phase of flight could help flight crews maintain airspeed awareness in much the same way that altitude alert systems now help flight crews maintain altitude awareness. Such a system would provide an earlier cue to flight crews about low and decreasing airspeed prior to the occurrence of a stall warning, providing them with more time to manage a potential problem before it becomes an emergency.

Recommending a requirement for this kind of low-airspeed alert system represents a departure from the previously accepted premise that adequate low-airspeed awareness is provided by flight crew vigilance and existing stall warnings. However, the history of accidents involving flight crew lack of low-airspeed awareness suggests that flight crew vigilance and existing stall warnings are inadequate to prevent hazardous low-airspeed situations. Moreover, the accident record suggests that this safety issue is not limited to autopilot operations or flight in icing conditions.

The introduction of a low airspeed alerting system could prevent low airspeed / stall related accidents. If a low-airspeed alert had been installed on the King Air involved in the Eveleth accident and had activated when airspeed dropped below 1.2 V_S (about 92 knots), the flight crew could have received about 15 seconds advance warning before the airplane decelerated to its stalling speed. This might have directed the crew's attention to the airplane's decaying airspeed in time to initiate appropriate corrective action. Moreover, if such a system could helped the crew maintain airspeed at or above a minimum operational thresholds such as 1.2 V_S, the likelihood of an accelerated stall initiated by abrupt last-second maneuvering could have been reduced, and improved margins above stalling speed during flight under icing conditions could have been more reliably maintained.

The nature of the airspeed monitoring task varies depending on the level of automation in an airplane cockpit. During a manually flown, a pilot is actively engaged in balancing airspeed, pitch, power, and vertical speed in closed-loop fashion. This requires frequent checking of the outside visual picture and the flight instruments to guide control movements. Alternatively, a pilot using the fully integrated autoflight system in a modern transport airplane monitors flight parameters, including airspeed, in a more supervisory fashion. The issue of airspeed awareness for crews using highly automated flight management systems was raised in an FAA Human Factors Team Report (Federal Aviation

Administration, 1996). Expressing concern about a history of accidents involving lack of low-airspeed awareness among flight crews monitoring automated systems, the report stated:

> Transport category airplanes are required to have adequate warnings of an impending stall, but at this point the airplane may already be in a potentially hazardous low energy state. Better awareness is needed of energy state trends such that flight crews are alerted prior to reaching a potentially hazardous low energy state.

The need for better low airspeed protection and alerting was also cited by the FAA's Flight Guidance System (FGS) Harmonization Working Group of the Aviation Rulemaking Advisory Committee, when, in March 2002, it proposed revisions to 14 C.F.R. Part 25.1329 and associated Advisory Circular 25.1329 to require low-airspeed protection and alerting during autopilot operations for newly certified transport-category airplanes. The proposal stated:

> The requirement for speed protection is based on the premise that reliance on flight crew attentiveness to airspeed indications, alone, during FGS…operation is not adequate to avoid unacceptable speed excursions outside the speed range of the normal flight envelope….Standard stall warning and high speed alerts are not always timely enough for the flight crew to intervene to prevent unacceptable speed excursions during FGS operation….A low speed alert and a transition to the speed protection mode at approximately 1.2 V_S, or an equivalent speed defined in terms of V_{sr}, for the landing flap configuration has been found to be acceptable.

The changes proposed for Part 25.1329 were aimed at future transport category aircraft. However, it may be feasible to develop low airspeed alert systems for less sophisticated, existing airplanes as well. Moreover, the FAA's work, in combination with the Safety Board's accident and incident findings, suggest a need for low airspeed alerting throughout a variety of aircraft with a range of automated features. A low airspeed alert was recently developed for Embraer EMB-120 turboprop airplanes for use in icing conditions. This low airspeed alert system activates an amber-colored indicator light installed in the control panel and provides an auditory alert when airspeed drops below the minimum operational icing speed. In addition, several avionics manufacturers offer low airspeed alerting devices for use in a broad array of general aviation airplanes. These developments suggest that it may be feasible to develop low airspeed alerting systems for most airplane types.

In a letter to the Safety Board dated April 12, 2004, the FAA said it would study cases involving low airspeed awareness that had been identified by the Safety Board and determine what action should be taken. The FAA described existing requirements for stick shakers and stall warnings in transport category airplanes, and cited the increasing prevalence of color-coded visual displays of airspeed found in many modern cockpits. The FAA also stated that it would consider addressing the issue of low airspeed awareness in efforts in progress under its Safer Skies programs and other initiatives. However, as of February 2005, the FAA had not yet announced activities specifically aimed at addressing this issue.

Human Factors Concerns

Technical, operational, and human factors issues must be carefully evaluated and addressed in connection with the design and implementation of any new cockpit alerting system (Pritchett, 2001). Some issues that deserve consideration in association with the possible introduction of new low airspeed alerting systems include: the integration of this system with other aircraft systems; the determination of appropriate threshold speeds for alert activation; examination of the impact of the system's reliability on flight crew confidence in the system; the selection of appropriate strategies for differentiating the alert from existing cockpit alerts and warnings; the development of appropriate flight crew procedures for use in conjunction with the system; and the need for flight crew training in use of the system and related procedures.

Clearly there are many concerns associated with the possible introduction of these systems in commercial airplanes. Despite these concerns, it is possible such systems could significantly improve flight crew performance and increase safety. This is a matter the aviation psychology community is well suited to address. Moreover, the aviation psychology research community has a long history of suggesting and evaluating alternative design solutions for new aircraft systems through applied research.

NTSB Case Numbers for Low Airspeed / Stall Related Events During Approach and Landing[3]

Part 135 Icing Related
SEA82DA017
MKC89LA073
MKC85LA028
MKC84FA033
LAX02LA030
LAX02FA108
DEN90FA068
DEN83LA029
DEN04MA015
DEN01FA094
DCA97MA017
DCA90MA011
CHI98LA084
CHI98FA119
CHI95LA053
CHI86LA090
CHI85FA139
ANC89LA025
ANC02FA020

Part 135 Non Icing Related
MIA89LA193
DEN99FA137
DEN87FA042
DCA94MA027
DCA03MA008
CHI99LA078
CHI01LA109
ANC94LA031
ANC94LA021
ANC91LA015
ANC89LA039
ANC01LA053

Part 121 Icing Related
DCA87IA015
CHI90IA106

Part 121 Non Icing Related
NYC02LA013
LAX90FA148
LAX00LA192
FTW96LA111
BFO85IA036
ATL93IA135
ATL01A064

[3] Information on these cases can be found at http://www.ntsb.gov/ntsb/query.asp.

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ATCS AGE AND EN ROUTE OPERATIONAL ERRORS: A RE-INVESTIGATION

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Public Law 92-297 requires that air traffic control specialists (ATCSs), hired on or after May 16, 1972, retire at age 56. This law is based on testimony given in 1971 that as controllers aged, the cumulative effects of stress, fatigue (from shift work), and age-related cognitive changes created a safety risk (U.S. House of Representatives, 1971). The hypothesis has been considered in two studies of en route operational errors (OEs) with contradictory results (Center for Naval Analyses Corporation (CNAC), 1995; Broach, 1999). The purpose of this re-investigation was to test the hypothesis that controller age, controlling for experience, was related to the occurrence of OEs using a statistical method appropriate for rare events. A total of 3,054 usable en route OE records were extracted from the FAA OE database for the period FY1997 through FY2003 and matched with air route traffic control center (ARTCC) non-supervisory controller staffing records, resulting in a database of 51,898 records. Poisson regression was used to model OE count as a function of the explanatory variables age and experience using the SPSS® version 11.5 General Loglinear (GENLOG) procedure. The Poisson regression model fit the data poorly (Likelihood Ratio $\chi2 = 283.81$, $p < .001$). The odds of OE involvement, estimated with the Generalized Log Odds Ratio, for older controllers (GE age 56) were 1.02 times greater than the odds for younger (LE age 55) controllers, with a 95% confidence interval of 0.42 to 1.64. The range of odds indicated that neither age group was less or more likely to be involved in an OE, controlling for experience. This analysis does *not* support the hypothesis that older en route controllers are at greater risk of involvement in an OE. This finding suggests that the original rationale for the mandatory retirement of ATCSs may need to be re-evaluated. Additional research is recommended.

Public Law 92-297 requires that Air Traffic Control Specialists (ATCSs), hired on or after May 16, 1972 by the FAA, retire at age 56[1]. Controllers with "exceptional skills and abilities" may be given a waiver and continue working until reaching the 61st birthday. The primary evidence offered in support of the mandatory retirement of ATCSs at age 56 in 1971 consisted of anecdotal reports of stress from controllers, studies of self-reported "stress-related" symptoms, physiological correlates of stress, and medical disability retirements of controllers. Despite strong assertions made by various parties, no testimony or data were presented in 1971 to demonstrate that older controllers were more likely than younger controllers to make errors that might compromise the safety of flight.

Several studies of ATCS age and performance have been conducted since passage of P.L. 92-297 (see Broach & Schroeder, in press, for a review). A variety of measures of job performance have been examined in research, ranging from over-the-shoulder subjective evaluations to computer-based measures. Three studies focused specifically on operational errors (OEs). An OE results when an ATCS fails to maintain appropriate separation between aircraft, terrain, and other obstacles to safe flight. OEs are rare compared to the number of operations handled in the U.S. air traffic system. For example, there were 1,145 OEs in fiscal year (FY) 2000 compared to 166,669,557 operations, or 6.8 OEs per million operations (Pounds & Ferrante, 2003; DOT Inspector General, 2003a). Despite their rarity, OEs may pose safety risks, depending on the degree to which separation is lost, and are critical safety indicators for the operation of the air traffic control system (Department of Transportation Inspector General, 2003a,b). OEs occur when through a controller's actions (or inaction), less than standard separation is maintained.

Spahn (1977) investigated the relationship of age to System Errors (now called Operational Errors) and concluded that "no age group has neither more nor less than its proportional share of system errors" (p. 3-35). The Center for Naval Analyses Corporation (CNAC) found in 1995 that the likelihood of an OE in the period January 1991 to July 1995 declined dramatically in the first few years at an air route traffic control center (ARTCC) and then appeared to approach a constant value. However, CNAC did not examine controller age nor control for age effects. Broach (1999) re-analyzed the CNAC data set from the perspective of controller age and found that the likelihood of an OE might increase with age. The regression analysis also found that experience might mitigate the risk of an OE associated with increasing age. Additional research on the relationship of chronological age, experience, and OEs was recommended. The present study builds on that recommendation. This study was designed to test the hypothesis that older controllers were more likely than younger controllers to commit errors that reduced the safety of flight.

Method

Source Data

A total of 3,054 usable en route OE records were extracted from the FAA Operational Error/Deviation System (OEDS) for the period FY1997 through FY2003. Records for controllers employed at ARTCCs were extracted from the FAA Consolidated Personnel Management Information System (CPMIS) for each fiscal year. There was one CPMIS record in a year for each controller. The OE and CPMIS records were matched by controller identifier and year, producing a database with 51,898 matched records. The number of ATCS with and without OEs is presented by fiscal year in Table 1. For example, of the 7,178 non-supervisory ATCS stationed at ARTCCs in FY1997, 6,864 (95.6%) had no operational errors, while 303 controllers (4.2%) had one OE, and 11 had 2 errors (0.2%). No ATCS had 3 errors in that fiscal year.

Methodological Considerations

Both CNAC (1995) and Broach (1999) calculated the dependent variable of interest as the ratio of controllers with errors in an experience or age range to the total number of controllers in that experience or age range. CNAC labeled this ratio as the "likelihood" of involvement in an error. In fact, both CNAC and Broach calculated the proportion of controllers in a given category that were involved in an error at a given point in time, that is, the prevalence rate. The result is a person-based estimate of risk. However, a person-based estimate of risk does not take into account the varying degrees of exposure between controllers. For example, a controller working a busy, low-altitude transitional sector with multiple merging airways that feed a major hub during an afternoon rush will have a greater opportunity to commit an OE than another controller working a high-altitude sector with sparse cross-continental traffic in steady, predictable east/west flows. Time on position may vary as well. For example, a controller working longer on a given position will have greater opportunity to commit an OE than another controller working less time on a position. As noted by Della Rocco, Cruz, and Clemens (1999), a measure of exposure is required to analyze the risk of being involved in an OE appropriately. However, such measures were unavailable for the present study, leaving the count of errors and prevalence as the variables of interest.

Analysis of counts, such as the number of OEs committed by a controller during a specified period of time, poses analytic challenges. Events such as OEs are rare, compared to the number of operations in the air traffic control system, the number of hours worked by controllers, or even the number of controllers working. While rare events such as OEs are important because of their signal value and potential costs, they are also difficult to study (Hulin & Rousseau, 1980). Techniques borrowed from epidemiology such as count-oriented regression have proven useful in the analysis of rare events. Poisson regression, a count-oriented regression technique, was used in the present study to investigate the degree to which the number of errors is related to controller age.

Poisson Regression

Poisson regression is a statistical technique used to model the expected count of some event as a function of one or more explanatory variables. Examples of events that follow a Poisson distribution are doctor visits, absenteeism in the workplace, mortgage pre-payments and loan defaults, bank failures, insurance claims, and airplane accidents (Cameron & Trivedi, p. 11). In statistics, the "law of rare events" states that the total number of events of interest will take, approximately, the Poisson distribution if (a) the event may occur in any of a large number of trials, but (b) the probability of occurrence in any given trial is small (Cameron & Trivedi, 1998). This statistical "law of rare events" might apply to air traffic control operations as well: there are a large number of aircraft under the control of a relatively large number of controllers at any given moment, but the likelihood of an OE for any given aircraft by any single controller is very small. In this application, the analytic goal was to model the number of OEs incurred by a controller as a function of age and experience (e.g., tenure in the FAA).

Procedure

The data for this analysis consisted of the 51,899 records for non-supervisory center controllers with and without OEs for the period FY1997 through FY2003 (see Table 1). Tenure was recoded into discrete categories to simplify the analysis. The first category for tenure was based on the average of about three years required to complete on-the-job training for center controllers (Manning, 1998). The next interval was 6-years wide (4 through 9), followed five-year increments (Table 2). Age was recoded into two groups: age 55 and younger; and age 56 and older. This split was used to specifically assess the risk that might be associated with controllers older than the mandatory separation age.

Table 1: *N non-supervisory en route ATCS on-board with 0, 1, 2, or 3 operational errors by fiscal year*

	N ATCS with Operational Errors (OEs)				
Fiscal Year	0	1	2	3	AOB Total
1997	6,864	303	11	0	7,178
1998	6,932	389	16	0	7,337
1999	6,869	422	21	0	7,312
2000	6,833	487	31	0	7,351
2001	6,827	549	45	1	7,422
2002	7,110	416	32	0	7,558
2003	7,410	313	17	1	7,741

Table 2: *Tenure by age cross-classification table for Poisson regression analysis*

	Number of OEs (n_{ij})		ATCS Population (N_{ij})	
Tenure Group	LE Age 55	GE Age 56	LE Age 55	GE Age 56
LE 3 Years	44	4	3,587	110
4 – 9 Years	488	10	7,574	191
10 – 14 Years	1,112	20	15,758	280
15 – 19 Years	1,007	2	14,816	128
20 – 24 Years	343	2	5,615	67
GE 25 Years	142	57	2,587	1,186

The data were aggregated by fiscal year, age group, and tenure group to create a cross-classification table suitable for Poisson regression, as shown in Table 2. The columns labeled "Number of OEs (n_{ij})" contain the counts of OEs reported for each age and tenure group combination. For example, there were 44 OEs in the period FY1997 to FY2003 for controllers age 55 or less and with 3 years or less tenure, and 4 OEs for controllers age 56 or older and with 3 years or less tenure. The columns labels "ATCS Population (N_{ij})" contain data representing the number of controllers "exposed" to the risk of incurring an OE during the observation period for each age-tenure combination. For example, there were 3,587 records for en route controllers age 55 or less with 3 years or less tenure who were "at risk" of incurring an OE during the observation period. The goal of the regression analysis is to assess the relative effects of age and tenure on the ratios of errors to "at risk" population. The SPSS® version 11.5 General Loglinear (GENLOG; SPSS, 1999) method was used to conduct the Poisson regression analysis

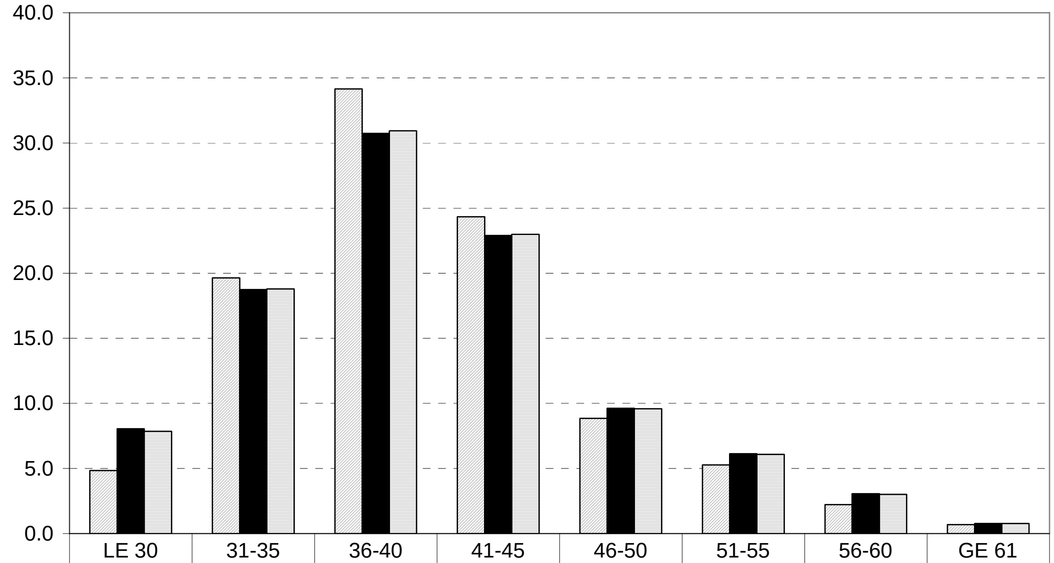
Results

Descriptive Statistics

The initial analyses consisted of simple descriptive statistics. First, the number of OEs per age group for the observation period (FY1997 through 2003) was examined, as shown in Table 2. In this analysis, each controller could have as many as seven records, one for each fiscal year. The records were pooled and then broken out by the number of OEs reported for that age group across the 7 years of observation. As shown in Tables 2, most controllers were not involved in an operational error during the 7-year period. Moreover, the error distribution appears to be similar to the distribution of age, that is, more errors are observed for the more populous age groups. The distribution of controllers with no and one or more OEs by age group is illustrated in Figure 1, relative to the age distribution for all non-supervisory enroute controllers. As found by Spahn in 1977, the distribution of errors by age was very similar to the distribution of age across controllers. No particular age group appeared to experience OEs at a rate disproportionate to their representation in the workforce.

Poisson Regression

Overall, the Poisson regression model fit the data poorly (Likelihood Ratio $\chi2 = 283.81$, $p < .001$). The parameter estimate for the main effect of age (3.50) was significantly different from 0 (with a 95% confidence interval of 3.29 – 3.70), as were the parameter estimates for tenure. To consider the effect of age across tenure, the two age groups were contrasted. The Generalized Log-Odds Ratio was



	LE 30	31-35	36-40	41-45	46-50	51-55	56-60	GE 61
OE>=1	4.8	19.6	34.2	24.3	8.8	5.3	2.2	0.7
OE=0	8.0	18.7	30.7	22.9	9.6	6.1	3.1	0.8
Total ATCS	7.9	18.8	30.9	23.0	9.6	6.1	3.0	0.8

Figure 1: *OE Involvement by age group compared to distribution of age for all ARTCC controllers, FY1997-2003*

used to estimate the odds ratio for age, that is, the odds of OE involvement for older (GE age 56) controllers (see SPSS, 1999, p. 202 – 203). The odds of OE involvement for older controllers (GE age 56) were 1.02 times greater than the odds for younger (LE age 55) controllers, with a 95% confidence interval of 0.42 to 1.64. A confidence interval for the odds ratio that includes 1.0 indicates that the odds of involvement for the two groups are equal: neither age group was less or more likely to be involved in an OE.

Discussion

The Poisson regression analysis did not support the hypothesis that the likelihood of involvement in an en route OE increased with age. This finding undermines the explicit assertion that early retirement of controllers was "primarily a safety measure" (Testimony of Donald Francke, U.S. House of Representatives, 1971). As noted by Li, Baker, Grabowski, Qiang, McCarthy and Rebok (2003), age in and of itself may have little bearing on safety-related outcomes if factors such as individual job experience, workload, traffic complexity, and time-on-position are taken into consideration (p. 878). For example, supervisors may assign older controllers to less difficult sectors or provide assign an assistant controller during periods of heavy traffic. All other things being equal, age may influence performance through two conflicting pathways. On the one hand, the inevitable changes in cognitive function, particularly speed of processing, may result in slower and less efficient performance. On the other hand, experience is gained with age, and compensatory strategies and meta-strategies may result in safer and more efficient performance by controllers. Additional research on OEs, age, and ATCS performance is recommended to extend and confirm the findings of the present study.

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End notes:

[1]Mandatory separation is not required for controllers hired before May 16, 1972. The number of controllers age 56 and older increased from 155 in FY1997 to 488 in FY2003.