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Foreword

The papers in this Record are reports on research topics chosen by graduate students selected for awards from a nationwide competition under the fifth (1990–1991) Graduate Research Award Program on Public-Sector Aviation Issues. This program is sponsored by the Federal Aviation Administration and administered by the Transportation Research Board. Its purpose is to stimulate thought, discussion, and research by those who may become the future managers and policy makers in aviation. The papers were presented at the 71st TRB Annual Meeting in January 1992. The authors, their university affiliations, their faculty research advisors, and their TRB monitors are as follows.

Robert S. Dodd, a doctoral candidate at the Johns Hopkins University School of Hygiene and Public Health, examined factors involved in crash survival of emergency medical service helicopter occupants. His faculty research advisor was Susan P. Baker of the Injury Prevention Center, Johns Hopkins University. TRB monitors were Howard Collett, Journal of Aeromedical Transport, and Gary R. Kovach, MBB Helicopter Corporation.

Michael T. Drollinger, a master's degree candidate in city and regional planning at Rutgers University, investigated land use planning approaches to mitigating aircraft noise effects near airports. His faculty advisor was John Pucher, Department of Urban Planning, Rutgers University. TRB monitors were John W. Fischer, Congressional Research Service, and Sally D. Liff, Special Projects Division, Transportation Research Board.

Julie Anne Yates Hegwood, an Indiana State University master's degree candidate in human resource development, developed a method for identifying and categorizing human factors in general aviation accidents. Her faculty research advisor was Lowell D. Anderson, Industrial Technology Education Program, Indiana State University. TRB monitors were Gerald S. McDougall, The Wichita State University, and Ronald L. Swanda, General Aviation Manufacturers Association.

Susan J. Heidner, a candidate for a master's degree in civil engineering at Purdue University, analyzed trends and developed forecasts of international air travel to and from U.S. gateway airports. Her Purdue University faculty advisor was Robert K. Whitford, Department of Civil Engineering. TRB monitors were Vicki L. Golich, The Pennsylvania State University, and J. Bruce McClelland, British Aerospace, Inc.

Virginia L. Stouffer, a doctoral candidate at George Mason University, researched methods of measuring safety and risk in commercial aviation. Her faculty advisor at George Mason University was Jerome Ellig of the Center for the Study of Market Processes. TRB monitors were Lawrence F. Cunningham, University of Colorado at Denver, and Lemoine V. Dickinson, Jr., Failure Analysis Associates.

Factors Involved in Emergency Medical Service Helicopter Occupant Crash Survival

ROBERT S. DODD

Since the first hospital-sponsored emergency medical service (EMS) helicopter transport program began in 1972, more than 846,000 patients have been transported by helicopter, the majority since 1980. During the same period, 84 EMS helicopters were involved in crashes. The National Transportation Safety Board (NTSB) evaluated 59 EMS helicopter crashes occurring during the period 1980 to 1986. The NTSB found, among other things, that in numerous EMS helicopters the interior was not modified to the applicable FAA standards for crashworthiness or good engineering practices. Injury outcomes for EMS helicopter occupants and those in air taxi helicopters are compared. NTSB crash records were reviewed and survivors surveyed to determine occupant injury experience. It was found that occupants of EMS helicopters were more likely to be seriously injured in a survivable crash than those in the comparison population (relative risk = 2.10, 95 percent CI $1.21 < RR < 3.64$, $p < 0.008$). Forty-two percent of the injured EMS helicopter survey respondents identified medical equipment or components as a factor in their injury compared with just 3 percent of the injured comparison population when asked about the helicopter interior and their injury causation. Twenty-three percent of the EMS helicopter passengers experienced serious head injuries, a level twice as large as any other group in the study. Opportunities exist to reduce the exposure of EMS helicopter occupants to serious injury during the design and modification of the helicopter interior for the EMS patient care mission.

The use of helicopters to transport injured and ill patients is a relatively new part of the nation's health care transportation system. Since the first hospital-sponsored helicopter transport program began in 1972, more than 846,000 patients have been transported by helicopter, the majority since 1980. During the same period, 84 emergency medical service (EMS) helicopters were involved in crashes.

As of July 1, 1990, 178 EMS helicopter programs were in operation throughout the nation. The majority of the programs are operated by hospitals that either own and operate or lease their own EMS helicopters. The programs operate 225 helicopters that are dedicated to patient transfers and modified for the patient transport mission (*1*). Besides hospitals, state governments and other publicly funded agencies, such as police departments, operate EMS helicopters. Currently, 11 such agencies operate more than 30 helicopters in the EMS role (*2*).

EMS helicopter missions include the transport of cardiac patients, critical medical patients, neonatal patients, and trauma victims. The hospital-based programs typically operate both direct flights to the scene of accident or injury and interfacility flights from one hospital to another. The interfacility transports are often planned in advance and account for approximately 70 percent of all EMS helicopter flights (*3*). EMS helicopters are normally available 24 hr a day, 365 days a year. The decision to incorporate an EMS helicopter into a health care system represents a significant commitment in capital, manpower, training, and operating costs.

Helicopters used for EMS transport are highly complex and expensive. Usually, they are extensively modified for the EMS mission by the addition of multiple medical components to provide advanced life support. Before the medical components are installed, the interior of the aircraft is generally stripped of all unnecessary furnishings, carpeting, and equipment, leaving only the pilot's station. The helicopter is then modified with new seats for medical personnel, patient litters, and medical equipment. The modifications are usually conducted to the contracting hospital's specifications and are often based primarily on a need for compatibility with other hospital emergency equipment (*4*). The helicopter medical crew is typically composed of a pilot and two medical care professionals: a physician or critical care nurse and a paramedic or equally trained technician (*5*). The medical care personnel are highly trained for advanced, and, if necessary, aggressive medical care in the flight environment and represent a valuable resource as skilled health care practitioners.

EMS HELICOPTER CRASH EXPERIENCE

In 1987, the National Transportation Safety Board (NTSB) initiated a special study on commercial EMS helicopter safety. In this descriptive study, NTSB found that, from 1980 to 1985, EMS helicopters under commercial operation for hospitals had an estimated crash rate of 12.34 per 100,000 flight hr while on patient transport missions. Similar helicopters operating as commercial air taxis, not involved in EMS activities, experienced a crash rate of 6.69 per 100,000 flight hr, approximately half that of the EMS helicopters.

During the same period, EMS helicopters on patient transport missions had an estimated fatal crash rate (where at least one occupant died) of 5.40 per 100,000 flight hr. Commercial air taxi helicopters had a fatal crash rate of 1.60 per 100,000 flight hr, a rate less than one-third that of the EMS helicopters. For crashes in which occupants were not fatally injured,

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there was little difference: EMS helicopters had a rate of 2.31 per 100,000 flight hr and air taxi helicopters had a rate of 2.45 per 100,000 flight hr.

The NTSB study evaluated 59 EMS helicopter crashes occurring during the period 1980 to 1986 (*5*). The NTSB found that poor weather—specifically, reduced visibility due to precipitation, darkness, and fog—was a predominant factor in 25 percent (15) of the crashes studied. Eleven of the 15 crashes resulted in at least one fatality, leading to a conclusion by NTSB that ". . . it is clear that poor weather conditions pose the greatest single hazard to EMS helicopter operations."

Whereas reduced visibility was clearly an important variable in many crashes, NTSB was also critical of the potential compromise of the EMS helicopter's crashworthiness by the interior modification process. Crashworthiness has been defined as ". . . the relative ability of a particular vehicle design to withstand crash impact forces with minimal structural damage. Progressive structural collapse may be engineered to reduce the loads on the occupant through energy absorbent techniques. Thus, crashworthiness relates to protection of the occupants" (*6*).

NTSB found that in numerous EMS helicopters, the interior was not modified to the applicable FAA standards for crashworthiness or good engineering practices (*4*). Findings included lack of shoulder harnesses, seats improperly attached to the floor, seats constructed from nonapproved materials, medical equipment (such as oxygen cylinders) not properly restrained, fixed intravenous hooks projecting from the helicopter interiors, and loosely stored or mounted equipment, some of it of substantial mass. The lack of crashworthiness considerations in many EMS helicopter designs may be a factor in the 3.5-fold increase in fatality rates seen by NTSB compared with helicopters that have not been modified.

A recent study by Rhee et al. (*7*) failed to find a difference when the crash experience of United States hospital-based EMS helicopters were compared with Federal Republic of Germany EMS helicopters for the period 1982 to 1987. The authors found that the U.S. EMS helicopter crash rate of 11.7 per 100,000 flight hr was not significantly different from the West German rate of 10.9 per 100,000 flight hr. The fatal crash rates were also similar to a U.S. rate of 4.7 and a West German rate of 4.1. The authors conclude that the similarity in crash and fatality rates between the two countries may indicate a shared experience inherent in EMS operations.

A study conducted by Conroy et al. (*8*) evaluated fatal occupational injuries related to helicopters. The authors found that 62 percent of the women in the study were killed while functioning as medical personnel on EMS helicopters. Death rates were not developed for this group since relevant exposure data were not available. The authors state, however, that their findings suggest that women in medical occupations who routinely fly in EMS helicopters may be at proportionately higher risk for fatal occupational injuries than other female occupational groups. The authors suggest that this is an area that deserves additional study.

CRASH SURVIVAL: EXPERIENCE AND THEORY

Whereas efforts to reduce injuries and death in aviation crashes have historically focused on preventing crashes rather than preventing or minimizing injuries when a crash does occur, significant research has been conducted on crashworthiness and occupant survival (*9*). Little research has been conducted on civilian helicopter crashworthiness and occupant survival, however, and none has been conducted on EMS helicopters. Most helicopter crash survival research has been conducted by, or for, the U.S. Army over the last 30 years and has included a combination of experimental and observational approaches. The cumulative findings from this research are compiled in a seminal five-volume design guide for U.S. Army aircraft to improve crash survival (*10*). Topics covered include aircraft design criteria for crashworthiness, the crash environment and human tolerance, aircraft structural crashworthiness, seats and restraint systems, and postcrash fire reduction or elimination.

Current Helicopter Crashworthiness Standards

Measurement of impact forces in aircraft are usually reported along one of the three major axes of aircraft motion. The axes are longitudinal (fore and aftdenoted as $\pm G_x$), lateral (left or right denoted as $\pm G_y$), and vertical (up or down and denoted as $\pm G_z$). FAA sets the performance and safety standards for all aircraft manufactured in the United States. The standards for crashworthiness are far below the impact tolerance thresholds determined through research, experience, and the available technology for aircraft crashworthiness. For helicopter crashworthiness, the FAA states:

> The (helicopter) structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when—
> 1) Proper use is made of seats, belts, and other safety design provisions;
> 2) The wheels are retracted (where applicable); and
> 3) The occupant experiences the following ultimate inertia forces relative to the surrounding structure:
>
> | | | |
> |---|---|---|
> | (i) | Upward | 1.5 g |
> | (ii) | Forward | 4.0 g |
> | (iii) | Sideward | 2.0 g |
> | (iv) | Downward | 4.0 g |
>
> or any lower force that will not be exceeded when the rotorcraft absorbs the landing loads resulting from impact with an ultimate descent velocity of five feet per second (3.4 mph) at design maximum weight. (*11*)

The FAA regulations require only the copilot and pilot positions to have shoulder harnesses.

U.S. Army Standards

The U.S. Army has developed crashworthiness standards far in excess of those required by FAA for civilian helicopters (*11*). The Army requires that helicopters be designed to protect occupants in crashes with average aircraft *g* loadings as follows: downward ($+G_z$), 24 *g*; longitudinal ($+G_x$), 15 *g*; and lateral ($\pm G_y$), 9 *g*.

These standards have been incorporated in all new Army helicopters, and a retrofit program is in place to improve the crashworthiness of older Army helicopters where feasible. The program has proven successful and indicates that the knowledge and technology exist to improve crash survival.

Vertical Loads and Spinal Injury

In many helicopter crashes, occupants receive serious back injuries because of the associated high vertical loads. Shanahan and Mastrolanni (*12*) evaluated spinal injury of occupants involved in survivable crashes in U.S. Army OH-58 series helicopters, an older design without enhanced crashworthy features. The OH-58 is similar to a common EMS helicopter, the Bell model 206. A review was conducted of all crashes between 1971 and 1981 in which ground contact occurred. Information on spinal injury was categorized as (*a*) no spinal injury, (*b*) sprain or strain, (*c*) fracture or dislocation, or (*d*) multiple extreme injury.

The authors found that there was a moderate correlation between vertical velocity change and injury category and no, or very weak, correlation between horizontal velocity change and spinal injury category. A dramatic increase in the rate of spinal injury occurring just above the design sink speed of the helicopter landing gear (12 ft/sec) suggests that the fuselage and seat provided little additional impact protection above that of the landing gear alone. The authors conclude that 80 percent of all spinal injuries in survivable and partially survivable crashes in the OH-58 occur at impact velocities less than 30 ft/sec vertical velocity. They recommended that the helicopter be modified by the incorporation of energy-absorbing seats.

Civilian Helicopter Crashworthiness Research

Coltman et al. (*13*) conducted a comprehensive retrospective evaluation of civilian helicopter crash survival. In this study, all civilian helicopter crashes occurring between 1974 and 1978 were reviewed. Only crashes judged to be survivable and that had postcrash fire, major or minor injury, or major structural damage were included (a total of 311).

The authors found that the following hazard mechanisms, listed in order of importance, accounted for the majority of injuries in the study population: burns due to fuel system failure on impact, spinal injuries due to excessive vertical loading, injuries of all types due to in-flight wire strike on the frontal plane of the helicopter, secondary impact of the upper torso and head due to restraint system deficiencies, and secondary impact due to lack of upper torso restraint. They also found that, for survivable crashes reviewed in the study, the average yearly distributions of occupant injuries in civilian helicopter crashes were as follows: 68 percent (370) received no injuries, 17 percent (95) received minor injuries, 11 percent (57) received serious injuries, and 4 percent (23) died.

The authors concluded that the study indicated a need for improved crashworthiness in U.S. civilian helicopters. Most research indicates that prevention of injuries among helicopter occupants through improved crashworthiness is both desirable and achievable. There are also indications that the crashworthiness of existing helicopter designs can be improved by modifications of the aircraft.

RESEARCH ISSUES

The civilian EMS helicopter crash experience has clearly been worse than non-EMS helicopter populations studied. Research conducted to date has not adequately explored the factors involved in the differences in survivable crash outcomes in EMS helicopters compared with other civilian helicopter crash populations. Occupant risk of fatal or serious injury appears to be greater in EMS helicopter crashes than in crashes of other helicopter populations.

The basic research questions are as follows:

1. Are EMS helicopters more hazardous for occupants than non-EMS helicopters?
2. To what extent is the modification of the helicopter for the medical role related to the injury experience of the occupants?
3. Can specific crash hazards be identified for the development of preventive measures?

This paper reports on the exploration of these issues.

METHODS

A nonconcurrent cohort study design was used to evaluate exposure and relative risks of injury and death for occupants involved in crashes of EMS helicopters. (The relative risk, or risk ratio, indicates the strength of certain associations and is equal to the risk in Group A divided by the risk in Group B.) The study cohort included occupants of all EMS helicopter crashes that occurred between 1978 and 1990. Exposure and outcome data for the study population were obtained from crash investigation records maintained by NTSB and follow-up questionnaires for crash survivors. The occupants of the EMS helicopters were the exposed population. The nonexposed comparison population consisted of occupants of similar non-EMS helicopters involved in crashes for the time period 1983 to 1990.

The study consisted of three phases. The first phase was the development of preliminary measures in which crashes that were survivable or not survivable in both populations were identified. Incidence rates for various injury categories and rates of injury outcome were developed. The focus of this analysis was the evaluation of variables likely to have an influence on crash survival.

The second phase of the study focused on the variables with the greatest potential influence on injuries among EMS helicopter occupants. This evaluation examined the impact conditions associated with survivable crashes as well as factors determined from Phase 1 to have potential influence on the dependent variables of interest.

The last phase of the study focused on the identification of the hazards most important to injury causation among the occupants of survivable crashes.

Data Sources

The primary data source for this study was records maintained by NTSB. NTSB defines an aircraft accident as an occurrence associated with the operation of an aircraft that results in fatal or serious injury or in substantial damage to the aircraft. A fatal injury is one that causes death within 30 days of the crash. Serious injuries include any injury that (*a*) requires hospitalization for more than 48 hr; (*b*) results in fractures

(except simple fractures to the nose, fingers, and toes); (*c*) causes severe hemorrhages, nerve, muscle, or tendon damage; (*d*) involves any internal organ; or (*e*) involves second- or third-degree burns over 5 percent or more of the body surface (*14*).

In this study, all crashes of non–public use EMS helicopters that meet the NTSB definition of an accident were included as the study population. All crashes of turbine engine–powered helicopters operating as air taxis [Federal Aviation Regulation (FAR) Part 135] and not modified for other non-passenger operations composed the pool from which the comparison population was selected.

The comparison population sample was limited to FAR Part 135 air taxi helicopters meeting the following criteria:

1. The make and model of aircraft were limited to the same type used by EMS helicopter operators.
2. Water contact crashes were not included.
3. The crashes included were limited to passenger operations conducted under FAR Part 135. No agricultural operations, sling loads, or other special use helicopters were included.

The period for inclusion of EMS helicopter crashes was 1978 to 1990 (the majority of the crashes occurred after 1983). The period for the comparison population was 1983 to 1990.

Exposure information using hours flown for the Part 135 helicopter air taxis was obtained from an annual survey of helicopter operators conducted by FAA (*15*). Hour estimates for EMS helicopters were based on the number of patients transported per year, a surrogate measure for hours flown. Past research indicates that one patient transport correlates well with 1 flight hr (*5*).

A follow-up questionnaire was also administered to helicopter crash survivors of both groups by mail. The questionnaire was sent to a sample of survivors identified through the NTSB records. The questionnaire was designed to obtain supplemental information from the survivors not available from the NTSB crash record. The questionnaire requested information on the survivor's age and weight, function in the helicopter at the time of the crash, seating position and orientation, individual restraint availability and use, damage to the seat, personal protective equipment (such as Nomex flight suits or helmets), damage to the helicopter, events remembered of the crash sequence, injury status and severity, identification of injury source, and presence or absence of post-crash fire.

Causal Factors

Each crash was reviewed to determine causal factors. Both the narrative contained in the hard copy record and the official NTSB probable cause were used in the development of these causal factor categories. Up to two causal factors could be listed for each crash. The factors are as follows:

1. Mechanical problems, not including engine failure, that were directly related to the crash;
2. Engine failure;
3. Weather—specifically, poor visibility;
4. Wire strike while in flight;
5. Control problem, usually involving mechanical problems with the control system of the helicopter;
6. Spatial disorientation of the pilot, usually associated with poor visibility or dark nights;
7. Power loss or reduced power;
8. Pilot judgment error;
9. Tail rotor failure;
10. Weather (other than poor visibility), such as high winds and downdrafts;
11. Loss of control;
12. Struck object;
13. Foreign object damage, usually caused by material being sucked into the engine or rotor systems;
14. Fire;
15. Fuel exhaustion;
16. Fuel starvation (fuel was present on board the aircraft but was unavailable to the engine); and
17. Other not covered by the preceding categories.

Crash Survivability

The survivability and severity of the crashes were determined through review of hard copies (microfiche) of the NTSB crash record. Injury status of the occupants was not evaluated during this phase of the study to avoid the introduction of bias based on the injuries actually received by the occupants. Information reviewed included estimates of both horizontal and vertical velocity provided by the investigator, structural damage to the helicopter, ground scarring, and review of photographs when available. The primary goal of this analysis was to determine which crashes were clearly survivable, which were clearly not survivable, and those for which survivability could not be ascertained.

Crashes were categorized as survivable, not survivable, or unknown. For a crash to be considered survivable, the estimated acceleration forces experienced by the occupants had to be within the accepted limits of whole body *g*-loading tolerance for properly restrained individuals. In addition, enough space needed to remain within the helicopters for the occupants to survive.

Crash severity was also evaluated during the determination of the crash survivability. The measurement of crash severity was based on the narrative description of damage to the helicopter contained in the NTSB crash record or from the responses of the occupants to the questionnaire, or both. The primary goal of the crash severity measure was to develop a relative baseline for comparison between the two populations. The crash severity measures are as follows:

1. Hard landing/minor damage: The aircraft landed hard in a primarily vertical direction and experienced relatively little damage. Typical damage includes minor damage to the landing gear with skin wrinkles on the fuselage and tail boom. Aircraft whose tail boom was severed by the rotor blades flexing down were also included in this category.
2. Rollover/minor damage: This crash scenario typically involved a helicopter that rolled over either after a low-impact landing or from a low hover. The damage to the aircraft could be substantial although the *g* forces were relatively minor.

Typical damage includes transmission and rotor damage along with fuselage skin damage and broken windows. The interior usually received no major damage.

3. Hard landing/substantial damage: The aircraft landed hard in a primarily vertical direction and experienced more substantial damage than described in Measure 1. Typically, the landing gear received substantial damage, with skids being separated and wheeled landing gear being seriously damaged. The fuselage also received damage with tail boom separation, possible structural damage, and perhaps broken plexiglass. The interior was not compromised and did not receive major damage.

4. Hard landing/rollover/substantial damage: This crash scenario resulted in damage to the aircraft as described in Measure 3 but was followed by rollover of the helicopter after the initial impact.

5. High vertical impact with survivable space and substantial damage: This type of crash was characterized by high vertical impact in which the landing gear was destroyed, with serious damage to the structural members of the helicopter attached to the landing gear. The fuselage also received considerable damage, with crushing of the fuselage floor and possible distortion of the cabin or cockpit. Space remained for the occupants, but the interior may have also experienced disruption, with distorted seats, loosened interior panels, broken windows, and distorted floor panels.

6. High vertical impact/survivability unknown: The aircraft was typically destroyed along with the landing gear. The fuselage received significant damage, which often included some crushing and loss of occupant space. Also, the interior usually received extensive damage. The damage to the aircraft was such that potential survivability of the occupants could not be determined with any accuracy.

7. Slow-speed collison with ground/substantial damage: The aircraft had a greater longitudinal than vertical impact component. The speed at which impact occurred was below 60 kts and the aircraft received substantial damage, with landing gear destruction, significant fuselage damage and distortion, and interior distortion.

8. High-speed collision with ground/severe impact: This type of crash involved greater longitudinal than vertical impact forces and occurred at speeds greater than 60 kts. The forces were such that fuselage was usually destroyed.

9. Collision with object: Most of these crashes involved collisions with wires or other high obstructions such as trees or structures. These crashes typically occurred during approach or departure but could also occur during cruise flight.

10. Midair collision/severity unknown.

11. Unknown: Not enough information to make an estimate of crash severity.

12. Other: Fits none of the categories above.

Injury Coding

Each occupant in both the study and comparison populations had been classified by NTSB according to injury level (none, minor, serious, or fatal). In addition, information on specific injuries sustained by occupants was collected through additional review of the associated NTSB crash record and from the questionnaires. Injury status was determined through survey responses, data contained in the injury supplement (Supplement K) of the NTSB accident report, and review of the narratives written by the investigator contained in the official NTSB report. All occupants of the EMS helicopter population and a random sample of the occupants of the non-EMS helicopter population were included in this review.

Once the individual injuries sustained by the occupants were determined, they were coded using the Abbreviated Injury Scale (AIS), 1990 revision (*16*). The AIS was first developed in 1972 to provide researchers with a numerical method for ranking and comparing injuries by severity and to standardize the terminology used to describe injuries. Since that time, the AIS has become a widely used method for measuring blunt force injuries. AIS scores range between 1 (very minor) and 6 (not survivable), and each individual injury is scored. Specific information is coded for body region of the injury, type of anatomic structure, and the specific anatomic structure involved.

Though the AIS is a well-developed and accepted method for measuring injuries, it does not allow for an evaluation of the cumulative effect of multiple injuries. For this reason, Baker's injury severity scale (ISS) was also calculated for each injured occupant. The ISS is calculated by taking the square of the highest three AIS scores in three different body regions and summing the values. The resulting value gives a much better fit between overall injury severity and probability of survival.

RESULTS

Crash Evaluation and Rates

The NTSB data base contained 75 EMS helicopter crashes occurring between May 11, 1978, and November 2, 1989, with 239 occupants. Of the 75 crashes, approximately 68 percent (51) resulted in injuries (including fatalities) to occupants, whereas 32 percent (24) caused no injuries to the occupants. Of the 239 occupants, 33 percent (80) received no injuries, 19 percent (45) received minor injuries, 15 percent (36) received serious injuries but survived, and 33 percent (78) died. Of the 75 crashes, 27 percent (20) were determined to be unsurvivable. The survivability status could not be determined for four.

From January 6, 1983, to October 10, 1989, 663 crashes of FAR Part 135 turbine-powered air taxi helicopters were investigated by NTSB. Of these, 147 with 486 occupants were eligible for inclusion in the study. Fifty-seven percent (83) of the crashes had occupants who were injured (including fatalities), and 43 percent (64) resulted in no injuries to the occupants. Of the 486 occupants, 56 percent (274) received no injuries, 22 percent (113) received minor injuries, 11 percent (54) received serious injuries, and 10 percent (45) died. Of the 147 non-EMS crashes included in this study, 11 percent (16) were deemed to be unsurvivable. The survivability status could not be determined for six.

Table 1 compares the injury status of the crash for both EMS and air taxi helicopters for all crashes, survivable and unsurvivable, and provides the same comparison for survivable crashes alone.

TABLE 1 MOST SEVERE INJURY CATEGORY

INJURY STATUS	EMS HELICOPTERS (n=75 crashes) NUMBER	RATE*	AIR TAXI HELICOPTERS (n=147 crashes) NUMBER	RATE*	RELATIVE RISK	CONFIDENCE INTERVAL#
SURVIVABLE AND NON-SURVIVABLE CRASHES						
MINOR	15	20.0	34	23.13	0.86	0.50<RR<1.48
SERIOUS	9	12.0	25	17.00	0.71	0.35<RR<1.43
FATAL	30	40.0	24	16.33	2.45	1.55<RR<3.88
SURVIVABLE CRASHES						
MINOR	15	29.41	34	27.20	1.08	0.65<RR<1.81
SERIOUS	9	17.64	25	20.00	0.88	0.44<RR<1.76
FATAL	3	5.88	2	1.6	3.68	0.63<RR<21.36

* Rate per 100 crashes.
\# 95% confidence interval.
Note: C.I. for the relative risk that does not include 1 represents significance at the 5% level.

As can be seen, the only significant difference between the two populations appears at the fatal crash level, in which at least one aircraft occupant died (relative risk = 2.45, 95 percent CI $1.55 < RR < 3.88$, $X^2 = 13.86$, $p = 0.0002$). When the crashes were evaluated for their survivability status, that is, whether the impact forces were within the range considered survivable, the difference between the crash severity groups at the fatal level disappeared.

Crash Factors

Twenty-four percent (18) of all EMS crashes in this study involved poor visibility. Poor visibility was involved in only 10 percent (15) of the non-EMS air taxi helicopter crashes. Mechanical failure (including engine failure) was involved in 27 percent (20) of the EMS crashes and 26 percent (38) of the non-EMS air taxi crashes. Other categories include wire strike [EMS = 8 percent (6), non-EMS air taxi = 6 percent (9)], power loss [EMS = 4 percent (3), non-EMS air taxi = 10 percent (14)], loss of control [EMS = 8 percent (6), non-EMS air taxi = 20 percent (29)], and struck object [EMS = 8 percent (6), non-EMS air taxi = 5 percent (7)].

Crash Severity

Evaluation of the distribution of crash severity categories indicated no difference of interest in crash severity between EMS and non-EMS air taxi helicopters. Detailed evaluation of the injuries experienced by the occupants with relation to the crash severity was not conducted, but initial review indicated that an increase in injuries and injury severity occurred as the crash forces increased. This dose response was expected.

Occupant-Based Analysis

Occupant Injuries

Occupant injuries were evaluated through information gathered from survey responses, narrative information contained in the NTSB hard copy crash records, and coded information contained in Supplement K of the NTSB computer crash records. There were 159 occupants in survivable crashes of EMS helicopters and 430 eligible occupants in survivable crashes of air taxi helicopters. In EMS helicopters, 56 percent (89 occupants) received no injuries, 25 percent (40) received minor injuries, 16 percent (25) received serious injuries, and 3 percent (5) died. In air taxi helicopters, 63 percent (273 occupants) received no injuries, 26 percent (112) received minor injuries, 10 percent (43) received serious injuries, and 0.4 percent (2) were fatally injured.

When occupant injuries were compared between the two groups by injury status considering the occupant location (pilot or passenger), a statistically significant increased risk of serious injury for EMS helicopter passengers and crew was found when compared with non-EMS air taxi passengers (RR = 2.10; 95 percent CI $1.21 < RR < 3.64$, $X^2 = 7.11$, $p = 0.008$). No significant association for serious injuries was discovered for pilots of the two different populations. The difference in injury severity by location was not unexpected, since the pilot's position in EMS helicopters is typically not changed when the interior is modified for the medical mission. The injury experience of the two pilot groups should therefore be essentially the same given similar crash acceleration forces. No statistical evaluation was conducted for difference in fatal injury outcome among occupants between groups, since the total number of fatal injuries was too small.

Injury Severity

The injury information for the EMS helicopter population was developed from review of the NTSB crash records for all occupants and from survey information for a small subset of occupants. The injury information derived from these sources can be considered representative, since all EMS helicopter occupants were accounted for. Information was collected on 55 injured EMS helicopter occupants in survivable crashes. Injury information for the air taxi helicopter occupants was also obtained from review of NTSB crash records and survey information. All non-EMS air taxi crashes, however, were not reviewed. A systematic sampling technique was used to

select 57 crashes for detailed review. In these crashes, the injuries of 51 occupants were coded for detailed analysis.

The injuries of these occupants were coded using the AIS and a summary measure was developed by calculation of the ISS. The mean ISS scores were then calculated for pilot and passengers for both EMS and non-EMS air taxi helicopters. The results of this analysis are given in Table 2.

The injuries of EMS helicopter pilots were, on the average, less severe than those of the pilots of non-EMS helicopters, as indicated by the mean ISS score. The injuries of EMS helicopter passengers, however, were more severe than those sustained by the comparison passengers in non-EMS air taxi helicopters, on the average. In neither case were the differences statistically significant. When the ISS scores are evaluated, it should be remembered that these are mean values of all ISS scores of the occupants for each group. For this reason, the range of scores for each group is presented for additional insight. In addition, the ISS score is nonlinear and should be interpreted accordingly.

Injury Characteristics

Once specific injuries were coded, they were further categorized for ease of analysis and review. The categories are as follows:

- Serious back injuries include spinal fractures of the lumbar, thoracic, and cervical spine along with disc compression or rupture.
- Serious head injuries include concussion, subdural bleeds, skull fracture, and serious lacerations.
- Minor head injuries include unspecified head injuries and head contusions.
- Internal injuries include any damage to internal organs and are of varying severity. They include heart or lung contusions, ruptured spleen, bladder contusion, and bruised kidneys.
- Fractures include fractures of the extremities, facial bones, and ribs.

Table 3 gives the results of the analysis of specific injury categories.

For all four groups, serious back injuries constituted a major injury risk. This finding supports the conclusions of Shanahan (*12*) and Coltman (*13*) already cited. As in those studies, the majority of the occupants in the rear of the aircraft evaluated for this study were not wearing shoulder harnesses. Past research indicates that shoulder harnesses improve resistance to back injury slightly. The other finding of interest is the difference in serious head injuries among the groups. The rate for EMS helicopter passenger serious head injury per 100 injured passengers of 23.25 is roughly threefold greater than that of non-EMS helicopter passengers.

Survey Responses

The survey was developed to gain additional insight into the variables associated with occupant injury, or lack of injury,

TABLE 2 MEAN ISS SCORES FOR OCCUPANTS INJURED IN SURVIVABLE CRASHES

	MEAN PILOT ISS SCORE	PILOT ISS SCORE RANGE	MEAN PASSENGER ISS SCORE	PASSENGER ISS SCORE RANGE
EMS HELICOPTERS	3.17	1-9	6.98	1-34
AIR TAXI HELICOPTERS	5.46	1-12	4.40	1-12
DIFFERENCE	-2.29		2.57	
P-VALUE *	0.16		0.17	

* Kruskal-Wallis test for two nonparametric groups.

TABLE 3 INJURY CATEGORY FOR OCCUPANTS BY LOCATION

	EMS PILOTS n=12	AIR TAXI PILOTS n=26	EMS PASSENGERS n=43	AIR TAXI PASSENGERS n=25
SERIOUS BACK INJURIES	16% (2)	38% (10)	47% (20)	36% (9)
SERIOUS HEAD INJURIES	8% (1)	8% (2)	23% (10)	8% (2)
MINOR HEAD INJURIES	0	12% (3)	7% (3)	8% (2)
INTERNAL INJURIES	0	0	12% (5)	4% (1)
FRACTURES	8% (1)	23% (6)	19% (8)	28% (7)

Note: Percentages may total less than 100 % since very minor injuries not included. Percentages may also total more than 100 % since many occupants had more than one injury.

in a sample of both EMS and air taxi helicopters. The questionnaire was pretested on a sample of 20 air taxi helicopter pilots. The pilots, and the associated crashes, were not included in the air taxi helicopter data base used for this study.

Once the pretest questionnaires were received, they were reviewed and appropriate modifications made. A total of 350 questionnaires were then mailed to a sample of both EMS and air taxi helicopter crash survivors. Only occupants whose complete address was part of the NTSB crash record (not all NTSB investigators record this information) were mailed a questionnaire with a postage-paid return envelope.

Overall, the response rate after the two mailings was 37 percent (128). Approximately 30 percent (106) of the 350 survey subjects had moved and left no valid forwarding address for the questionnaire package, which indicates that approximately 33 percent (116) survey subjects received the questionnaire but did not respond.

Whereas this response rate may not appear impressive, it is not difficult to understand the low rate when it is remembered that the event being investigated was probably emotionally traumatic for the individual, and concern about legal issues in events such as these is always present. However, the descriptions of the injuries received by the occupants, and their associated comments and recommendations, were of considerable value.

Although the possible influence of EMS helicopter interior modifications on the severity of occupant injuries was not clearly shown in this preliminary analysis, the responses to the survey offered some interesting insight into the issue of injuries in EMS helicopter crashes. In addition to formatted questions which allowed no flexibility in response, the questionnaire asked the following questions about the occupant injuries:

> Please provide a description of your injuries (such as a broken left arm, with cuts and abrasions, or multiple bruises to the face and a sprained left ankle). Please be as detailed as you can.
>
> Do you know what caused your injuries? For example, what object or structure inside the helicopter did you contact? If yes, please describe in as much detail as possible.

The major responses to these questions were categorized for ease of analysis and presentation for both the EMS and non-EMS survey respondents who were injured. The categories for injury causation are as follows:

- Aircraft interior: This category includes occupants striking doors or windows or their associated structures, instrument panel, and throttle quadrant.
- Harness problem: This involved shoulder harnesses being fastened incorrectly and failure of the shoulder harness.
- Medical/other equipment: Occupants struck or were struck by patient stretcher, oxygen tanks, portable radios, cardiac monitors, medical equipment panels behind pilot, and fire extinguisher.
- Hit other occupant.
- Lap belt related: involved lap belt/abdominal trauma and seat belt clasp injury unspecified.

Table 4 gives the findings from this analysis.

The most noticeable difference in these responses appears in the medical/other equipment category. The fact that 42 percent of those passengers and crew injured in EMS helicopters attribute their injuries to striking medical equipment is certainly of interest. None of these occupants cited other loose equipment in the aircraft other than the medical equipment. The one non-EMS passenger who responded in this category struck his head on a fire extinguisher that was mounted near his seat. Although Table 4 summarizes the experience of the occupants, the following excerpts from the surveys are typical and offer an additional perspective on the experiences of injured occupants.

One nurse who was wearing only a lap belt, and whose aircraft hit hard and rolled over, described her experience by saying

> I had a concussion with a large laceration over the right side of my skull. I also had bruises and abrasions to all of my face. . . . I assumed the crash position and while we were rolling, the cardiac monitor broke loose from its case and gave me the head injuries.

Another flight nurse, restrained by a lap belt, was in a helicopter that had a very hard landing after an engine failure. She described her experience and injuries this way:

> I received fractured ribs, multiple lung contusions, fractured lumbar vertebrae [L5-S1], multiple facial lacerations, and a broken arm and ankle. . . . [The damage] to my face and teeth was caused by the oxygen tank, the broken arm and ribs caused by slamming into medical pouches and 1/2" plexiglass behind the pilot's seat. . . . The fractured ankle happened because it was stuck under the stretcher and I pulled it out to free my foot breaking [it] in the process.

Other observations by both EMS and non-EMS passengers seriously injured include the following:

> I believe that the forces of the helicopter and not having shoulder restraints was the main cause of my injuries. . . . We were lucky, the aircraft landed in six feet of fresh powdered snow.

TABLE 4 INTERIOR HELICOPTER STRUCTURE AND EQUIPMENT IMPLICATED IN OCCUPANT INJURIES

	EMS OCCUPANTS n=29	AIR TAXI OCCUPANTS n=35
AIRCRAFT INTERIOR	31% (9)	34% (12)
HARNESS PROBLEM	10% (3)	8% (2)
MEDICAL/OTHER EQUIPMENT	42% (12)	3% (1)
HIT OTHER OCCUPANT	7% (2)	0
LAP BELT RELATED	17% (5)	0

> Head hit back firewall, other nurse's knees in my chest, other injuries from striking items inside the cabin [such as] patient litter, portable oxygen tank, etc.

> I assume it was all "whiplash" injury due to not having a shoulder harness.

> I only know [the] monitor was airborne and hit me in the face.

> I feel that 3 or 4 point restraint system certainly would have reduced number of injuries.

Equally interesting were the observations of those not seriously injured in the crashes. One EMS helicopter pilot observed:

> The use of helmets by everyone may have prevented injury. The diagonal shoulder harness was useless. Recommend installation of lap belt and double shoulder harness in all crew and passenger stations.

A paramedic who received minor head and burn injuries in a crash stated:

> Our program has initiated the use of Nomex flight suits as well as helmets. If I had been wearing these at the time of the incident, I believe I would not have injured.

A physician who received minor injuries in an EMS helicopter observed that "the helmet prevented much more serious injuries."

DISCUSSION OF RESULTS

The fact that a statistically significant association exists between the risk of serious injury among helicopter passengers and the type of helicopter they are passengers in (i.e., EMS versus non-EMS) supports the hypothesis that EMS helicopters are more hazardous to passengers than the non-EMS helicopter comparison population used in this study (RR = 2.10; 95 percent CI $1.21 < RR < 3.64$, $X^2 = 7.11$, $p = 0.008$). There is, however, no statistical difference between the injury experience of the pilots of the two study groups. This finding generally supports the supposition that EMS helicopter pilots should be at the same risk for injury as non-EMS air taxi helicopters pilots, since the modification of EMS helicopters typically makes little or no changes in the pilot's position.

Evaluation of any differences in fatal injury outcome in survivable crashes between the two groups was not feasible due to the lack of reliable information. The survivability of many of the potentially survivable crashes in which occupants died could not be determined with accuracy. In these cases, the crashes were coded conservatively as "survivability unknown." This category was not included in the analysis of occupant injuries. Furthermore, specific information on the injuries sustained by the occupants killed in potentially survivable crashes was not available in the NTSB crash record. The NTSB investigators almost universally coded the occupant as having received multiple injuries in lieu of completing the injury supplement. This bias made the NTSB record of no value for this aspect of the analysis. A logical follow-up of this study would be the reëvaluation of the potentially survivable crashes through review of additional records and collection of autopsy data for individuals killed in the crashes to exactly determine their injuries.

Evaluation of individual injuries of those who survived the crashes does not provide enough evidence to reliably determine that the modification of the EMS helicopter was the sole cause of the increased risk of serious injuries. It is reasonable to assume, however, that this lack of association might be due to limitations in the sample sizes or measurement methods used at this level of analysis and may not be because of no difference between the two study groups. This assumption is supported by the EMS occupant survey responses in which 42 percent indicate that they believe their injuries were caused or exacerbated by the medical or other equipment in the helicopter. This percentage stands in contrast to the 3 percent of non-EMS occupants who identified other equipment in the helicopter as involved in their injuries. In addition, the fact that EMS helicopter passengers received serious head injuries twice as often as passengers of non-EMS helicopters or the pilots of either group supports the general hypothesis that the medical modification of the EMS helicopter may be responsible for increased injuries among this group.

The review of injuries among all occupants in this study indicates that serious back injury is a serious problem for all survivors of helicopter crashes. This finding supports the conclusions of the research conducted by both Shanahan (*12*) and Coltman (*13*) and indicates that the most serious helicopter crash scenario for occupant injuries involves a component of vertical acceleration in excess of the design requirements specified by the FAA for helicopters, but well within that tolerated by the human body. Incorporation of double shoulder harnesses and energy-absorbing seats in currently designed helicopters, where feasible, would prevent, or reduce, these injuries.

CONCLUSIONS

The preliminary review and analysis of the crash and injury data for these two populations indicate that there is an increased risk of serious injury among EMS helicopter passengers and that these injuries are, at least in part, due to medical modifications and associated equipment in the helicopter. Strategies to reduce, or eliminate, the seriousness of injuries among this group include the incorporation of double-strap shoulder harnesses for all passenger locations in the helicopter along with energy-absorbing seat. The results from this study support previous research indicating that these features should be made available to all helicopters, not just EMS helicopters.

Portable equipment such as cardiac monitors, oxygen cylinders, and radios also pose a hazard. Preventive interventions for these components would have to be developed on a case-by-case basis, but some general design characteristics might include the following:

1. Oxygen cylinders should be mounted outside the passenger compartment and should be constructed only of aviation-approved cylinders and hardware. Common sense also dictates that the oxygen flow should be controllable at cylinders regulator and that all oxygen lines into the aircraft passenger compartment should be low pressure.

2. Cardiac monitors should be permanently mounted in the passenger compartment. In cases where portable monitors must be carried when not in use, they should be stored in a secure location where they will not come loose in a survivable crash.

3. Patient stretchers and other structures of mass such as infant incubators should be secured to the aircraft in such a way that they will not come loose during very mild accelerations as allowed by the FAA in the design specifications for helicopter crashworthiness.

4. IV hooks in the interior and other projections such as oxygen line connections should be mountd behind the sidewall of the aircraft and not project into the interior.

The need to design both for crashworthiness and for efficient patient care may appear to be mutually exclusive. The opportunity exists, however, to incorporate both factors into the helicopter when designing for interior modification. The potential for preventing or reducing serious injuries, and perhaps preventing needless death, makes the effort worthwhile.

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Land Use Planning Approaches To Mitigating General Aviation Aircraft Noise

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Land use controls are one technique for regulating the adverse impact of aircraft noise in airport environs. Air carrier airports have generally been the focus of land use compatibility planning. However, general aviation airports represent the vast majority of airports in the United States. Encroaching development in the vicinity of general aviation airports in suburbanizing regions will, absent effective land use planning, result in public pressure to close airports. An examination of the characteristics, advantages, and disadvantages of available land use planning techniques and strategies for mitigating aircraft noise is presented. The effectiveness of land use controls depends on the implementation of policies and regulations at different governmental levels. A case study of airport noise compatibility planning in New Jersey is presented. It appears that some effective planning controls exist to regulate land uses and to limit land use incompatibilities. However, the concentration of land use regulatory powers at the local level has not and cannot ensure that noise compatibility planning will take precedence over other local interests. A more direct role for the state and federal governments in regulating land use compatibility in the airport community environment is suggested. Their participation is necessary in order that the viability of the national system of airports not be lost.

Aircraft noise in the airport environs continues to be a serious problem in the United States. It has been estimated that more than 5,000,000 people living near airports are subject to adverse noise levels from aircraft (*1*). Though technological advances have significantly lessened the amount of noise from aircraft engines, the problem of noise is expected to grow as the air transport industry continues to expand. The goal of reducing the amount of aircraft noise concerns land use planners as well as engineers. "Airport land use compatibility planning and implementation" describes the achievement and maintenance of land uses in the airport environs that are not adversely affected by aircraft noise. The process involves developing plans and using strategies and techniques that preserve the airport and maintain its economic viability. Planning is by its nature continuous and forward-oriented and must create, lead, and respond to changes in development patterns, legal constraints, and the political climate.

Airport land use compatibility planning is becoming increasingly important as urbanization encroaches on an ever greater number of airports, both air carrier and general aviation. Many of these airports were once remotely situated and were never intended to be compatible with noise-sensitive land uses, especially residential uses. General aviation refers to all civil aircraft operated in the United States except those operated under Parts 121 and 127 of the Federal Aviation Regulations (FAR) (*2*). The predominant types of aircraft in the general aviation fleet are piston-powered aircraft, turboprops, and corporate jet aircraft. The general aviation fleet comprises more than 210,000 aircraft, representing almost 98 percent of the entire U.S. civil fleet (*3*). However, less attention is generally paid to aircraft noise impacts near general aviation airports. This research focuses on general aviation airports, which make up 97 percent of the nation's airports (*3*).

The goal of the research is to describe the land use controls that are used to mitigate aircraft noise impacts and to analyze the effectiveness of the controls considering technical, political, and practical realities. The analysis focuses on the following subject areas:

- An analysis of the land use planning controls applied to regulate land uses in the airport vicinity,
- Legal considerations in airport land use planning,
- The roles and responsibilities of various levels of government with regard to airport land use compatibility planning,
- A case study of airport land use compatibility planning in New Jersey, and
- Options to strengthen noise compatibility planning around general aviation airports on the basis of the analysis of the preceding subject areas.

The importance of finding an acceptable and effective method of ensuring land use compatibility around general aviation airports is necessitated by the continuing and steady decline in the number of public use airports [airports open to the public without prior permission and without restrictions within the physical capacities of available facilities (*4*)]. From 1979 to 1986 the number of public use airports in the United States dropped from 6,659 to 5,626, a decline of 15.5 percent (*3*). In addition to facing the burden of property taxes and real estate development pressures, general aviation airports must face the challenge of accommodating growth while maintaining compatibility with the airport environs.

LAND USE CONTROLS

The regulation of noise around airports takes two major forms: operational noise control measures (e.g., curfews, noise

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abatement flight tracks, etc.) and land use control measures. Cline (*5*) surveyed aircraft noise control methods. The survey involved updating the information contained in FAA's Airport Noise Control Strategies report. More than 400 airports were sampled. A rank order of the land use control techniques is presented in Table 1. This research focuses on six of the most common land use controls: zoning, comprehensive or master plan, land acquisition, easement purchase, development rights (purchase and transfer), and land banking. The characteristics, advantages, and limitations of the six land use controls are examined.

Zoning

There are many types of zoning controls. In general, zoning is defined as "the dividing of a municipality into districts and the establishment of regulations governing the use, placement, spacing and size of land and buildings" (*6*). Zoning normally consists of a zoning ordinance, which delineates the zone districts and defines the use and bulk requirements of each district, among other things. The zoning ordinance is usually based on the land use element of a community's comprehensive (master) plan.

The most commonly used types of airport zoning are height and hazard zoning, noise impact zoning, exclusive zoning, floating zones, and performance standards. They are defined as follows:

- Height and hazard zoning: regulations designed to protect runway approaches from the hazards of high objects or structures;
- Noise impact zoning: districts established in areas with high levels of aircraft noise with the purpose of directing uses compatible with different noise levels;
- Exclusive zoning: districts permitting a singular type of use;
- Floating zones: an unmapped zone district where all the zone requirements are contained in the ordinance and the zone is fixed on the map only when the application for development is approved and certain conditions are met (*6*); and
- Performance standards: a set of criteria relating to nuisance elements that a particular use may not exceed.

Zoning as a means of ensuring noise compatibility is not perfect. For example, zoning is not retroactive. Incompatible land uses that predate zoning are usually permitted to remain. However, they are designated "nonconforming" until the use changes voluntarily. In some states, an amortization period is permitted in which the use must be made conforming.

Airports may extend into more than one political jurisdiction. The zoning within the different jurisdictions may conflict and must be coordinated to achieve desired objectives.

Finally, local politics have an important influence on zoning. Citizen opposition may force an airport to be zoned as a nonconforming use, requiring an expensive and time-consuming application procedure for airport expansion.

A governing body is not bound by prior zoning plans, and frequent changes, often in response to political pressure, can be detrimental to effective long-term planning for the airport operator. A locality may also want a larger tax base or more population growth, which may not be consistent with the need to preserve land around airports for other than residential purposes.

The effectiveness of zoning to regulate land uses in the airport vicinity is still debated. On one hand zoning is seen as "the most widely used and potentially the most effective land use regulatory mechanism available" (*7*), whereas zoning is also criticized as "overrated" in its effectiveness (*8*). Zoning, though, will probably continue to be the dominant land use control technique despite its shortfalls.

Master Plan

An adopted master plan is a long-range plan designed to guide the growth and development of a region or community. The

TABLE 1 AIRPORT NOISE CONTROL STRATEGIES (*1*)

Rank Order	Land Use Control	Airport Communities Number	Airport Communities Percent
1	Zoning	133	33.0
2	Comprehensive Plan	108	26.8
3	Land Acquisition	77	19.1
4	Avigation Easement	49	12.1
5	Noise Disclosure	34	8.4
6	Environmental Impact Review	33	8.2
7	Building Code	32	7.9
8	Capital Improvements	18	4.4
9	Sound Insulation	18	4.4
10	Development Rights	10	2.4
11	Site Design	9	2.2
12	Land Banking	7	1.7

Sample Size: 402 airports

master plan provides analysis of trends, recommendations, and implementation strategies for such areas as housing, land use, population, and transportation. The master plan, specifically the land use element, is frequently the basis of the zoning ordinance. In most cases, the master plan is the policy document guiding land use, whereas zoning is the means of implementing the policy. In some cases, the master plan may be the sole document guiding land use.

The master plan can be an effective method to ensure long-term development and compatible uses in the airport vicinity. As mentioned, the master plan is often the basis for zoning regulations. The master plan is the opportunity for a governmental entity to make a policy statement recognizing community assets, such as airports, and suggesting techniques to preserve and enhance them.

Land Acquisition

Land acquisition of adversely noise-affected property involves fee-simple acquisition of lands to achieve noise compatibility. This can be done by either an airport proprietor or local government. Land may also be acquired through condemnation proceedings; however, this option exists only for public agencies with the power of eminent domain.

An advantage of land acquisition is that the airport proprietor or governmental entity has direct control over the land and can restrict it to compatible uses. Land under control of a public entity may be resold with covenants or easements restricting development to compatible uses. Redevelopment of land with compatible uses is one strategy to maximize that use of property and to keep property on the tax roles (*9*). Though land acquisition may be an effective way to achieve noise compatibility, it is the most expensive, especially where property is already developed.

Easements

An easement is a grant of one or more property rights by a property owner to another entity, public or private. Purchasing a property easement for noise compatibility purposes involves purchasing the right to fly (and make noise) over a property [known as an avigation (aviation navigation) easement] and the right to develop noncompatible land uses. An avigation easement permits the trespass of aircraft and aircraft noise within given time parameters and for a set fee (*10*).

The major advantage of easements is their permanence; title is held unless sold or released by the owner. This contrasts with zoning, which can be more easily changed by action of the governing body. Easement purchase is also usually not as expensive as fee-simple purchase of property. In addition, easement purchase, rather than outright purchase, permits land to remain on the tax roles and available for compatible development (*11*).

Development Rights (Purchase and Transfer)

A development right is the right to develop or build on a property. Transfer of development rights (TDR) involves the removal of this right (usually in the form of development density, such as dwelling units per acre) from land in one zone district to land in another district.

Purchase of development rights (PDR), or conservation easements, involves outright purchase of the right to build on a property. Because the development restriction is on the deed, PDR gives long-term assurances that land uses will remain compatible. In addition, the owner receives compensation for restrictions imposed on his property. Attempting to accomplish the same objective using zoning could constitute a taking of property (*12*).

TDR and PDR are relatively new concepts in land use planning. They have been used primarily in farmland preservation and historic preservation in urban areas.

Land Banking

Land banking is a process by which a public agency purchases land for future use and development to implement a public land use policy (*1*).

Land banking, when coupled with a long-range master plan, can be an effective mechanism with which to preserve land for airport expansion or to maintain or create a noise compatibility buffer. However, land banking is expensive, especially if development exists on lands surrounding an airport. The constitutionality of land banking varies from state to state. The courts have deemed pursuit of a land-banking program without a clear public purpose an illegal taking of property.

Are Available Land Use Controls Effective?

Six widely used land use controls are described here: zoning, comprehensive plan, land acquisition, easement purchase, development rights (purchase and transfer), and land banking. Each technique has its particular advantages and disadvantages. The availability of a particular land use control to a governmental entity varies from state to state and depends on enabling legislation.

Land use controls do not function in a vacuum. Their effectiveness in a given situation depends on a number of factors. First, there are legal considerations and restrictions that may limit their applicability. Second, land use controls function within a multijurisdictional governmental framework. Finally, the effectiveness of land use controls and airport land use compatibility planning depends on political considerations. The following sections examine the legal restrictions on land use planning, the responsibility of government, and the governmental framework in which land use compatibility planning functions.

LEGAL PRECEDENTS

The responsibility for controlling aircraft noise rests with the airport owner and the government. Both have legal rights and responsibilities related to airport land use compatibility planning. This section briefly explores these legal issues.

The airport owner has rights to use his property in a manner that does not adversely affect adjacent landowners. The government has the responsibility to protect the health, safety, and welfare of the population from the adverse impacts of airports.

Whereas the airport proprietor has the right to use his property, he is also responsible for impacts on surrounding property owners that may be deemed a nuisance or a taking. The taking issue was addressed in *Griggs v. Allegheny County, Pennsylvania* 369 U.S. 85 (1962). In the *Griggs* case it was ruled that the flight path of the airport created a direct and immediate interference with the enjoyment and use of the lands of surrounding property owners and thus a taking had occurred (*13*). An airport owner that is a governmental agency may use the eminent domain power to take a property for just compensation to create a noise compatibility "buffer." Eminent domain is the power to take private property for public use by a governmental entity for just compensation (*14*).

Airport owners that are not governmental entities do not have the power of eminent domain and have limited options. In fact, the airport owners may be limited to seeking zoning support from their governing zoning agency to ensure land use compatibility and continued economic viability.

Thus, private airport owners have almost no options to influence land use decisions in the airport environs except through the political process and rely heavily on the effectiveness of government regulation.

GOVERNMENT ROLES AND RESPONSIBILITIES IN AIRPORT LAND USE COMPATIBILITY PLANNING

The roles and responsibilities of governmental units in airport land land use planning are important components of the framework in which land use planning policy decisions are made. The effectiveness of land use compatibility planning depends on the preparation and implementation of plans at a given level of government. However, the more political entities involved, the more complicated and less effective the coordination process becomes. The following is a review of the roles of each governmental unit in airport planning.

Federal

The role of the federal government, namely FAA, in airport planning is generally limited to providing funding for airport improvements, land purchase, and technical assistance to state and local governments. The most direct role of the FAA in noise compatibility planning is defined within FAR Part 150. FAR Part 150 prescribes procedures, standards, and methodology by which airport noise compatibility programs and aircraft noise exposure maps are governed. Part 150

1. Prescribes systems for measuring noise in the airport environs,
2. Prescribes systems for determining exposure of individuals to noise, and
3. Identifies the compatibility of land uses at various sound levels.

FAR Part 150 was created in response to a demand for better coordination of noise compatibility planning, the development of noise exposure maps, and guidance relative to the compatibility or incompatibility of various land uses, but the programs and systems for planning are voluntary.

The National Plan of Integrated Airport Systems (NPIAS) is the national airport system plan for the development of public use airports in the United States. The plan is prepared by the FAA every 2 years. The plan contains the type and estimated costs of "eligible airport development considered necessary to provide a safe, efficient and integrated system of public use airports to meet the needs of civil aviation" (*15*). Airports within the plan are classified as either commercial service airports, primary airports, or reliever airports.

State

Generally, state governments do not take an active role in airport land use compatibility planning and delegate the zoning and planning powers to local governments. The states are primarily involved in preparation of state airport system plans, provision of financial aid for airport development, and technical assistance.

Local

The land use planning power is generally in the hands of a municipal or county government, although enabling legislation varies from state to state. The specific powers of local governments to plan and zone also vary from state to state.

One other important variable has not thus far been mentioned: politics. Land use controls do not implement themselves; their effective implementation is the responsibility of government, and this is driven by politics, or in more academic terms, public policy. How does airport noise compatibility function given political realities? Airport noise compatibility planning in New Jersey is used as a case study and is examined next.

CASE STUDY: NEW JERSEY

A number of effective land use strategies and techniques are available for land use compatibility in the airport environs. A case study is used to assess the effectiveness of available land use techniques in a political and practical framework.

New Jersey was chosen for the case study for several reasons:

- New Jersey is a suburbanizing state with incompatible development encroaching on many airports.
- The state has a network of public use general aviation airports with many serving as relievers of the major air carrier airports in the New York and Philadelphia metropolitan areas.
- Land use planning powers are largely delegated to municipal governments.

New Jersey is the most densely populated state in the nation, with 1,042 persons per square mile compared with a national average of about 63 persons per square mile (*16*). New Jersey is part of two large metropolitan areas, New York and Philadelphia. Yet, New Jersey still has areas with low

population densities that are just now beginning to experience the pressures of suburbanization.

Airport Land Use Compatibility Planning in New Jersey

Airport land use compatibility planning in New Jersey functions under a system of airports operating within state and local regulations and policies.

Airport Network

The network of airports in New Jersey consists of 52 licensed public use airports (excluding three public use seaplane bases) (Figure 1). Five of the airports (Newark International, Atlantic City International, Atlantic City-Bader, Mercer County, and Cape May County) are served by scheduled air carriers. The remaining 47 are general aviation airports, of which more than 70 percent are privately owned, public use airports. The state does not own any airports (*17*).

FIGURE 1 New Jersey public use land airports (*17*).

The number of public use airports in New Jersey has been declining at a significant rate in the past 25 years, as indicated in Table 2. A total of 23 public use airports, or almost one-third of the public use airports in New Jersey, closed between 1965 and 1990. As indicated in Table 2, there was a sharp increase in the number of airport closings between 1985 and 1990. The majority of the airport closings were in the rapidly suburbanizing counties in northern and southern New Jersey, namely, Atlantic, Burlington, Gloucester, Hunterdon, Morris, and Monmouth.

The loss of general aviation airfields in suburbanizing areas is not limited to New Jersey, although New Jersey, as the most densely populated state in the nation, is feeling the effects more than less-populated states (*23*). Suburban Connecticut and the Washington, D.C., suburbs are other areas where this trend has been identified (*24*, *25*).

Meanwhile, general aviation operations in New Jersey are increasing or are projected to increase as the major metropolitan airports of New York and Philadelphia experience continued congestion. The New Jersey Department of Transportation projects that at least 13 airports will be near or above capacity by 2010 (*26*).

State Aviation Regulations and Policies

Air Safety and Hazardous Zoning Act The Air Safety and Hazardous Zoning Act of 1983 is the most significant piece of state zoning legislation that affects New Jersey airports.

In 1985, regulations of the act became effective that established "minimum standards for the control of airport and aeronautical hazards, and standards for land use adjacent to airports" (*27*). The regulations apply to nearly all state-licensed public use airports, and municipalities are required to adopt the rules into their zoning ordinances and master plans.

Originally, the regulations stipulated that airport hazard areas composed of two different subzones be delineated around airports. Within the hazard areas the only land uses permitted were industrial, commercial, open space, agricultural, transportation, and airport uses. Expressly prohibited uses included residential dwelling units, planned unit developments and multifamily dwellings, hospitals, schools, above-ground flammable or toxic gas storage, landfills or other uses that attract birds, and above-grade major utility lines.

The act was amended in 1989. A new zone known as the "clear zone" was created within the hazard zone (Figure 2). The revised regulations permitted low-density residential development (with a minimum lot size of 3 acres) within the hazard zone but outside the clear zone. The revised regulations also classified all preexisting residential structures as conforming land uses, where they had previously been classified by the act as nonconforming uses. The act also specifies that airports must be classified as permitted uses in local zoning ordinances.

The primary purpose of the Air Safety and Hazardous Zoning Act is hazard zoning, but the act has the secondary benefit of directing land uses that are noise compatible. However, the 1989 amendments to the act weaken its effectiveness by allowing residential uses near airport runways.

State Aviation System Plan New Jersey recently prepared the first comprehensive reexamination of the State Aviation System Plan since 1975. The new plan recognizes the importance of smaller airports as part of the overall system. The plan notes that presently "except for a few airports which are part of the federal system, each New Jersey airport is a self-contained unit and little thought or action had been given to serving as a system to meet the growing needs of the State" (*26*).

The plan establishes a hierarchy of airports by level of importance. Thirty-one airfields were identified as New Jer-

TABLE 2 PUBLIC USE AIRPORTS IN NEW JERSEY, 1965–1990* (*18–22*)

County	1965	1975	1980	1985	1990	Net Loss 1965-90
Atlantic	5	5	5	4	3	-2
Bergen	1	1	1	1	1	--
Burlington	8	6	5	6	5	-3
Camden	1	1	1	1	1	--
Cape May	3	3	3	3	3	--
Cumberland	7	7	7	6	6	-1
Essex	2	2	2	2	2	--
Gloucester	6	6	6	7	4	-2
Hudson	--	--	--	--	--	--
Hunterdon	5	4	4	4	3	-2
Mercer	3	3	3	3	3	--
Middlesex	4	2	1	1	1	-3
Monmouth	5	4	3	3	2	-3
Morris	5	5	4	4	2	-3
Ocean	4	4	4	4	4	--
Passaic	2	1	1	1	1	-1
Salem	1	1	1	1	1	--
Somerset	4	4	4	3	3	-1
Sussex	6	6	4	4	4	-2
Union	1	1	1	1	1	--
Warren	2	2	2	2	2	--
TOTAL	75	68	62	61	52	-23

NOTES:
* Excludes public-use seaplane bases.
--: none

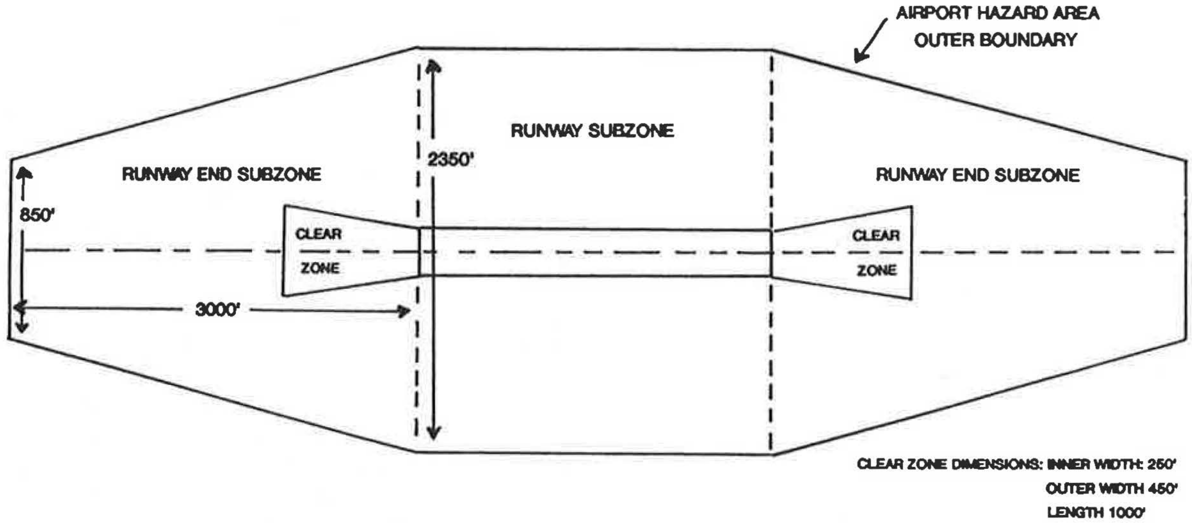

FIGURE 2 Runway end subzones and clear zones of an airport hazard area (*27*).

sey's "most important" airports, known as the core system. Of the 31 airports, 17 are privately owned. The plan recognizes that there is a significant threat that additional privately owned airports will be lost. It notes that "as a last resort, purchase should be considered to ensure the survival of this critical element of the aviation system" (*26*). However, the state has estimated the cost of purchasing all 17 "threatened" airports at almost $100 million. Given fiscal realities, public purchase of general aviation airports in New Jersey is unlikely.

Planning for Noise Compatibility in New Jersey

The Air Safety and Hazardous Zoning Act was not specifically developed to address aircraft noise impact. The State Aviation System Plan is a guidance document developed by the New Jersey Department of Transportation and has no legal power. Local governments in New Jersey are still primarily responsible for implementing airport land use compatibility strategies and techniques. Present state legislation does not require local governments to plan for noise compatibility or consider the future expansion of an airport. Thus, there are instances in which municipalities permit local pressures and issues to take precedence over land use compatibility planning. Other municipalities actively pursue land use compatibility strategies. The following cases illustrate this point.

Whereas there are a number of effective land use strategies to mitigate aircraft noise impacts, it is the responsibility of a municipality in New Jersey to pursue these policies. A local government may use its planning and zoning powers to negatively affect the economic viability of an airport.

Princeton Airport is a general aviation airport in a rapidly developing area of central New Jersey. In 1990, the township council imposed a number of restrictions on the airport, including land use controls, due to noise complaints from residents of an area just west of the airport (*28*). The township rezoned lands west of the airport from nonresidential to single family residential development on 1-acre lots (*29*). The township rezoned the airport from a permitted use to a conditional use, requiring the airport proprietor to meet more stringent regulations and file additional submissions when seeking expansion or development. This, in addition to operating restrictions, caused the airport owner to declare that the economic viability and future of the airport were threatened by local actions (*29*).

Local governments in New Jersey, using planning and zoning powers, can significantly affect the economic viability of a general aviation airport. However, progressive land use compatibility planning can also enhance the economic viability of an airport while ensuring compatible uses in the airport community environment. This is the case in Alexandria Township, New Jersey, which is located in western New Jersey and is largely rural.

Municipal zoning regulations in Alexandria Township permit noise-compatible development in the airport vicinity while permitting uses that enhance an airport's economic viability. There are two general aviation airports in Alexandria Township, Sky Manor Airport and Alexandria Airport.

In 1987 the township enacted zoning in compliance with the Air Safety and Hazardous Zoning Act (*30*). Three types of zones were established surrounding both airports (both within and outside the hazard zone): Airport Business-1, Airport Business-2, and Airport Residential Airpark. The purpose of each zone is to encourage uses "related to or compatible with or convenient for airport operations" (*30*). The business zones permit aviation, agricultural, commercial, business, recreational, and institutional uses, whereas the residential airpark zone permits these uses in addition to a residential airpark. A residential airpark is another term for an airport residential subdivision.

In the Alexandria Township case, the municipality recognized the airport as an asset and used its planning powers to zone for land use compatibility.

In summary, New Jersey municipalities have primarily relied on master plans and zoning to accomplish land use compatibility planning. Until 1985, municipalities had the sole responsibility to plan for airport land use compatibility. With the adoption of the Air Safety and Hazardous Zoning Act,

the state took a more active role in height and hazard zoning. However, municipalities still have significant planning and land use powers that can directly affect the economic viability and thus the future of airports, as indicated in Montgomery and Alexandria townships.

The primary planning tools for land use compatibility planning available to and used by New Jersey municipalities are master plans and zoning. There are presently no active land banking programs for airports in the state. Some airports purchase easements or acquire land, mostly to comply with FAR Part 77 regulations concerning obstacle clearance. There is presently no statewide legislation to permit TDR in New Jersey, although a pilot program is active in Burlington County. TDR could, however, be a useful technique for New Jersey planners. TDR could be used to transfer development rights from noise-affected areas or clear zones to less adversely affected areas.

One result of the ineffectiveness of local control of airport land use compatibility planning is that pilots using New Jersey's airports have suffered. Besides having fewer airports to choose from, pilots must contend with an array of published noise abatement operating restrictions at more than one-third of all airports (*17*). These operating restrictions include preferential runway use and specialized approach and departure procedures.

Lessons from New Jersey

General aviation airports in many parts of the United States are being "squeezed" by encroaching incompatible development. Land use compatibility planning is primarily a local function. Can the public welfare be adequately protected from the adverse effects of aircraft noise while a cohesive system of airports is maintained? Land use compatibility planning is the key to ensuring this relationship. Indications are, however, that local control of a function that protects a regional and national asset is not working successfully as the number of general aviation airports continues to decline.

The factors hampering effective local control of incompatible land uses are largely political:

- Local governments and the public do not see the cause and effect of poor land use compatibility planning around airports.
- Many communities do not recognize the airport as an economic asset.
- General aviation airports in particular are not recognized as an important component of the state or national system of airports.
- A local governments's desire for ratables often takes precedence over good land use planning.

The results of ineffective land use planning in the airport environs have been felt in New Jersey and will be felt in other states. The effect is the continued loss of general aviation airfields, which will undermine FAA's goal of maintaining an "efficient and integrated system of public use airports to meet the needs of civil aviation" (*15*). More areas will be cut off from the national air transportation system.

STRATEGIES AND POLICIES FOR IMPROVING LAND USE COMPATIBILITY PLANNING

General aviation airports today face threats to their survival from several fronts. Many airports are threatened with nuisance litigation from existing airport neighbors while facing the prospect of additional noise complaints from encroaching suburban sprawl. What options exist to protect the general aviation airport system while permitting noise-compatible development in the airport environs? What strategies could be implemented? Does the role of government in the land use planning process need to change? These issues are explored and strategies offered in the following.

To plan the airport environs in a noise-compatible manner will require a multifaceted approach. Recommendations include (*a*) enactment of legislation establishing the right of an airport to exist as a nuisance, a concept similar to "right-to-farm" laws protecting agricultural uses in many states; (*b*) involvement of state governments more directly in noise-compatibility planning by requiring zoning controls, such as acoustic clustering, to ensure compatible development of noise-sensitive residential uses; and (*c*) greater involvement of the federal government in providing funding for noise compatibility planning and requiring mandatory FAR Part 150–type planning for core general aviation airports, such as those identified in the NPIAS.

The "Right To Fly"

The airport owner is responsible for the impacts of aircraft noise on surrounding property owners. The adverse impact of aircraft noise that infringes on the use and enjoyment of a person's property may be deemed a nuisance. The encroachment of suburbanization in the vicinity of many airports makes it increasingly difficult for airports to function and operate due to incompatibility with and opposition from new suburban neighbors.

The situation is not unique to airport uses. Farmers, too, have experienced the negative impacts of suburbanization. However, in many states, the preservation of farmland and the protection of farming operations have been greatly enhanced by the enactment of right-to-farm legislation. Right-to-farm laws are an attempt to protect farmers from liability claims and nuisance suits where suburban sprawl has encroached on farming operations. This concept has application parallel to the protection of general aviation airports. A parallel to the right to farm, the right to fly, as it could be known, can become the basis by which airports are recognized as regional and national assets. The legislation would also shift some of the burden of protecting the public from aircraft noise impacts from the airport owner (who has no direct control over off-airport impacts) to local governments and surrounding property owners. The shift may have the secondary effect of encouraging the development of noise-compatibility planning and zoning on the municipal level and more noise-sensitive site planning from property developers.

Right-to-fly legislation would provide airports with a basic "right to exist." Under New Jersey's Right to Farm Act, municipal regulation of farms is preempted and a rebuttable

presumption is created whereby normal agricultural operations are not public or private nuisances (*31*). Similar legislation should be considered for airports. Some of the other provisions of right-to-farm ordinances that could also be applicable to a right-to-fly ordinance are

- A declaration that normal airport operations do not constitute a nuisance if begun before a complaining neighbor moved in,
- A notice provision requiring sellers and real estate agents to inform prospective home buyers that an airport is close by and that noise may accompany normal operations, and
- The creation of an arbitration committee to mediate disputes between an airport owner and residents (*32*).

Acoustic Clustering

Acoustic clustering is a planning concept that could be used as a zoning technique to permit residential development designed in a noise-compatible manner. Cluster development refers to a form of design that concentrates buildings in specific areas on the site to allow the remaining area to be used for open space, preservation of environmentally sensitive lands, or common recreation facilities (*6*). Cluster residential subdivisions have been successfully designed and built to achieve the aforementioned goals.

Acoustic clustering refers to the site-specific clustering of residences away from adversely noise-affected areas. The initial step in the development of a cluster plan would be a noise impact analysis that would result in the establishment of noise contours. Established noise assessment criteria such as those in FAR 150 could be used to establish a noise limit [e.g., 65 dB(A)] within which residential development would be prohibited. Outside of the noise limit contour, clustered residential development would be permitted, preferably as far from the noise impact zone as practical.

Whereas acoustic clustering offers the opportunity to plan residential uses in a noise-compatible manner, the technique also offers benefits to a developer or property owner. For example, clustering maintains the gross density of a tract, although the net density in developed areas is no higher than in a standard "x" acre lot subdivision. The developer also benefits by clustering through reduced infrastructure costs resulting from shorter streets and utility lines.

TDR can be used in connection with acoustic clustering of residences in cases where entire tracts of land lie within a noise-affected zone. Using TDR, development rights from properties within a noise zone could be transferred and clustered in areas outside noise-affected areas. This would preserve the development rights of property owners within noise impact zones, thereby addressing the taking issue.

Acoustic clustering in the airport environs has potential for applicability in New Jersey as an extension of the Air Safety and Hazardous Zoning Act. The act could include a provision mandating acoustic clustering and using, for example, FAR Part 150 as a guide.

Right-to-fly legislation could be a critical element in recognizing airports as an important local, regional, and national asset. Acoustic clustering is a zoning control that would accommodate residential development in the airport vicinity in a noise-compatible manner. The former would involve legislation on the state level; the latter would be a local zoning and site plan concern, although it could be mandated by the state government. The federal government also has a larger role to play in airport land use compatibility planning.

FAR Part 150 provisions should be made mandatory for airports identified in the NPIAS and those identified as core airports in state airport master plans. FAR Part 150 contains the elements necessary to develop a comprehensive noise compatibility plan. However, the Part 150 definition of airports eligible for noise compatibility planning funds should be expanded to all privately owned, public use airfields, not just privately owned reliever airports. FAA must also develop noise standards and controls for general aviation aircraft.

Mandatory FAR Part 150 planning would better ensure land use compatibility between the airport and its environs. A higher level of government should play more than an advisory role in ensuring the protection and preservation of an important national asset. Only in this way will FAA be able to carry out its responsibility of maintaining the nation's airport system to meet projected traffic demands in the 1990s and beyond (*33*).

CONCLUSIONS

This research has examined the characteristics, advantages, and disadvantages of land use controls to mitigate aircraft noise. In addition, the analysis focused on how effectively land use controls function given legal limitations, the roles and responsibilities of various levels of government, and political and practical realities using New Jersey as a case study. Particular attention was paid to public use general aviation airports, which play an important role in the national system of airports.

There is no one land use planning policy or control to ensure that noise-compatible planning in the airport environs will be totally effective in mitigating the impacts of aircraft noise. A commitment is required at various levels of government to establish general aviation airports as a regional and national asset to be preserved. The protection offered by right-to-fly laws, borrowed from analogous regulations in the agricultural sector, in addition to creative use of available zoning and other land use controls (specifically acoustic clustering) can effectively lessen the impacts of aircraft noise while protecting the economic viability of general aviation airports.

Given the increased reliance of Americans on air transportation, it is imperative that the preservation of a functioning and integrated network of airports be maintained and recognized as an important national and local asset. Airport land use compatibility planning is an important technique to preserve a functioning and economically viable network of general aviation airports as well as to ensure the development and maintenance of compatible land uses that are not adversely affected by aircraft noise. It may be appropriate for the federal government and state governments to take an increased role in land use planning around America's airports.

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Human Factors in 1988 General Aviation Accidents

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Variations in human behavior and performance are responsible for a large percentage of aviation accidents. Selected human factors that contribute to general aviation accidents are identified and classified and their frequency of occurrence is determined with the intent of providing means to reduce the accident rate. The purpose of human factors research in aviation is twofold. First, human limitations and capabilities are defined in terms of interaction with people and with mechanical, technical, and procedural systems. This definition spells out what a human can and cannot do; thus the limits of the human performance envelope are established. Second, knowledge concerning the envelope can be used to provide direction for modification of flight training, system design, and aircraft design. A checklist based on a systems approach to understanding human behavior in aircraft accidents was used to identify human factors that contributed to general aviation accidents. Accidents studied were selected randomly from all 1988 National Transportation Safety Board (NTSB) accident reports. Some types of human factors were readily identifiable from NTSB reports. Other factors were not identified directly by NTSB; it was difficult to detect their influence from the body of the reports. Although use of the modified checklist identified human factors as contributing to 90 percent of the accidents studied, it is likely that some contributing human factors were not detected, and that the actual percentage is higher. The high incidence of human factors contributing to general aviation accidents points out a need for increased or modified training in several areas. Incorporation of a human factors checklist into the NTSB accident investigation procedure would be a step toward identification of all factors contributing to aviation accidents. This information could then be used to modify pilot training and aviation systems development to reduce the accident rate.

Variations in human behavior and performance are responsible for a large percentage of aviation accidents. In this study 1988 general aviation (GA) accident reports were analyzed to identify human factors and determine how often they occur in accidents. The purpose of aviation human factors research is to provide a means to reduce the number of aviation accidents. The identification of which human factors contributed to GA accidents was particular concern.

NATURE OF GA INDUSTRY AND PILOT FLYING TASKS

GA safety is of concern because GA is vital to the American economy. GA is much more than private owners flying for pleasure; it is important to agriculture and business (approximately 35 percent of flying is for business purposes). Corporate flying and personal flights are other aspects of GA. It is also important in flight instruction. GA is nearly the only source of pilot training for the future. The military used to be a significant source of pilots for airlines, but now longer terms are required and forces are decreasing.

More airports and communities are served by GA than by air carriers. The U.S. business community relies on GA, which is the only means of air travel available to many small communities (*1*). In 1988 approximately 96 percent of U.S. airports and 89 percent of U.S. public use airports were served exclusively by GA. Air carriers served only 4 percent of the nation's 17,327 airports. In 1988 there were 210,000 GA aircraft, 98 percent of the active U.S. fleet, and 96 percent of certificated pilots were GA.

GA pilots flew 33.6 million hr in 1988, compared with 13 million hr flown by air carriers (*2*). "The number of hours flown by GA aircraft is expected to increase . . . to 36.8 million by fiscal year 1988" (*3*). The majority of hours flown by the U.S. GA fleet in 1988 were in piston engine aircraft, with 26.2 million hr flown. Turboprop aircraft flew 2.4 million hr, jets flew 1.7 million hr, and rotary wing and other aircraft accounted for 3.3 million fight hr (*4*).

GA pilots perform a wide variety of in-flight tasks, including primary control, machine management, navigation, communication, and compliance with air traffic control. These tasks are defined by hardware and required procedures. Pilots must interpret information from visual cues, radio, flight controls, instruments, printed materials, and their own memories. Integration of all this information is complicated because it requires shifting between an understanding of aerodynamic principles and how the aircraft responds to control movements, and interpretation of information provided by avionic systems and pilot sensory systems reacting to the real-world environment.

Campbell (*5*) maintains that skill and knowledge are necessary ingredients of a good pilot, but that good judgment, which leads to correct decision making, is essential. Good judgment is more difficult to learn than flying skills. According to Ritchie (*6*), a professional level of flying skills can be achieved in approximately 1,000 hr of flying time, if accomplished within 2 or 3 years. This is seldom a pattern followed by GA pilots, who are often part-timers, limited in the rate at which they can develop and maintain their skills. Ritchie says, "Some GA pilot tasks, particularly flying single-pilot instrument flight rules (IFR), are among the most difficult of flying tasks. Despite this, GA pilots must live and operate in a system which is designed for somebody else" (*6*, p; 587). The system, which consists of airspace structure, regulations, air traffic control, aircraft control, and instrument interpre-

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tation, was designed for professional pilots operating air carrier aircraft. The GA pilot must fit into this system, and it can be an uncomfortable fit.

OVERALL GENERAL AVIATION ACCIDENT PICTURE

Statistics from the National Transportation Safety Board (NTSB) (*7*) and FAA (*4*) indicate that in 1988 the accident rate for GA was approximately 10 times that for air carriers.

The GA accident rate is decreasing. In 1979 there was one accident in about every 10,000 flight hr. In 1989 that had decreased to one accident in almost 14,000 flight hr. Some types of flying within general aviation are more hazardous than others. NTSB (*7*) offers a comparison of risk for different types of flying (see Table 1).

The number of GA accidents continues to decrease even as hours flown increases. Though the numbers are moving in a favorable direction (*8*), it should not be overlooked that 805 people were killed in GA accidents in 1988. In addition to the loss of life, the cost due to legal liability are enormous and affect all pilots, airframe manufacturers, and suppliers, including engine and avionics firms (*9*). According to the General Aviation Manufacturers Association (GAMA), "unfair, exorbitant product liability costs have had a devastating effect on U.S. general aviation manufacturers, consumers and service organizations. Claims paid by the industry soared from $24 million to over $210 million the past decade" (*10*). Liability costs have made new piston airplanes too expensive for most customers and have shaped an industry in which almost no single-engine piston training aircraft are being built.

NTSB is usually accurate in its description of what happened in an accident but does not always explain why the accident happened (*11*). Accident investigation is difficult because human memory is fallible and adversely affected by trauma, and eyewitness accounts can give a distorted view of what happened (*12*). Identifying the complete train of events leading up to an accident is problematic, especially in GA accidents, because voice cockpit recorders are not required. The threat of litigation can bring about suppression of essential facts (*9*).

THE HUMAN COMPONENT IN GENERAL AVIATION ACCIDENTS

Purpose of Human Factors Research

Engen (*13*) said, "We spent over fifty years on the hardware, which is now pretty reliable. Now it's time to work with the

TABLE 1 1988 ACCIDENTS PER 100,000 AIRCRAFT hr FLOWN (*7*)

Type of Flying	Total Accidents	Fatal Accidents		Fatalities Aboard
	(#)	(#)	(%)	(#)
personal	1575	297	18.8	558
business	180	46	25.6	92
corporate	19	4	21.1	7
aerial application	175	11	6.3	10
instructional	337	30	8.9	56
ALL AIRCRAFT	2459	431	17.5	796

people." Human factors research is one way of addressing the people side of the accident equation.

One point of agreement among agencies investing or reporting on aviation accidents is that the pilot is responsible for a large percentage of these accidents. According to *The National Plan for Aviation Human Factors* (*14*), "Human error has been identified as a causal factor in 66 percent of air carrier accidents, 79 percent of commuter fatal accidents and 88 percent of GA fatal accidents."

The term "human error" implies that pilots are at fault. It is broad and general, and implies failure. Aircraft manufacturers set up weight and balance parameters for the loading of an aircraft (how fuel and cargo are to be loaded and where passengers sit). Human factors research identifies and sets out parameters for the human performance envelope. It is not appropriate to imply neglect or fault on the part of the pilot. Accidents occur as the result of human variables, some of which are inexperience, inattention, oversight, control reversal, apprehension, and distraction. They are not caused by one single factor. These accidents are caused in part by a mismatch between the human performance envelope and aircraft/aviation systems. Human factors were identified in 90 percent of the accidents studied during this research. That does not mean that human factors caused these accidents, but they were identified as contributing to the accidents.

Nance (*15*) clarifies the problem faced by researchers attempting to discover the causes of aviation accidents:

> Pilots and controllers and maintenance people err and cause accidents because they are human, and we imperfect humans are all prone to make such mistakes. Discovering that a human error—pilot error or otherwise—has occurred is merely the starting point. To have any hope of preventing such an error from causing such an accident again and again, the *reason* the error was made in the first place must be discovered, and the underlying cause of that human failure must be revealed and addressed in future operations.

Human factors research can provide a means to reveal these reasons and reduce the number of aviation accidents. This study was designed to identify which human factors contribute to GA accidents. Aviation agencies, institutions, and manufacturers may be able to use this information to modify aviation education objectives and methods, aircraft design, and design of procedural systems such as communication with air traffic control.

Pilot Error

Accidents in complex man-machine systems such as GA aircraft are typically caused by a progression of events that occur in an unforseen manner or sequence. "A malevolent deity does not strike down aircraft or hurl them to the ground with a mighty blow. Accidents require the coordinated occurrence of several flawed decisions, performance breakdown or oversights" (*16*). It is wrong to assume that a pilot involved in an accident is ignorant, careless, or lacking in knowledge. Pilots are often intelligent and highly skilled. Lack of technical or procedural knowledge is rarely the sole cause of an aviation accident (*17*).

Gay (*18*) explains that behavior is influenced by the context in which it occurs, and analysis of the behavior demands

understanding of that context. Human beings have built-in physical and cognitive limitations that are not always taken into account when aircraft are designed and built. There are obvious limitations, such as limits of reach and ability to lift. Less obvious limitations include time lags in sensory perception systems and in neuromuscular response (*19*).

The human brain has greater memory capacity than the most powerful computers and the ability to correlate and use the stored data in creative ways. However, the brain is slower than its electronic counterparts, and it is "prone to some rather bizarre perceptual distortions. It can make us see things that don't exist, not see things that do exist, see stationary objects seem to move and conjure up associations that are totally inappropriate to the circumstances" (*17*).

Poor judgment, decision making, and risk-taking contribute to aviation accidents. A pilot may do something potentially dangerous many times before that behavior results in an accident. Pilots do not believe that they are taking chances when forming a bad habit; they simply do not believe that an accident will happen to them. Bad habits are reinforced when a pilot makes a mistake or does something wrong and the action does not result in an accident. A poorly trained pilot, or one who has personality traits incompatible with aviation tasks, such as aggression or low self-esteem, can likewise continue to fly for a period of time without negative consequences (*20*).

Accident Prevention Strategies

The findings of this study substantiate a statement by Hansen (*17*) in which he proposes that in order to prevent GA accidents, pilots must improve their self-knowledge; they must gain insight into their own thought processes, behavior, and personalities. Through that increased knowledge they can then improve their performance. A Royal Canadian Air Force axiom makes a good point about judgment: "A superior pilot is one who stays out of trouble by using superior judgment to avoid situations that might damn well require the use of his superior skill" (*21*). The results of this study underscore the idea that good judgment and decision making skills are critical to safe flight. Over and over when accidents happen,"the pilot is brought down not by a failure of knowledge or skill, but of judgment" (*21*).

Most aviation training is directed toward the development of psychomotor skills and to the absorption of the large body of technical knowledge necessary for safe flight. An additional dimension necessry in pilot training is decision making and pilot judgment. According to Jensen, it may not be possible to change a pilot's personality, or even to screen potential pilots for personalities incompatible with safe flight, but attitudes can be changed (*21*). Judgment and decision-making skills can be taught.

According to Melton (*22*), accident investigation has not been effective in the prevention of human factors accidents. Factors precipitating aviation accidents have not changed over the years. Increased spending or stricter regulations will not necessarily reduce accidents (*17*). In an environment where total system management is feasible, such as the military, it is possible to reduce accidents. Civilians, however, are less likely to respond to regulation because training and enforcement of regulations is not as rigorous as it is in the military. Education and peer pressure are the most practical methods of change available (*22*).

Included in the objectives and recommendations in *The National Plan for Aviation Human Factors* are the following (*14*):

- To encourage the improvement of basic scientific knowledge and facilitate understanding of the factors, both positive and negative, that significantly influence human performance in aviation;
- To develop better techniques for the assessment of human performance in the aviation system;
- To develop enhanced methods of training and selection for aviation system personnel; and
- To develop formal procedures for evaluating human factors issues as part of every major system development and acquisition, modeled after the U.S. Army program, MANPRINT, and "Total Quality Management" programs in government and industry.

The information provided by the modified checklist (described later) can help achieve these objectives. Pilots need to be "confident of their abilities but know their limitations and [be] able to recognize and admit that they always have room for improvement" (*22*). Education is one way to reach this goal. The incorporation of a human factors checklist into NTSB procedure would increase the information available in accident reports and give flight teachers and instructors valuable tools to use in the education of safer aviation professionals.

RESEARCH PROBLEM STATEMENT AND STUDY DESIGN

The problem of this study was to identify human factors in 1988 GA accidents and to determine how often they contributed to the accidents. A checklist was used to categorize human factors as identified in NTSB 1988 GA accident reports. Answers were sought for the following research questions:

- In what percentage of 1988 GA accidents can human factors be identified from NTSB accident reports as contributing to the accident?
- NTSB assigns primary cause and contributing factors when reporting on an accident. Which of these are most frequently assigned by NTSB?
- How often does each of the human factors listed in the modified checklist contribute to GA accidents?

Fifty accidents were randomly selected from all GA accidents that occurred during calendar year 1988, and accident reports for them were obtained from NTSB. Human factors causes, NTSB primary causes and contributing factors, and demographics were recorded on an individual tally sheet for each accident. These data were summarized and evaluated.

RESEARCH METHOD—MODIFIED FEGGETTER CHECKLIST

The model for the checklist used was developed by Feggetter (*12*), a British accident investigator. Her checklist was based

on a systems approach to understanding human behavior in aircraft accidents. The purpose of the checklist was to assist investigators in identifying the more subtle human factors contributing to aviation accidents, while avoiding the use of the ambiguous description human error.

Feggetter (*12*) divided human factors in aviation accidents into three systems: cognitive, social, and situational. The cognitive system is concerned with how human beings acquire, store, manipulate, and use information, and is subdivided into three areas. Factors in the information-processing area include attention deficiencies, memory, judgment, decision making, and communication errors. Problems in the psychological/emotional area can arise from habits, motivation, fear or panic, complacency, and pilots' personalities. The third area involves skills and knowledge and includes problems due to training, experience, or currency deficiencies.

The social system includes pilots' perceptions of role and role conflicts and pressures from those with whom pilots interact. These include crew members, employers, family, air traffic control, and ground crew. Major personal events such as divorce or the death of a relative are also included in this system.

The situational system consists of physical, environmental, and ergonomic factors that stress the pilot. Physical condition, substance abuse, hypoxia, noise level, visual illusions, and cockpit organization are examples of factors in this system. Physical factors include lack of sleep, hunger, or substance abuse. Environmental conditions such as haze, fog, or visual illusions are included in this system. Ergonomics includes cockpit organization and placement of controls.

Feggetter's checklist (*12*) was modified by the author because NTSB accident reports in their final form were the sole source of information for this study, and there was no opportunity to use the more direct methods of interviews and questionnaires. Sensory perception factors were moved from the cognitive to the environmental area of the situational system, where they are designated as the acquisition phase preliminary to the thought process. Complacency was added as a factor in the psychological/emotional area of the cognitive system. In the situational system, the category of toxic fumes was added under environmental stress, and policy for dealing with emergencies was deleted from ergonomic stress. Seating and presentation of materials were combined into cockpit organization. The modified checklist is shown in Figure 1.

___ COGNITIVE SYSTEM
- ___ **Information Processing**
  - ___ attention/distraction
  - ___ memory/forgetfulness
  - ___ judgment/decision making
  - ___ communication
- ___ **Psychological/Emotional**
  - ___ false hypothesis
  - ___ habits
  - ___ motivation
  - ___ fear/panic
  - ___ complacency
  - ___ personality
- ___ **Skills/Knowledge**
  - ___ training
  - ___ experience
  - ___ currency

___ SOCIAL SYSTEM
- ___ **Social Pressure**
- ___ **Role**
- ___ **Life Stress**

___ SITUATIONAL SYSTEM
- ___ **Physical Stress**
  - ___ physical condition/body maintenance
  - ___ substance abuse
- ___ **Environmental Stress**
  - ___ altitude/hypoxia
  - ___ speed/motion
  - ___ visual illusions
  - ___ spatial disorientation
  - ___ lighting levels
  - ___ visibility/glare
  - ___ noise level
  - ___ vibration
  - ___ toxic fumes
- ___ **Ergonomic Stress**
  - ___ design of controls
  - ___ design of displays
  - ___ cockpit organization

FIGURE 1 Human factors checklist.

Validity

Copies of Feggetter's human factors checklist and the author's modified checklist were sent to five human factors experts for examination and comment. The five represented the DOT Transportation Safety Institute, Human Resources Research Division of the University of Kansas Medical Center, FAA, and human factors research.

One expert expressed concern that human factors are seldom recorded in NTSB reports. Because the purpose of this study was to identify human factors when they contributed to accidents, this reply led to speculation that results of the study might be negative. This was found to be partly true, and led the author to suggest changes in NTSB procedure.

Another expert suggested moving visual illusions and spatial disorientation from the environmental stress category to the cognitive system. This was not done, because the author believed that these factors deal with the pilot's perception of environment and did not directly involve the thought process. A further suggestion, that crew interaction be moved from the personality category in the cognitive system to the social system, was accepted. A third expert provided suggestions for expansion of the training category in the cognitive system; other experts made several small suggestions for change. These were all accepted.

The overall response to the modified checklist was positive and lent support to the validity of the checklist as a research tool.

Reliability

Three aviation professionals (herein referred to as reviewers) were chosen to perform a reliability test. One held a Ph.D. in educational psychology and research and was past Chief of Operational Hazards Analysis Division, U.S. Army Agency for Aviation Safety. The second was an aviation ground school and flight simulator instructor, and the third was a certified flight instructor.

Five accident reports were chosen at random from the 50 selected for the study. Photocopies of the reports were made for the reviewers, who were given a joint briefing by the author on the use of the checklist and on the meanings of the terms used in the checklist. Use of the checklist by these three aviation professionals achieved very similar results. It was concluded that the modified checklist is a suitably reliable instrument.

Overall, the reviewers identified a greater number of human factors than did the author. The reason for this is that it was easy to read emotions, motivations, decisions or events into the accidents that were not documented by NTSB. It would be improper, however, to assume these factors to be present when there was no evidence of them in the NTSB reports.

Two minor changes in the checklist were made as a result of the reliability test. Judgment and decision making were combined when it became apparent that a distinction could not be made between them with the information available. The term "training" was changed to "skill/knowledge" and three subdivisions of the term were added—training, experience, and currency.

FINDINGS

Human factors were identified in 90 percent of the accidents studied. This does not mean that human factors were the sole cause of the accidents, only that they contributed to the accidents.

Using the cognitive, social, and situational systems as a basis for comparison, NTSB reports identified human factors as either probable cause of factors relating to 41 (82 percent) of the 50 accidents studied. Use of the modified checklist identified human factors as contributing to 90 percent of the accidents studied. Cognitive factors were most easily identifiable using both methods. Because this study is limited to the identification of pilot human factors, the percentage of accidents to which human factors actually contribute is probably greater than 90 percent.

Reliability

A statistical comparison was made of the number of accidents attributed to human factors by the use of the checklist and by NTSB. Chi square was used, with $\alpha = .05$. The null hypothesis was that there was no difference in the identification of human factors when using the modified checklist or the NTSB reports.

$H_0: \chi = 0$

The Yates correction for continuity was used because of low frequencies in the social category. The critical table value of χ^2 was 1.39.

$\chi^2 = 0.603$

There was no significant difference between the two methods. This outcome further supports the reliability of the modified checklist.

Sample Characteristics

NTSB reports gave an excellent overview of each accident in terms of what happened and when it happened. Human factors that contributed to these accidents were not always mentioned in NTSB's summary (primary cause and contributing factors). It was possible, though, through the use of the checklist and careful reading of pilot statements and narrative portions of the reports, to identify additional human factors as having contributed to the accidents. Frequencies of human factors identified in this study are presented in Table 2.

Human factor-induced problems in the cognitive, or thought process, area were the easiest to identify using the checklist and NTSB reports; they were identifiable in 84 percent of the accidents studied.

Flaws in mental information processing were identified as having contributed to 80 percent of accidents studied. Two primary information processing factors accounted for this high percentage; judgment/decision making at 66 percent, and attention/distraction at 30 percent. An example of the judgment/decision making area is the case of a commercial pilot who had made an initial application of fertilizer. The weather was bad—rain showers, moderate turbulence, 30-knot gusts, and forecast thunderstorms. For unspecified reasons the owner of the airplane, a private pilot, took the airplane out for the second application flight. He was not rated for the aircraft, had a waiver on his medical certificate for a prosthetic leg, and was taking medication. He crashed the airplane and died.

Distraction was a factor in an accident off the coast of Florida. The pilot took off in an amphibious aircraft from an inland airport. He noticed that the elevator trim was not working right, so he decided to make a precautionary landing on the ocean. His passengers were excited and making of lot of noise. There was a lot of distracting radio traffic, and a harbor patrol rotorcraft was flying so close to him that it was splashed by the spray when he went down. He set up his landing and habit took over; he put the gear down and finished upside down in the water.

Psychological factors were identified as contributing to 52 percent of the accidents. Deficiencies in the third area of the cognitive system, that of skills and knowledge, were present in 40 percent of the accidents. Lack of experience and currency were problems in these accidents; insufficient training was evident, but to a lesser degree.

Social system factors were positively identifiable in only one of the accidents studied. In a number of the accidents it was easy to interpolate that these factors were present, but impossible to make an objective determination of whether they contributed to the accidents. This information was not in the NTSB reports.

Some factors in the situational system were identifiable. Physical stress contributed to 10 percent, and environmental stress was present in 12 percent of the accidents. There was no way to determine whether ergonomic stress was a factor in the accidents studied.

Demographics

Pilot-in-command certification varied greatly throughout the accidents in the study (see Figure 2). Fifty percent of the accidents involved student or private pilots. Flight instructors appeared to be more likely to have an accident than student pilots, but they were in the airplane with the students. When the student messed up, the flight instructor was pilot-in-command and got credit, so to speak, for the accident. Private

TABLE 2 HUMAN FACTORS CONTRIBUTING TO ACCIDENTS STUDIED

Human Factor	Frequency[a] factor (#)	area (#)	system (#)
COGNITIVE SYSTEM			42
Information Processing		40	
attention	15		
memory	5		
judgment/decision making	33		
communication error	1		
Psychological/Emotional		26	
false hypothesis	14		
habits	5		
motivation	3		
fear/panic	2		
complacency	13		
personality	1		
Skills/knowledge		20	
training	7		
experience	15		
currency	10		
SOCIAL SYSTEM			1
Social Pressure		1	
Role		0	
Life Stress		0	
SITUATIONAL SYSTEM			10
Physical Stress		5	
physical condition/body maintenance	4		
substance abuse	2		
Environmental Stress		6	
altitude/hypoxia	0		
speed/motion	1		
visual illusion	0		
spatial disorientation	2		
lighting levels	3		
visibility/glare	1		
noise level	0		
vibration	0		
toxic fumes	0		
Ergonomic Stress		0	
control design	0		
display design	0		
cockpit organization	0		

[a]The numbers presented in this table add up to more than 50 because frequently more than one factor contributed to an accident.

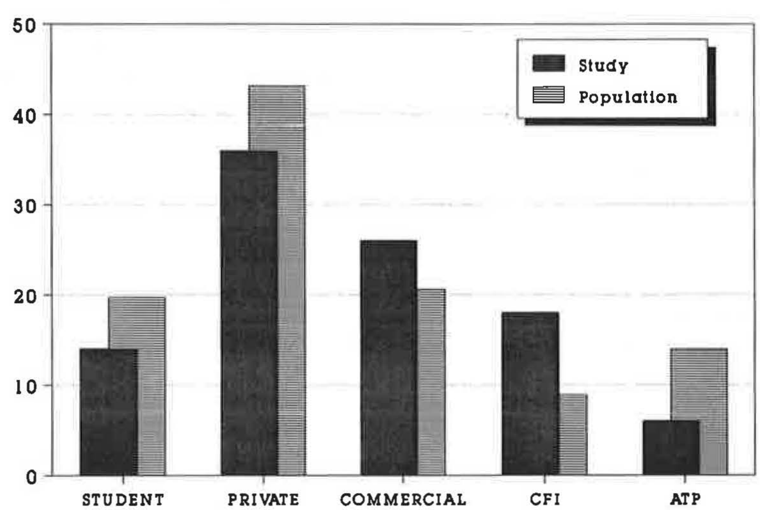

FIGURE 2 Flight certificate held.

pilots had many accidents, although the percentage of private pilots who had accidents was lower than the percentage of private pilots in the population at large. No certificate area was immune from having accidents.

The number of flight hours, an indicator of pilot experience, ranged from 18 to 20,000, with a mean of 3,055 and a median of 1,400. Peaks in the accident rate occurred at both low- and high-experience levels. Forty percent of the pilots in the sample had 1,000 to 5,000 flight hr, indicating substantial experience.

Of the 50 accidents studied, four pilots held a first class medical certificate, 23 held a second class, and 20 held a third class. Three of the pilots had no current medical certificate.

Forty-six pilots involved in the study were men and four were women. This distribution was not significantly different from the 1988 active pilot population, in which 94.2 percent were men and 5.8 percent were women. Sex was not a factor that affected the likelihood of having an accident. Data on pilot age and sex were compared with pilot population data using chi square, $\alpha = .01$.

Pilot ages are shown in Figure 3. The mean and median age of the pilots-in-command in this study are the same, 44 years. Ages ranged from 21 to 78. The ages of pilots who had accidents differed significantly from the age distribution of pilots active in 1988. Pilots between the ages of 40 and 54 had the highest accident rate compared with the pilot population. This ties in with the large number of accidents over 1,000 hr experience, and could be for a variety of reasons. Pilots under 40 may be in better physical condition, may be more current in their training, or may have been more affected by educational changes and safety programs than older pilots. It could be that pilots in the 40 to 55 age group have been flying a while and are getting complacent and too relaxed in the cockpit. Also, in that age group there are a lot of professionals with a fair amount of money. They may buy an airplane that is more complex than they are ready to handle. These pilots probably do not have enough time to stay current, flying maybe once a month.

Forty-six of the 50 accidents occurred during visual meteorological conditions (VMC). Of the four that took place in instrument meteorological conditions (IMC), only one pilot (the one that survived) was instrument rated and had filed an

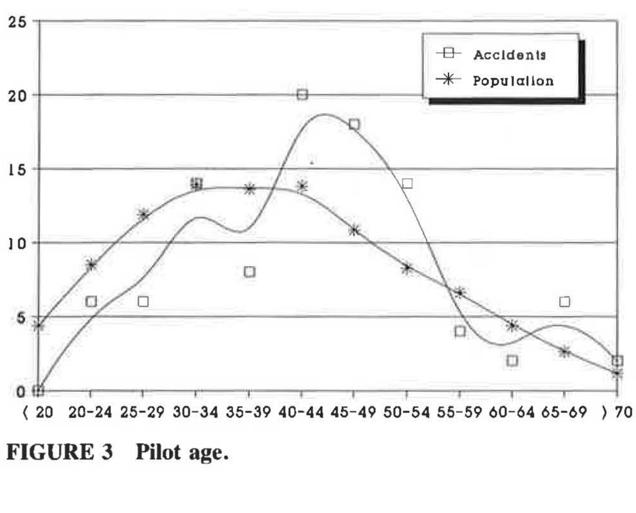

FIGURE 3 Pilot age.

IFR flight plan. VMC does not always mean good weather. There can be adverse conditions, thunderstorms in the area, that are not necessarily identified as IMC.

Out of the 50 accidents, 42 pilots did not file flight plans. Five pilots filed visual flight rule (VFR) flight plans, and three filed IFR flight plans. It is important to note that some pilots were doing touch-and-go landings or practicing near their home airports, but a large number of them were on cross-country flights.

The same trend shows up in weather briefings. Forty of the pilots either did not obtain a weather briefing or the source of their weather information was unknown. Of the remaining pilots, eight received flight service station briefings and two got information from television weather.

Of the 103 persons involved in the accidents studied, 49 were passengers, 2 were crew, and 2 were outside the aircraft. Fifty-five were uninjured, 12 sustained minor injuries, 18 were seriously injured, and 18 died. Twelve of the aircraft were destroyed, and 38 were substantially damaged. The high survival rate is due in part to the fact that GA aircraft are built to withstand a lot of crash stresses. The cockpit area stays pretty much intact. It also indicates that maybe there is some benefit from all the times that flight instructors pull the power and ask, "You just lost your engine—what are you going to do?" That type of education helps people stay in control during emergencies and makes many emergencies survivable.

CONCLUSIONS AND RECOMMENDATIONS

Suggested Further Research

Additional research into how human factors contribute to GA accidents is needed. The results of this study suggest several areas of further research, including replication for 1988 and more recent years.

There is need for research into the areas represented by the social and situational systems, as described by Feggetter (*12*). Little information was available about how human factors in these areas contributed to accidents.

Many studies have been done on human error and how the human brain recognizes and deals with error. This information needs to be correlated with current human factors knowledge.

Finally, there is need for the development and testing of a checklist to be used during the investigation of GA accidents. The checklist used in this study, in addition to Feggetter's checklist (*12*) and a Canadian checklist, which were designed for use during accident investigation, could be used as a basis for an improved GA accident investigator's checklist.

Implications of the Results

The results indicate a need for addition to aviation curricula in a number of areas, including judgment and decision making, distraction and attention overload, and self-knowledge. Education can improve a pilot's self-awareness of dangerous attitudes and habits and give the pilot important tools to use in making safe flying decisions.

Education can also be improved in attention/distraction. Pilots can be taught better scanning technique for use both inside and outside the cockpit. They can learn methods for reducing and coping with distraction. For example, the pilot who put down his gear for a water landing could have forcefully told his passengers to be quiet. He could have briefed them before takeoff that he was in charge. He could have turned off the radio to reduce the noise level. These actions might have enabled him to, first of all, fly the airplane.

Research into cockpit design and instrumentation and better cockpit management techniques are needed. Well-organized pilots will not spend time digging around looking for a chart or approach plate.

Pilots must somehow be made aware that accidents can happen to them; this awareness should lead to a decrease in complacency. Self-knowledge of their own personality factors, and counseling when appropriate, can aid pilots in flying safely.

Human factors in the social and situational systems that might have contributed to GA accidents were not readily identified using NTSB reports. Problems in these two systems are of the type that short-circuit the brain's error-detecting and correcting capabilities. The use of a human factors checklist by accident investigators would aid in developing a clearer picture of what went wrong in each accident. Interviews with pilots, crew, passengers, family, business associates, and witnesses, when appropriate, would add valuable insight into the human factors causes of the accidents. Information thus gained needs to be documented in an easily retrievable format, such as a checklist. It then could be used to modify pilot training and aviation systems development to reduce the accident rate.

NTSB reports miss key elements in the chain of events that ends in an accident, and often the flight crew is assigned responsibility for the accident. The limited scope of these reports reduces the likelihood that other factors will be detected. Factors that are not identified cannot be managed. Incorporation of a checklist into the accident investigation procedure would be a step toward identification of more, if not all, of the human factors contributing to aviation accidents. Everything that contributes to an accident needs to be identified and reported in a form that can be used and analyzed so that changes can be made.

SUMMARY

Aviation accidents are caused in part by a mismatch between the human performance envelope and aircraft/aviation systems. It is not a question of whether accidents are caused by this mismatch. Rather, it is a question of where the breakdown is occurring, and how often.

Pilots can be taught to break the chain of events that leads to accidents, but first educators must have a more complete definition of the human performance envelope. Educators need this fundamental information to teach pilots what to do and how to do it.

Accident investigation has not been effective in preventing human factors accidents because it is not providing the kind of information needed to combat this type of accident. Increased spending or stricter regulations are not the answer. FAA passed a regulation requiring fuel reserves—but pilots still run out of fuel.

It is critical to have better identification or documentation of human factors by NTSB. Without information about exactly what is happening, not a lot can be done to build the necessary curriculum changes. The inclusion of a human factors checklist in the NTSB's accident investigation and reporting procedure can be a major factor in improving the aviation education system.

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Trends at United States International Gateway Airports to Europe

Susan J. Heidner

What impact will the ongoing and predicted changes in Europe have on the United States gateways that serve the North Atlantic market? Standard ground transportation modeling and analysis methodology (trip generation, trip distribution, modal split, and trip assignment) was used on the 24 United States and 33 European gateways with scheduled service in 1989. Using gross domestic product to predict gateway boardings, the average annual growth rate ranged from 3.3 percent under status quo conditions to 3.5 percent under a high-growth scenario. Using average seats per aircaft and load factor with gateway boardings resulted in a 4.1 percent average annual growth in operations to 2000 and 2.3 percent from 2000 to 2010. This could affect the air traffic control system. The concluding step used a market share method to distribute the market gateway boardings and operations to the individual gateways, enabling the impacts on the gateways to be quantified along with the overall market impacts. This growth is expected to be largely absorbed by gateways other than New York (Kennedy and Newark), which will see a decline in market share.

Major changes have been occurring in Europe recently [liberalization of Western European air transportation under European Economic Community rules (EC 1992) and liberalization of Eastern Europe]. More changes have been predicted as the European Economic Community becomes more unified and the Eastern European economies stabilize. These changes should have an impact on airline passenger traffic within Europe as well as in the North Atlantic market, a market accounting for more than 40 percent of United States international air traffic (*1*). Traffic changes in the North Atlantic market would affect the United States gateways serving Europe.

There are four stages to defining how the changes in Europe would affect United States gateways serving Europe. The stages are researching and predicting the changes in Europe, predicing how those changes would affect air transportation, predicting how the air transportation changes would affect the North Atlantic market, and predicting how the changes in the North Atlantic market would affect the United States gateways serving Europe.

CHANGES IN EUROPE AND IMPACTS ON AIR TRANSPORTATION

The changes in Europe can be divided into four major geographical areas: the unified European Economic Community influencing Western Europe; the liberalized countries of Eastern Europe and their formation of new market economies; the continuing movement of the Soviet Union toward a market economy; and the newly independent Baltic countries.

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European Economic Community in 1992

The European Economic Community—Belgium, Denmark, France, West Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and the United Kingdom—is currently committed to an ambitious program to eliminate all existing internal barriers to the free movement of goods and services, including air services, by January 1, 1993 (*2*). The goal is to achieve increased economic productivity and growth for all countries involved by attaining a market similar in size to the United States while preserving the cultural heritage of each country.

The EC 1992 rules affecting intra-European air transportation will eliminate restrictions on routes, resulting in an anticipated increase in European airline competition (*3*). Expected consolidation of European airlines will make them stronger. They will be more capable of being fare competitive with United States flag carriers, which will affect the North Atlantic market (*4*). Also, with economic growth, airline passenger growth is assumed to increase because of increases in disposable personal income. In addition, increased economic activity will attract more business travelers as companies establish suitable partnerships and joint ventures leading to new or expanded markets between the United States and Europe.

Eastern Europe, Soviet Union, and Newly Independent Countries

Most of the Eastern European countries, the Soviet Union, and the newly independent Baltic countries are striving to establish market economies. (Since independent numbers were not available for the Baltic countries, their traffic volume was calculated as part of the Soviet Union in this study.) However, at this time, most of these countries face severe growth limitations, both economically and technologically (*5*), which will result in a very gradual increase in capacity in the North Atlantic market. Former East Germany, now part of a reunified Germany, may experience much faster growth than the other countries.

These countries should eventually experience North Atlantic airline passenger traffic growth well above their current service. These increases would be impeded until the airport facilities are enlarged to accommodate more passengers and upgraded to meet all the international airport security stan-

dards. More and better tourist amenities such as hotels, restaurants, and convention facilities are also needed (*5*). Rapid growth in these areas would require a significant infusion of capital resources. Whereas most of these countries presently have airlines, they have a shortage of equipment required to adequately meet their current demand. Most countries also lack the capital to meet future equipment needs, which will result in several years, or decades, of slow North Atlantic passenger growth. This is because under most agreements the market split is approximately 50/50, and if one country is unable to increase capacity, it is doubtful it would allow other countries to increase capacity in that market (*5*).

IMPACTS ON THE NORTH ATLANTIC MARKET

The North Atlantic market is the most mature of any United States international market, and passenger volume is still increasing (*1*). Recently, the North Atlantic market has felt the negative effects of an economic recession in the United States, Operation Desert Storm, and a terrorist scare. These types of events have happened in the past. Figure 1 shows the 1982–1983 United States recession and the European recession that followed. In 1986 a perceived unsafe market resulting from the Chernobyl nuclear accident, TWA hijacking, and the bombing of Libya resulted in a significant drop in passenger traffic.

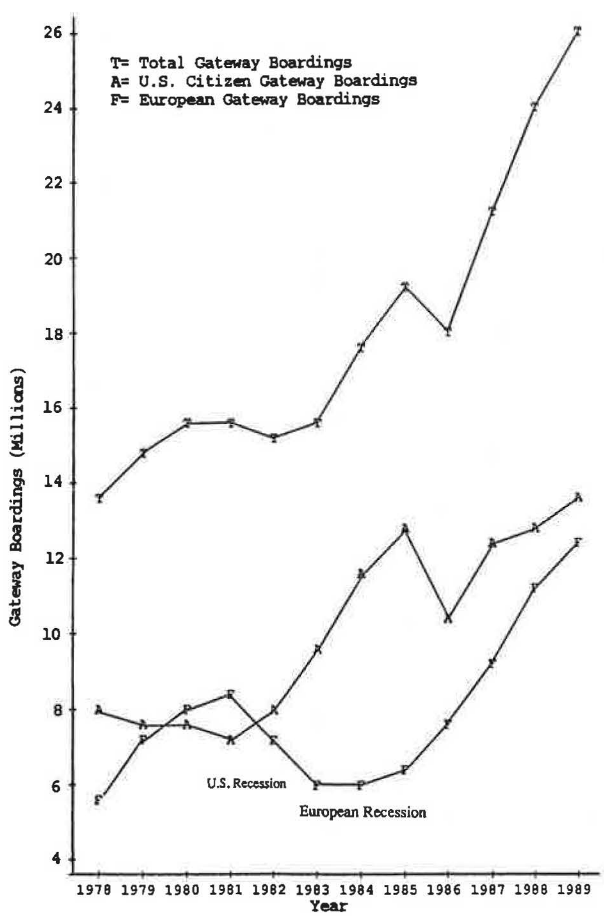

FIGURE 1 Gateway boardings by citizenship (source: U.S. International Air Travel Statistics).

Along with these types of events three main factors influence passenger growth in the North Atlantic market: (*a*) the changing structure of the international airline industry with renegotiated bilateral agreements and longer-range aircraft; (*b*) the interdependence of the countries involved in the international airline industry, so that travel between countries is possible; and (*c*) the regulation and deregulation of the international airline industry. Most airlines outside of the United States were and still are government controlled and subsidized, a situation that is not changing rapidly because most do not want to give up their "safety net."

CONVENTIONS AND BILATERAL AGREEMENTS

International air transportation is not a deregulated industry. Conventions and bilateral agreements constrain the growth of the market, with political and economic implications as discussed by Kasper (*6*), O'Connor (*7*), Taneja (*8,9*), and de Murias (*10*). The key factors of these agreements are as follows:

- Capacity control: Capacity control is the specified number of flights per week or market share that is allowed. Only recently have some of these controls been relaxed, leading to increased competition.
- Fare approval: Until recently all fares for the North Atlantic market were set exclusively by the IATA fare-setting forum. Under some agreements now, the fares are set and approved or rejected by the individual countries, which has allowed increased freedom for fare competition.
- Route authorization: This authorization controls what airlines operate on a specific route between what gateways. A recent example was the negotiations that took place to get authorization for American and United Airlines to fly into Heathrow instead of Gatwick as was specified in the bilateral agreement. Route authorization controls the third (right to set down traffic originating in the carrier's country in a foreign country), fourth (right to fly traffic from a foreign country to the carrier's country), and fifth (right to carry traffic between two foreign countries) freedoms. (First freedom is the right to transit over a country without landing, and second freedom is the right to stop for nontraffic purposes such as refueling.)
- Cabotage: Under bilateral agreements, cabotage, the right of a foreign airline to carry domestic passengers within that country, is denied. The question has been raised whether a unified Europe would lead to excluding intra-European flights by non-European airlines. In this study, it was assumed that this would not be possible until a single body negotiates all the European bilateral agreements, an event not looked upon happily by most European countries.
- United States domestic deregulation: After deregulating the domestic airline industry in the United States, the United States government tried to export deregulation to the rest of the world to increase competition. The limited result in the North Atlantic market was slightly more liberal bilateral agreements (*1*).

IMPACTS ON UNITED STATES GATEWAYS SERVING EUROPE

The standard ground transportation planning and analysis methodology was attempted using the 24 United States and 33 European gateways that had scheduled service in the North Atlantic market in 1989, the final year of data. The gateways are Kennedy, Chicago, Boston, Los Angeles, Atlanta, Miami, Newark, Dallas, Houston, Washington, D.C., Detroit, Orlando, San Francisco, Seattle, St. Louis, Cincinnati, Philadelphia, Baltimore, Charlotte, Denver, Minneapolis, Pittsburgh, Raleigh, San Diego, London, Frankfurt, Paris, Amsterdam, Copenhagen, Madrid, Rome, Brussels, Milan, Shannon, Helsinki, Dusseldorf, Oslo, Warsaw, Stockholm, Zurich, Moscow, Manchester, Belgrade, Zagreb, Dublin, Vienna, Prague, Lyon, Nice, Hamburg, Munich, Athens, Keflavik, Luxembourg, Lisbon, Geneva, and Prestwick.

The ground transportation planning and analysis methodology includes four steps: trip generation, trip distribution, modal split, and trip assignment. The first three steps were applied to this research with confidence. The results of trip assignment were not reliable, so this step was not pursued.

Trip Generation

Trip generation predicts the total number of trips taking place in a market regardless of their origin or destination. An important part of trip generation is the data base.

Data Sources

The data sources available and applicable to this study were *United States International Air Travel Statistics 1978–1989* (*11*), *In-Flight Survey* (*12*), *FAA Forecast for the Fiscal Years 1991–2002* (*13*), *Outlook for Commercial Aircraft 1991–2010* (*14*), *Current Market Outlook* (*15*), *Traffic by Flight Stage* (*16*), *Civil Aviation Statistics of the World* (*17*), and *On Flight Origin and Destination* (*18*).

United States International Air Travel Statistics collected by the U.S. Immigration and Naturalization Service (INS) and published by the Transportation Systems Center (TSC) of the U.S. Department of Transportation were the main data base for this study. These data are the number of trips between the United States gateway (airport in the United States immediately preceding or following the trans-Atlantic flight segment) and the European gateway where the passenger embarks on or disembarks from the flight with the same flight number, on the same airline, as the flight segment having a trip end in the United States. The data reflect gateways, not the actual origin and destination of the travelers. The data on United States domestic flights or intra-European flights immediately preceding or following the international trans-Atlantic flight were sought from the other sources, but the data were not available in the public domain.

The standard convention of passenger enplanements was not used with these data because FAA counts a businessman who travels from New York to Paris, where he clears customs, spends the day in a meeting, and then reboards a United States carrier for Rome, as two enplanements in the North Atlantic market. The data used in this study only counted the one enplanement in New York. To avoid confusion, the enplanements in this study were labeled gateway boardings.

Status Quo Model Development

Standard regression techniques were used to develop a model that would effectively translate the historical data into a forecast of North Atlantic gateway boardings (*19*). The regression used the following independent variables:

- Dollar—the weighted average of the U.S. dollar against major world currencies as calculated by the Federal Reserve Board to measure growth due to the rate of exchange (*20*);
- GDP—the combined United States and European gross domestic product, in billions of 1980 U.S. dollars, to measure growth related to economic conditions (*14,21,22*);
- EGDP—European gross domestic product only, also in billions of 1980 U.S. dollars, to measure growth of European citizen traffic (*14,21,22*);
- USGDP—United States gross domestic product only, in billions of 1980 U.S. dollars, to measure growth of U.S. citizen traffic (*14,21,22*);
- Yield—the North Atlantic airline yields of U.S. carriers (*23*) adjusted to real terms with the "CPI for airfares" (*24*), to measure the influence of fare on the volume of passengers; and
- "Fear variable"—a "zero or one" variable for world events that cause people to be afraid of flying or traveling (applied to 1986) to measure the passengers dropping out of the North Atlantic market because of a fear of unsafe European travel.

The following variables were also examined: time since 1978, United States national unemployment, United States GNP, and a "zero or one" variable for recession. Table 1 shows the four best sets of regression equations. The chosen equation set, Case 1, shown in Equations 1 and 2, used EGDP and U.S. dollar in an equation for foreign citizens and USGDP and U.S. dollar in an equation for U.S. citizens. This equation set allowed the flexibility to adjust the growth of U.S. and European citizens independently. Past growth patterns had been different.

European citizen gateway boardings:

$$\begin{aligned} &\text{Eurocitz} = -7{,}895{,}044 + 3{,}911.64\,(\text{EGDP}) - 56{,}912\,(\text{dollar}) \\ &R^2 = 0.7903 \quad (0.774) \quad (0.0003) \quad (0.0043) \\ &(\text{probability} > |T|) \end{aligned} \tag{1}$$

U.S. citizen gateway boardings:

$$\begin{aligned} &\text{UScitz} = -154{,}276{,}641 + 7{,}147.38\,(\text{USGDP}) + 41{,}065\,(\text{dollar}) \\ &R^2 = 0.9205 \quad (0.0001) \quad (0.0001) \quad (0.0052) \\ &(\text{probability} > |T|) \end{aligned} \tag{2}$$

The regression results are sensible. The positive correlation between the GDP variables and gateway boardings explains that the higher the GDP, the stronger the economy and the

TABLE 1 FOUR BEST REGRESSION EQUATIONS (SETS) FOR TOTAL GATEWAY BOARDINGS

Case 1. Separate Equations for Citizens

ForCitz = -7895044 + 3911.64(FGDP) - 56912(dollar) R2 = 0.7903
(0.0774) (0.0003) (0.0043)
Predicted: Forcitz 2000 = 16446498 Forcitz 2010 = 22685173

Amcitz = -15427641 + 7147.38(AGDP) + 41065(dollar) R2 = 0.9205
(0.0001) (0.0001) (0.0052)
Predicted: Amcitz 2000 = 20379585 Amcitz 2010 = 27891485

Predicted: Total 2000 = 36826083 Total 2010 = 50576658

Case 2. One Equation for All Citizens

Total = -26482187 + 5207.50 (GDP) R2 = 0.9417
(0.0001) (0.0001)
Predicted: Total 2000 = 35679741 Total 2010 = 49458264

Case 3. Separate Equations for Citizens Utilizing Fear Variable for U.S. Citizens Only

Forcitz = -7895044 + 3911.64(FGDP) - 56912(dollar) R2 = 0.7903
(0.0774) (0.0003) (0.0043)
Predicted: Forcitz 2000 = 16446498 Forcitz 2010 = 22685173

Amcitz = -15963579 + 7408.95(AGDP) + 39893(dollar) - 1374430(fear) R2 = 0.9405
(0.0001) (0.0001) (0.0027) (0.0552)
Predicted: Amcitz 2000 = 20940065 Amcitz 2010 = 28726872

Predicted: Total 2000 = 37386563 Total 2010 = 51412045

Case 4. One Equation for All Citizens Utilizing Fear Variable

Total = -28290887 + 5447.91 (GDP) - 2925186(fear) R2 = 0.9682
(0.0001) (0.0001) (0.0033)
Predicted: Total 2000 = 36740815 Total 2010 = 51555440

(Probability > |T|)

Source: GDP from WEFA Group (up to 1996), extrapolated to 2010 with growth rate from McDonnell Douglas
GDP 2000 = 11937.0 GDP 2010 = 14582.9 1980 U.S. Dollars
FGDP 2000 = 7386.8 FGDP 2010 = 8981.7 1980 U.S. Dollars
AGDP 2000 = 4550.2 AGDP 2010 = 5601.2 1980 U.S. Dollars

more people can afford to travel, which leads to an increase in gateway boardings. The negative correlation between European citizen gateway boardings and the U.S. dollar is a result of travel to the United States becoming more expensive as the U.S. dollar gets stronger. The reverse is true for U.S. citizens; foreign travel is less expensive when the U.S. dollar is strong, thus more people can afford to travel.

It was decided not to include the "fear variable" because there is only a small improvement in the coefficient of determination and a slight increase in the growth rate by discounting the bad year. Also, there is no method of predicting when world events that cause a bad year will happen.

The equations that were also considered are given in Table 2. GDP and yield are standard variables used to predict air travel. These variables were used in the forecasts by Boeing (*15*) and Greenslet (*25*) for world revenue passenger miles (RPM). The correlation between gateway boarding and GDP should be positive as was found in this study. It was expected that the correlation between yield and gateway boardings would be negative because a lower yield stems from lower fares designed to encourage more people to fly. The regression results in this study showed a positive correlation, which is counter intuitive. This unexpected result has not been rationalized. Therefore it was not used, even though this equation resulted in a higher growth rate and coefficient of determination.

Two possible hypotheses were offered but not proven. First, the positive correlation between yield and total gateway boardings could result from poor gateway boarding growth, which caused the airlines to lower fares to attract passengers. However, the airlines still were not able to attract enough passengers to cover the decrease in revenue from lower fares

TABLE 2 OTHER EQUATIONS CONSIDERED FOR TOTAL GATEWAY BOARDINGS

Linear: GDP and Yield

Total = -41982542 + 6551.58(GDP) + 4355494(Yield) R2 = 0.9417
(0.0005) (0.0001) (0.0626)
Predicted: Total 2000 = 38858740 Total 2010 = 55988857

Logarithmic: GDP

Log(10)Total = -2.0623 + 2.3686Log(10)GDP R2 = 0.9382
(0.0166) (0.0001)
Predicted: Total 2000 = 39293049 Total 2010 = 63119323

(Probability > |T|)

Source: GDP from WEFA Group (up to 1996), extrapolated to 2010 with growth rate from McDonnell Douglas 1991
GDP 2000 = 11937.0 GDP 2010 = 14582.9 1980 U.S. Dollars
Source: North Atlantic Yield from Airline Monitor Nov. 1991, adjusted with CPI for airfares from U.S. Statistical Abstract and growth rate from Boeing 1991(1990-2000, extrapolated to 2010)
Yield 2000 = 6.05 Yield 2010 = 5.58 1982-1984 U.S. Cents per RPM

(conversation with John W. Drake, Dec. 11, 1991). Second, passengers, especially business travelers, have become smarter about buying lower-fare, advance-purchase tickets. If that is true there would not be a major change in market or fare structure, but the yields would be lower (conversation with John W. Drake, Dec. 11, 1991).

One of the other models examined was the logarithmic model. The linear model was chosen over the logarithmic model because the logarithmic model corresponds to a developing market and linear models correspond to a mature market like the North Atlantic market (*1*).

Comparison of Forecasts

Table 3 compares the resulting annual growth rates with the FAA, Boeing, and McDonnell Douglas forecasts. The results of the regression equation are lower. This could be due to several items:

- The data set for the FAA enplanement forecast and this gateway boarding regression model are different.
- The yield was dropped from the model because of the unexplained positive correlations.
- Twelve years of data were examined, and there is a risk of examining only part of an economic cycle, which would yield a different growth rate than a full cycle.
- Encouraging low fares may have matured the market more rapidly, resulting in a lower growth rate.
- RPM growth rates should be higher because they incorporate the increase in the number of people flying as well as the trend toward longer nonstop flights.

Growth Scenarios

To model the changes in Europe from the status quo conditions, an increase in average annual GDP growth rates, which translates into increased gateway boardings, was assumed. Three different levels of growth were assumed for each region. There are several steps in calculating the growth scenarios.

- An increase in the average annual GDP growth rate was assumed for each scenario by region.

TABLE 3 COMPARISON OF VARIOUS FORECASTS

		Average Annual Growth Rate			Enplanements or
Time Period	Forecast	Gateway Boardings	Rev. Pax. Enplanements	Rev. Pax. Miles	Gateway Boardings Data Source
1989-2000	Federal Aviation Administration	-	4.21%	4.62%	RSPA Form 41
1990-2000	Boeing	-	-	4.8%	unknown
1990-2000	McDonnell Douglas	-	-	4.9%*	unknown
2000-2010	McDonnell Douglas	-	-	4.5%*	unknown
1989-2000	Regression (Case 1)	3.29%	-	-	TSC/INS
1989-2010	Regression (Case 1)	3.26%	-	-	TSC/INS
2000-2010	Regression (Case 1)	3.22%	-	-	TSC/INS

*Revenue Passenger Kilometers
- not available

Sources: McDonnell Douglas, Outlook for Commercial Aircraft 1991-2010
FAA Aviation Forecasts Fiscal Years 1991-2002
Boeing, Current Market Outlook 1991

- The individual GDPs were calculated and used in the appropriate equation to yield gateway boardings.
- The gateway boardings were divided into the European regions under assumed market shares.

Western Europe was assumed to have a 5 percent increase in the average annual GDP growth rate under low growth, 10 percent under medium growth, and 20 percent under high growth for 1990 to 2010.

Eastern Europe and the Soviet Union (separately) were assumed to have the average annual GDP growth rate increased by 5 percent under low growth, 10 percent under medium growth, and 20 percent under high growth for 1990 to 2000. Once these countries stabilize their economies, they have a greater potential for growth; thus from 2000 to 2010 the average annual GDP growth rate was assumed to increase 10 percent under low growth, 20 percent under medium growth, and 40 percent under high growth. The Soviet Union is starting from a predicted negative growth rate due to the current instability in that country (*21*).

The United States was assumed to experience induced economic growth because of European economic growth that would increase markets for United States exports. The United States average annual GDP growth rates were assumed to be 0 percent under low growth, 5 percent under medium growth, and 10 percent under high growth.

The assumed increases in the average annual GDP growth rates for all regions are given in Table 4. The resulting average annual GDP growth rates are given in Table 5.

The percentage of citizens traveling to and from each region in Europe was also estimated. It was assumed that with growth in Eastern Europe, it would gain a greater share of the market. The percentage share of the market by citizenship is given in Tables 6 and 7.

The resulting gateway boardings are given in Table 8 for all the scenarios.

TABLE 4 PERCENT CHANGE IN AVERAGE ANNUAL GDP GROWTH RATE BY SCENARIOS

Region	Year	Status Quo	High Growth	Medium Growth	Low Growth
United States	1991-2000	0.00	10.00	5.00	0.00
	2001-2010	0.00	10.00	5.00	0.00
Western Europe	1991-2000	0.00	20.00	10.00	5.00
	2001-2010	0.00	20.00	10.00	5.00
Eastern Europe	1991-2000	0.00	20.00	10.00	5.00
(excluding USSR)	2001-2010	0.00	40.00	20.00	10.00
Soviet Union	1991-2000	0.00	20.00	10.00	5.00
	2001-2010	0.00	40.00	20.00	10.00

TABLE 5 AVERAGE ANNUAL GDP GROWTH RATE BY SCENARIO

Region	Year	Status Quo	High Growth	Medium Growth	Low Growth
United States	1991-2000	2.60	2.86	2.73	2.60
	2001-2010	2.10	2.31	2.21	2.10
Western Europe	1991-2000	2.60	3.12	2.86	2.73
	2001-2010	2.10	2.52	2.31	2.21
Eastern Europe	1991-2000	0.50	0.60	0.55	0.53
(excluding USSR)	2001-2010	2.40	3.36	2.88	2.64
Soviet Union	1991-2000	-1.02	-0.82	-0.92	-0.97
	2001-2010	1.20	1.68	1.44	1.32

Source: Status Quo GDP Rates from WEFA Group up to 1996, 1997-2010 growth rate from McDonnell Douglas 1991

TABLE 6 PERCENT OF U.S. CITIZEN GATEWAY BOARDINGS BY EUROPEAN REGION

Region	Year	Status Quo	High Growth	Medium Growth	Low Growth
Western Europe	1989	98.28	-	-	-
	2000	98.00	96.00	97.00	97.75
	2010	98.00	94.00	95.50	97.00
Eastern Europe	1989	1.45	-	-	-
(excluding USSR)	2000	1.50	2.50	2.00	1.50
	2010	1.50	3.50	2.75	2.00
Soviet Union					
	1989	0.27	-	-	-
	2000	0.50	1.50	1.00	0.75
	2010	0.50	2.50	1.75	1.00

- not applicable

Source: 1989 data from U.S. International Air Travel Statistics (TSC/INS)

TABLE 7 PERCENT OF EUROPEAN CITIZEN GATEWAY BOARDINGS BY EUROPEAN REGION

Region	Year	Status Quo	High Growth	Medium Growth	Low Growth
Western Europe	1989	98.08	-	-	-
	2000	98.00	96.00	97.00	97.75
	2010	98.00	94.00	95.50	97.00
Eastern Europe	1989	1.25	-	-	-
(excluding USSR)	2000	1.25	2.50	2.00	1.50
	2010	1.25	3.50	2.75	2.00
Soviet Union	1989	0.67	-	-	-
	2000	0.75	1.50	1.00	0.75
	2010	0.75	2.50	1.75	1.00

- not applicable

Source: 1989 data from U.S. International Air Travel Statistics (TSC/INS)

Trip Distribution

The next step in transportation modeling methodology is to distribute the trips to the regions of their origin or destination. The Fratar method of network balancing or the Gravity Model of attractiveness to distribute the gateway boardings to the individual gateways was desired, but the available data failed to yield a reliable result. Therefore, the distribution of gate-

TABLE 8 TOTAL GATEWAY BOARDINGS UNDER VARIOUS SCENARIOS

Region	Year	Status Quo	High Growth	Medium Growth	Low Growth
Western Europe					
(U.S. citizens)	1989	13572931	-	-	-
	2000	19971993	20395448	20200866	19921044
	2010	27333655	27144925	27050875	27054740
(Western European Citizens)	1989	11753510	-	-	-
	2000	16117568	17365173	16909948	16725934
	2010	22231470	22854920	22431748	22405522
Eastern Europe (excluding USSR)					
(U.S. Citizens)	1989	200099	-	-	-
	2000	305694	531131	416513	305694
	2010	418372	1010715	778952	557830
(Eastern European Citizens)	1989	149677	-	-	-
	2000	205581	452218	348659	256664
	2010	283565	850981	645940	461970
Soviet Union					
(U.S. Citizens)	1989	37445	-	-	-
	2000	101898	318679	208256	152847
	2010	139457	721939	495697	278915
(Soviet Citizens)	1989	80845	-	-	-
	2000	123349	271331	174329	128332
	2010	170139	607844	411053	230985
Total	1989	25794507	-	-	-
	2000	36826083	39333980	38258571	37490515
	2010	50576658	53191324	51814265	50989962

- not applicable

Source: 1989 data from U.S. International Air Travel Statistics (TSC/INS)

way boardings was approached by using a market share forecast.

The history of market share indicated that except for New York, most of the market shares varied only slightly, making regression inaccurate (see Table 9). New service at gateways mainly drew market share away from New York (Kennedy and Newark), thus reducing its market share, even though the volume of gateway boardings from the North Atlantic market still grew.

The first step in distributing the gateway boardings to the gateways was to form a regression equation with GDP as an independent variable to predict the gateway boardings (arriving and departing) at New York, Kennedy and Newark combined (see Equation 3).

$$\text{New York total} = -5{,}682{,}648 + 1{,}793.37\ (\text{GDP})$$
$$R^2 = 0.8390 \qquad (0.0180) \qquad (0.0001)$$
$$(\text{probablity} > |T|) \qquad (3)$$

The reduction in market share at Kennedy was distributed to the other gateways by grouping them in four categories: premier gateways, East Coast gateways, internal gateways, and thru-traffic hub gateways, on the basis of characteristics such as major carriers, location, and growth potential.

Premier Gateways

There are three premier gateways in the United States: New York, Chicago, and Los Angeles. They attract traffic from international markets because of their strategic location and the fact that they directly serve the largest population centers in the United States. They are also convenient hubs to serve other nearby population centers. It was assumed that the market share among these gateways will continue to shift to Chicago and Los Angeles. The overall share of these gateways will decrease somewhat as some of New York's market share shifts to other types of gateways.

East Coast Gateways

Several gateways are important because of their East Coast location and convenient service to a fair proportion of the United States domestic market: Boston, Atlanta, Washington, Orlando, Philadelphia, Charlotte, and Raleigh.

Thru-Traffic Hubs

Several United States gateways appear to serve primarily as hubs to bring South and Central American traffic together with European traffic. Others on the West Coast serve Far Eastern markets. These gateways are Miami, Dallas, Seattle, Houston, and San Francisco.

Internal Gateways

Detroit, Cincinnati, Minneapolis, St. Louis, Denver, and Pittsburgh combine to serve only 4 percent of the market. They will continue to be served primarily by domestic flights in the United States or the less frequent flights from London or Paris.

The 1989 market share at each gateway and the predicted market share are given in Table 10 (the percentages do not sum to 100 because his table does not include gateways with only charter service). The gateway boardings by gateway are given in Table 11.

Aircraft Operations

Aircraft operations at each gateway were forecast by calculating the average seats on an aircraft at each gateway from the July 1991 International OAG airline schedules, which include aircraft type (*26*). The aircraft were categorized as follows on the basis of seating capacity:

- B747—400 seats;
- DC10, MD11, and L1011—250 seats; and
- B767 and A310—200 seats.

The average aircraft size at each gateway is given in Table 12. In the North Atlantic market the average number of seats per aircraft was 278. This was higher than the FAA forecast average seats per aircraft of 272 for the Atlantic routes in 1991 because FAA includes only United States carriers, which use a higher percentage of twin-engine wide-bodies than the Europian carriers, although the European carriers are also increasing use of twin-engine wide-bodies. FAA forecast the average seating capacity to decline by 19 seats during the next 6 years from the trend toward using more twin-engine wide-bodies. FAA forecast that, starting in 1998, the number of seats per aircraft would increase by one to two seats per year because congested European airspace would lead to the use

TABLE 9 MARKET SHARE HISTORY OF U.S. GATEWAYS

Gateways	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Kennedy	57.01	56.96	53.87	52.77	54.70	58.17	54.97	49.60	48.52	47.86	46.12	43.96
Chicago	8.05	7.04	6.51	6.04	6.15	5.41	6.11	6.12	7.28	7.59	7.04	7.45
Los Angeles	5.78	5.90	7.77	8.09	6.94	6.54	6.82	6.84	7.57	7.21	6.84	6.71
Miami	3.79	4.47	7.38	8.65	7.11	4.93	4.19	3.41	5.17	5.52	6.60	6.62
Boston	7.17	6.95	7.59	6.47	6.54	6.39	6.33	6.48	5.90	5.93	6.31	6.37
Atlanta	0.94	1.84	2.11	3.40	3.90	3.80	3.77	4.93	4.27	4.60	4.29	4.22
Washington DC	3.50	3.36	2.97	2.48	2.08	2.35	2.55	2.96	3.22	3.51	3.40	3.49
Dallas	1.01	1.63	1.63	1.01	1.43	1.38	1.75	2.53	2.67	3.12	3.09	3.12
Newark	0.35	0.39	0.04	0.35	0.11	0.86	2.63	3.01	3.54	2.72	2.83	3.28
San Francisco	1.54	2.09	2.27	2.52	2.59	2.17	2.45	2.22	2.40	2.63	2.71	2.41
Orlando	0.01	0.03	0.03	0.10	0.08	0.07	0.04	0.22	0.50	0.79	1.67	2.32
Houston	2.12	1.26	1.48	1.67	1.87	1.33	1.34	1.69	2.23	1.91	1.64	1.67
Seattle	2.60	2.15	2.01	1.94	1.67	1.40	1.53	1.45	1.45	1.32	1.26	1.28
Detroit	1.20	0.79	0.53	0.47	0.47	0.98	0.47	1.00	0.76	0.92	0.85	1.23
Philadelphia	0.95	1.15	0.71	0.47	0.45	0.45	0.64	0.78	0.74	0.53	0.62	0.55
Minneapolis	0.96	0.61	0.66	1.04	1.06	0.77	0.96	1.04	1.04	0.88	0.66	0.62
St. Louis	0.06	0.02	1.18	0.22	0.10	0.06	0.29	1.11	0.52	0.64	0.77	0.55
Cincinnati	0.02	0.02	0.01	0.00	0.10	0.01	0.00	0.00	0.00	0.26	0.48	0.44
Baltimore	0.06	0.22	0.06	0.62	1.27	1.59	1.86	3.35	1.29	0.54	0.58	0.42
Denver	0.06	0.05	0.04	0.36	0.10	0.12	0.06	0.05	0.06	0.24	0.41	0.35
Pittsburgh	0.09	0.05	0.01	0.13	0.00	0.00	0.00	0.01	0.09	0.08	0.10	0.12
Charlotte	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.48	0.44
Raleigh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.34
San Diego	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10

Source: U.S. International Air Travel Statistics (TSC/INS)

TABLE 10 FORECAST MARKET SHARE AT UNITED STATES GATEWAYS

		1989		2000		2010		
Type of Gateway	Gateway Name	Market Share	Gateways Served	Market Share	Gateways Served	Market Share	Gateways Served	Forecast Basis
Premier	New York*	47.24	32	42.7	34	40.5	34	Regression of gateway boardings
	Chicago	7.45	18	8.65	20	9.60	23	American and United Airlines Hub, 2nd largest North Atlantic gateway 3rd airport proposed
	Los Angeles	6.71	9	7.85	12	8.55	15	Increased aircraft range Stopover for Far East
East Coast	Boston	6.37	10	6.2	10	6.0	11	Maintain strong gateway
	Atlanta	4.22	7	4.5	8	4.7	9	Delta Hub, Delta expanding in Europe
	Washington**	3.91	4	4.4	5	4.4	6	World political center
	Orlando	2.32	3	2.6	4	2.65	4	Florida attractions and service to South America
	Philadelphia	0.7	2	0.6	2	0.5	2	May keep current traffic
	Raleigh	0.34	1	0.5	1	0.6	2	American Airlines hub, expand service
	Charlotte	0.44	1	0.50	1	0.5	2	Domestic hub will attract
Thru-Traffic Hubs	Miami	6.62	6	6.6	6	6.5	6	Maintain strong gateway
	Dallas	3.12	4	3.8	5	4.2	5	Delta and American Airlines hub, new runways proposed
	San Francisco	2.41	3	2.5	3	2.55	3	Growth on existing routes
	Houston	1.67	4	1.65	4	1.6	4	Maintain, Connects to South America
	Seattle	1.28	3	1.25	3	1.25	4	Stopover on great circle route to Far East
	San Diego	0.1	1	0	0	0	0	Service Discontinued
Internal	Detroit	1.23	3	1.6	4	1.7	5	Northwest Airlines hub foreign carrier service
	Cincinnati	0.65	2	0.7	2	0.8	3	Delta hub
	Minneapolis	0.62	1	0.7	2	0.8	3	Northwest hub, most Europe traffic routed thru other hubs foreign carrier service
	St. Louis	0.55	3	0.40	2	0.1	1	Lose most service if TWA stops flying
	Denver	0.35	1	0.6	2	0.8	3	New airport, United Airlines Hub, increased aircraft capability
	Pittsburgh	0.12	1	0.12	1	0.12	1	Philadelphia continuation

*J.F. Kennedy and Newark combined

**Dulles and Baltimore-Washington combined

Source: 1989 data from U.S. International Air Travel Statistics 1989 (TSC/INS)

TABLE 11 MARKET SHARE OF GATEWAY BOARDINGS (ARRIVALS PLUS DEPARTURES) AT UNITED STATES GATEWAYS

	1989		2000					2010				
	Market	Gateway	Market	Gateway Boardings				Market	Passengers			
Gateway	Share	Boardings	Share	Status Quo	Low	Medium	High	Share	Status Quo	Low	Medium	High
New York	43.96	11276741	39.20	14439745	14696282	14997360	15418920	36.50	18460480	18611336	18912207	19414833
Chicago	7.45	1912087	8.65	3186321	3242930	3309366	3402389	9.60	4855359	4895036	4974169	5106367
Los Angeles	6.71	1721158	7.85	2891633	2943005	3003298	3087717	8.55	4324304	4359642	4430120	4547858
Miami	6.62	1698690	6.60	2431181	2474374	2525066	2596043	6.50	3287483	3314348	3367927	3457436
Boston	6.37	1635050	6.20	2283837	2324412	2372031	2438707	6.00	3034599	3059398	3108856	3191479
Atlanta	4.22	1083614	4.50	1657624	1687073	1721636	1770029	4.70	2377103	2396528	2435270	2499992
Washington DC	3.49	894544	4.00	1473443	1499621	1530343	1573359	4.00	2023066	2039598	2072571	2127653
Newark	3.28	841208	3.50	1289263	1312168	1339050	1376689	4.00	2023066	2039598	2072571	2127653
Dallas	3.12	800948	3.80	1399771	1424640	1453826	1494691	4.20	2124220	2141578	2176199	2234036
San Francisco	2.41	618366	2.50	920902	937263	956464	983350	2.55	1289705	1300244	1321264	1356379
Orlando	2.32	596404	2.60	957738	974753	994723	1022683	2.65	1340281	1351234	1373078	1409570
Houston	1.67	428168	1.65	607795	618593	631266	649011	1.60	809227	815839	829028	851061
Seattle	1.28	327502	1.25	460451	468631	478232	491675	1.25	632208	637375	647678	664892
Detroit	1.23	316079	1.60	589377	599848	612137	629344	1.70	859803	866829	880843	904253
Philadelphia	0.71	183096	0.60	221016	224943	229551	236004	0.50	252883	254950	259071	265957
Cincinnati	0.65	167089	0.70	257853	262434	267810	275338	0.80	404613	407920	414514	425531
Minneapolis	0.62	157935	0.70	257853	262434	267810	275338	0.80	404613	407920	414514	425531
St. Louis	0.55	141527	0.40	147344	149962	153034	157336	0.10	50577	50990	51814	53191
Charlotte	0.44	113767	0.50	184180	187453	191293	196670	0.50	252883	254950	259071	265957
Baltimore	0.42	106793	0.40	147344	149962	153034	157336	0.40	202307	203960	207257	212765
Denver	0.35	89475	0.60	221016	224943	229551	236004	0.80	404613	407920	414514	425531
Raleigh	0.34	86123	0.50	184180	187453	191293	196670	0.60	303460	305940	310886	319148
Pittsburgh	0.12	30716	0.12	44203	44989	45910	47201	0.12	60692	61188	62177	63830
San Diego	0.10	24783	0	0	0	0	0	0	0	0	0	0

Source: 1989 Data from U.S. International Air Travel Statistics 1989 (TSC/INS)

TABLE 12 AVERAGE SEATS PER AIRCRAFT AT EACH GATEWAY

Gateway	1991	2000	2010
New York	277	265	279
Chicago	254	242	256
Los Angeles	274	262	276
Miami	335	323	337
Boston	258	246	260
Atlanta	244	232	246
Washington DC	261	249	263
Newark	319	307	321
Dallas	254	242	256
San Francisco	286	274	288
Orlando	283	271	285
Houston	351	339	353
Seattle	319	307	312
Detroit	250	238	252
Philadelphia	307	295	309
Cincinnati	236	224	238
Minneapolis	380	368	370
St. Louis	300	288	302
Charlotte	260	248	262
Baltimore	225	213	227
Denver	250	238	252
Raleigh	200	200	200
Pittsburgh	300	288	302
San Diego	200	200	200
Total	278	266	280

Note: If currently serviced by all B767's and/or A310's (200 seats) then average seats per aircraft remained constant.

of larger aircraft (*13*). This growth rate was extrapolated to 2010. The opeations by gateway are given in Table 13.

Modal Split

Modal split is the choice between different types of transportation. In this study, the choice is actually between types of service rather than mode, because the split is between scheduled and charter traffic or between traffic carried on United States flag carriers and on foreign flag carriers. Charter flights played an important role in the North Atlantic market for many years because of their lower fares. But, as the North Atlantic market matured and became more competitive, the total market share dropped from 19 percent in 1978 to 7 percent in 1989. In the future, charter traffic is expected to stay at its 1989 market share of 7 percent or decrease unless some special niche reopens in the market (e.g., scheduled fares become less competitive).

The other split is between passengers carried on United States and foreign flag carriers. The percentage of United States flag carrier traffic varied slightly, maintaining about 45 percent of the total North Atlantic traffic during this study time frame. There is no reason to expect this to change. The 45 percent is lower than an expected 50/50 split because, when a government enters into an agreement that gives it access to Fifth Freedom traffic, it is, in effect, bartering some of its Third and Fourth Freedom traffic for access to Fifth Freedom traffic. This is not necessarily a one-to-one exchange, but it is inherent in the whole bilateral system that the right to carry traffic between two foreign countries is paid for by the grant to other counries of increased access to the home market (*1*).

CONCLUSIONS

The North Atlantic market is expected to continue growing, but at an average annual growth rate ranging from a low of 3.3 percent to a high of 3.5 percent, compared with an average annual growth rate of 5.3 percent from 1978 to 1989. The market share growth in the North Atlantic should be absorbed at the gateways except in New York, which would experience gateway boarding growth but market share decline.

Under the high-growth scenario, 7 percent more passenger traffic is forecast by 2000 than under the status quo scenario. This change is not as dramatic as was originally anticipated.

TABLE 13 ANNUAL AIRCRAFT OPERATIONS (ARRIVALS PLUS DEPARTURES) AT U.S. GATEWAYS

	Aircraft Operations								
	1989	2000				2010			
Gateway	Estimated	Status Quo	Low	Medium	High	Status Quo	Low	Medium	High
New York	61964	81694	83145	84848	87233	97304	98099	99685	102334
Chicago	11458	19740	20091	20502	21079	27892	28119	28574	29333
Los Angeles	9561	16547	16841	17186	17669	23041	23229	23605	24232
Miami	7718	11285	11485	11720	12050	14346	14463	14697	15087
Boston	9646	13919	14166	14456	14863	17164	17304	17584	18051
Atlanta	6393	10712	10902	11126	11438	14210	14326	14558	14945
Washington DC	5217	8872	9029	9214	9473	11312	11405	11589	11897
Newark	4014	6296	6408	6439	6723	9268	9344	9495	9747
Dallas	4800	8672	8826	9007	9260	12203	12302	12501	12833
San Francisco	3291	5039	5128	5234	5381	6586	6639	6747	6926
Orlando	3208	5298	5393	5503	5658	6916	6972	7085	7273
Houston	1857	2688	2736	2792	2870	3371	3399	3454	3545
Seattle	1563	2249	2289	2335	2401	2896	2920	2967	3046
Detroit	1924	3713	3779	3856	3964	5018	5059	5140	5277
Philadelphia	908	1123	1143	1167	1199	1204	1213	1233	1266
Cincinnati	1078	1726	1756	1792	1843	2500	2521	2561	2629
Minneapolis	633	1051	1069	1091	1122	1558	1570	1596	1638
St. Louis	718	767	781	797	819	246	248	252	259
Charlotte	666	1113	1133	1156	1189	1419	1431	1454	1493
Baltimore	722	1037	1056	1077	1107	1311	1321	1343	1378
Denver	545	1392	1417	1446	1487	2361	2380	2419	2483
Raleigh	655	1381	1405	1434	1474	2231	2250	2286	2347
Pittsburgh	156	230	234	239	246	296	298	303	311
San Diego	189	0	0	0	0	0	0	0	0
Total	141227	207245	210927	215248	221298	265156	267322	271644	278863

Note: Estimated 1989 aircraft operations used 1991 average seats per aircraft

Source: FAA Forecast 1991 - 2002
1989 Load Factor = 65.7%
2000 Load Factor = 66.7%
Extrapolated 2010 Load factor = 68.0%

The direct traffic from Eastern European countries will grow rapidly from just under 500,000 boardings to more than 1.5 million by 2000. This will cause only a slight ripple in the market, which is dominated by Western Europe.

Air traffic control will need to contend with an average annual increase in North Atlantic traffic of about 4.1 percent in operation per year between now and 2000, due to both forecast increases in passengers and a decrease in average seats from 278 to 266 as many European carriers follow the United States carriers' lead and make greater use of twin-engine wide-bodies. Between 2000 and 2010, the operations should increase at a lower rate of 2.3 percent as a result of a lower passenger growth rate and an increase in average seats per aircraft during the latter period.

The major deterrent to growth on both continents will be capacity constraints in the air traffic control system and airports. The transatlantic airways may also become saturated unless the present separation rules are changed or more corridors are used.

FURTHER RESEARCH

This study has raised two important issues that deserve further research.

Inadequacy of the Data

The data are not fine enough to indicate the effects of service changes. Without finer data, it is impossible to predict what percentage of the passengers on a new route shift from a previous routing to the new gateway and what percentage is due to induced demand.

Regression Analysis Anomaly

The other area of further research is the positive correlation between yield and gateway boardings. Research should be done to determine whether this was a product of the data used or there is a more significant underlying reason.

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Commercial Aviation Safety and Risk

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Airline safety research affects policy recommendations, so the scale of a safety index creates important effects. Indices of safety and airline financial health, safety and airline size, safety and government oversight, and the public perception of safety are surveyed. Conclusions depend on data selection and statistical techniques. Aircraft accidents are infrequent and random, making any testing difficult. Overall, time progression and a rough airline size-safety relation, with important qualifiers, are correlated with safety. The literature survey raises recurrent questions that are analyzed further in statistical testing of recent aviation accidents. National Transportation Safety Board accident investigations report data for 1966 to 1990. Statistical tests measure the effects of deregulation, technological progress, Congress, and FAA in accident prevention. Deregulation and FAA have had positive effects on airline safety above and beyond technological and time improvements, though FAA faces diminishing returns.

Measurement of airline safety provokes controversy because safety levels affect federal approval of airline mergers; alter federal funding of air traffic control, airport repairs, and aircraft safety studies; and could prompt policy makers to roll back or expand airline deregulation. "Safety" itself is not some constant index like temperature, but may be measured in accidents, minor mishaps, or fatalities, against miles traveled, against number of flights, or over time. Airline safety can compare ground travel, short flights, commuter flights, or international flights. Different methods of measuring safety may contradict each other, adding to the puzzle of how to improve safety when it is difficult to even ascertain what is safer.

For example, if safety is measured by accidents over distance flown, then an airline that makes numerous short flights and crashes very infrequently may have the same safety record as an airline that flies only from Japan to San Francisco and crashes every other trip. However, the average traveler is probably much more willing to take a series of 50-mile hops on the short-distance airline than to take the flight to Osaka. If the same airlines are compared by accidents per departure, the Pacific flight is more dangerous, yet the statistic hides the fact that the longer flight spends more time in the air and faces more time without emergency airport assistance in which to crash.

Measures of safety and several such measurement problems are surveyed, and the accident record of United States commercial airlines is statistically analyzed. The survey reveals strengths and weaknesses of current safety analyses.

The view of a United States air traveler is adopted, so the focus is on transport used by most United States travelers: larger U.S. airline companies—or Part 121 air carriers in FAA parlance—flying to and from U.S. and territorial scheduled destinations. Commuter airlines are included where commuters operate as a substitute for large jet transport (for example, code sharing).

The safety record of the airline industry has improved continuously, so that accidents have become rarer (three occurred out of 7 million departures in 1990). Safety improvements by manufacturers, airlines, employees, and government oversight agencies ensure that fewer and fewer accident trends even show up. Accidents must be assumed to be random, or at least independent events, the products of a confluence of several random safety threats such as bad weather, improper navigation, engine trouble, and poor judgment.

Researchers have looked for systematic influences on the random output, accidents, from several areas. These inputs can be divided into four groups: the financial-safety relation, the size-safety relation, the political structure-safety relation, and public awareness of airline safety. Financial theses usually propose that airline deregulation engendered cutthroat competition, which has caused airline firms to cut back on maintenance, causing accidents. The size-safety thesis postulates that airline size is related to maintenance expenditures, which affect safety. The political-structure-and-safety relation examines the market's ability to ensure safety and whether travelers choose the airlines that best meet their air safety wants. Finally, public-perception research asks whether the public competently measures safety and whether safety indices matter.

FINANCIALS AND "MARGIN OF SAFETY"

The theory of the "margin of safety" states that regulation held up airline fares to increase airline profits and, in addition, allowed airlines to spend more on inputs. During regulation, airlines could afford to exceed the FAA-mandated minimum level of safety inputs, regulated by maintenance and inspection. The margin was a cushion above the hard minimum. Deregulation exposed airlines to price and cost competition, which has caused them to reduce pay scales, increase employee work hours, shrink seat width, and shrink the safety margin. The shrinkage made airlines, according to Nance (*1*), "obviously . . . by definition, less safe." However, "this decline has nevertheless failed to show up as a measurable increase in accidents and/or casualties."

The margin of safety theory will not hold if FAA is not the dictator of minimum safety levels (i.e., if airlines supply safety to suit travelers' desires). Chalk (*2*) examined whether FAA really ensured a minimum safety level through its inspection and fine system. The average fine of $1,000 for a safety violation was a mosquito bite on the financial sheet of the major

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airlines. Chalk found that rule interpretation was capricious and inconstant. Safety enforcement varied in definition, time, and place. Chalk concluded that FAA enforcement did not determine airline minimum safety.

Golbe (*3*) examined statistically the relation between operating margins and accidents per departure, testing whether wider margins correlated with fewer accidents. Using a sample of 11 large airlines from 1963 through 1970, Golbe found that firms with higher profits also had higher accident rates. The speculative answer to these results is that larger firms had both high profits and more flights, and with more flights went more accidents.

Golbe identified a few measurement problems, including the fact that use of accidents per passenger mile as a measure of risk discriminated against airlines that typically fly short trips. Golbe asserted that 70 percent of accidents occur during takeoff or landing, as opposed to en route flight, and used an accidents-per-departure measure as a cure. However, 70 percent implies that her risk measure may be only 70 percent correct. Furthermore, if the analysis were extended to the deregulation era, the error would be worse. Deregulation decreased the number of stops per flight; therefore, use of accidents per departure would make the deregulation era look less safe.

Golbe also noted that fatalities, her risk variable, would make full planes look more dangerous. An airline company filling all its planes, and doing better financially for it, would have a greater number of fatalities per accident than if a plane only half full had crashed. More passengers per plane, or higher load factors, are also a characteristic of deregulation.

Finally, there is more than one way to measure profit. Golbe used net income over the gross national product (GNP) deflator to represent not only better maintenance, an expense, but also purchase of new planes, a capital improvement. She included GNP to signify periods of greater demand and congestion, but it did not affect accident rates.

Despite Golbe's finding that higher accident rates go with higher margins, Rose (*4*) found that profits have an influence on safety, once all other factors are controlled. Accidents occur so infrequently that there is a lot of "noise" in estimating their causes, so Rose removed certain influences from the estimation. Once the primary accident-correlated conditions of flight length, number of takeoffs and landings, and international and territorial flights were taken out, Rose found that operating margins also affected accidents, for small airlines. Operating margins on large airlines had no effect.

Rose avoided the per-mile and per-departure debate by measuring accidents per year for each airline; this actually opens her work to criticism from both fields. Data from 35 airlines for 29 years (1957 to 1986) were used; still the data were difficult to work with because of the small number of accidents. An interesting side point can be made about Rose's method of testing: because of the noisiness of the data, a Poisson distribution was used, and grouping in the errors was corrected by taking the square root of the independent variable. This technique, though widely used in aviation studies (*4–6*), has no strong theoretical justification.

Theoretically and statistically, the financial-safety thesis is weak, if not a failure. An explanation for the failure raises a new thesis: larger airlines may tend to have better managers, steadier profits, and possibly better safety rates.

SIZE AND SAFETY

Larger airlines can offer better salaries, more power to executives, a better-stocked repair shop, and larger planes that are easier to repair and fly. Larger airlines may be safer. The 20 largest commuter airlines are twice as safe as the next 30 largest commuters and carry more than half of all commuter passengers, according to Oster and Strong (*7*). The 20 largest are six times safer than all the smaller air travel companies, measured by the joint probability of being involved in a fatal accident and being killed in that accident. Nearly all of the 50 largest commuter airlines share computer reservation codes with a major airline.

Oster and Strong claim that there is a perverse "safety mismatch" in the size-safety relationship. A self-trained pilot may get his first job flying for a small commuter; he has the least experience, flying the smallest, hardest-to-maintain planes, on poorly kept airfields, with the greatest lack of instrument support. Large airline pilots, on the other hand, with 20 to 30 years of experience, fly the safest aircraft, from well-maintained airports, with complete weather and air traffic support (*8*). It would be a wonder if major airlines did not have lower accident rates than the smaller companies.

Accordingly, Golaszewski and Bomberger (*9*) found that whereas accident rates vary with the size of airlines, the difference is most pronounced among the smallest airlines. Among the major airlines, no one airline had a different safety rate. The majors, which are the common means of transport for most travelers, as a group had a better safety rate than smaller planes. The majors' safety rate is particularly difficult to measure because of the rarity of accidents.

Airline size is defined by flight hours or number of departures. The choice of the size variable affects the results. Differences in safety rates are more pronounced when accidents are analyzed per flight hour and hardly significant when analyzed per departure. Rose (*4*) found that the safety-by-departures rate has less variance than other safety measures.

Because of repeated difficulty with insufficient numbers of accidents to perform statistical testing, researchers have tried to find other measures of safety. Maintenance expenditures make a poor measure, since they vary with company size and type of plane. Further, as Rose (*10*) pointed out, companies use maintenance dollars with varying effectiveness. And $100 of maintenance expense cannot be considered equal to $100 of new aircraft, though both are safety inputs.

The National Transportation Safety Board (NTSB) records both accidents and incidents. An incident is a small abnormality in aviation operation, such as brake slippage, improper repair procedure, or flying at an incorrect altitude. Incidents indicate that some part of the overlapping system of safety features in an aircraft or airport is not performing up to full potential. Incidents are more frequent than accidents, but incidents perform poorly as safety measures.

Golaszewski (*11*) tested the size-safety relation using accidents, incidents, and enforcements alternatively as safety indices. Enforcement refers to the yearly fines FAA levies against airlines for safety violations. The incident rate and the enforcement rate were not consistent with the accident rate: airlines that appeared most risky according to one scale were moderate or even most safe on the other two scales. The lack of correlation may occur because incidents are voluntarily

reported and subject to "enthusiasm" bias. The Newark and West Virginia airports report far more incidents than other areas; this is probably due more to enthusiasm than actual risk (*12*). Enforcements are suspected to be similarly more sensitive to the mood of FAA than to actual risk (*8,13*).

Two other possible measures of safety remain: one is near-midair collisions, a subclass of incidents, which occur when two aircraft pass within as much as 2 mi of each other. Closer encounters are highly publicized. The federal government created the other possible measure when it conducted the 1984 National Air Transportation Inspection (NATI) program, which assigned safety ratings to several airlines on the basis of a rigorous inspection. Kanafani and Keeler (*6*) examined maintenance expenditures, NATI ratings, and near-collisions of each airline, and found that maintenance significantly explained safety of new airlines, while NATI and near-collisions did not.

The Kanafani and Keeler examination of new airlines is valuable because it addresses size, finance, and free-market incentives (political structure) all at once. Airlines that started service since 1978 are smaller, have small profit margins, and may be more responsive to travelers' safety wants because they do not yet have a reputation for safety. This study found that new airlines spend more on maintenance and have better safety records. Many new entrants had no accidents during their entire service careers.

In possibly another example of "market enforcement," Rose (*10*) found that, even near bankruptcy, airlines do not skimp on safety. Near bankruptcy a firm's president is thinking of the company's resale, especially planes. The value of a company is enhanced by a safe record and proper maintenance.

Larger airlines have more accidents simply because they handle more traffic and have greater exposure to risk. By another measure, the major airline companies and their code-sharing partners are far safer than smaller airlines. Among the major airlines themselves, size appears to make no difference. It is safe to conclude what technological research has already shown: larger companies tend to have larger, safer planes and attract successful pilots through better wages and job security. Very roughly, bigger can be better.

POLITICAL STRUCTURE: THE "MARKET AS ENFORCER" THEORY

In the face of uncertain results of financial-safety and size-safety studies, another rough correlation appears: whereas the largest airlines tend to be safest, they also tend to be located in the western world. Airlines not sheltered by national ownership or national monopoly must provide the safety level demanded by finicky travelers, who can choose among airlines. Oster and Strong (*7*) test this idea in a way that takes unique advantage of a measurement problem. One approach toward accident causality is that the first mishap created the opportunity for danger and thus caused a subsequent crash. A second approach is that the accident could have been avoided up until the last possible contributing factor. Oster and Strong reason that if free markets force airlines to cut costs, under deregulation, maintenance and equipment should show up as a first cause more often. Cost-cutting pressure on the crew should cause pilot error to show up more often as the final cause. Even if total accidents do not increase, under deregulation these causal trends should appear.

The results confirm the opposite. Equipment-related accidents in the deregulated period are less than one-third of those in the regulated period in the United States. Cockpit crews, now facing more diverse tasks, have become more effective. The reason for the latter result may be that, before deregulation, many pilots held second jobs and consequently did not use the time alloted for rest (*14*). There has also been growing emphasis on cockpit training.

The number of new, younger pilots in the airline fleet is frequently mentioned as a source of air travel risk. Lauber (*15*) reported that the median experience level of pilots involved in accidents had fallen from 16,000 hr (1975 to 1978) to 13,000 hr (1982 to 1985). However, the entire fleet of airline pilots is on the average younger, and any subsample, whether the ones that are involved in accidents or the ones that eat fish, is also younger. The important question is whether youth or inexperience has caused more accidents, and neither has been proven. In fact, aircraft accident reports reveal that in the 1960s and 1970s many older pilots had heart attacks in the pilot seat, and some even died.

Oster and Strong (*7*) also hypothesize that increased air travel since deregulation caused more aircraft to crowd the sky, creating more air traffic control errors. Again, their results do not support the hypothesis. Oster and Strong may be victims of a measurement problem or a misperception. The measurement problem is that control errors are recorded as incidents unless a crash results. However, pilot errors are recorded as accidents, though the air traffic error and the pilot error pose equal risk (*4*). The misperception is that the skies are more crowded. In the face of the 1981 Professional Air Traffic Controllers Organization strike, FAA cut air traffic to 75 percent and capacity of 23 major airports to 50 percent of prestrike levels. FAA also eliminated in-air holding, literally clearing the skies. Congestion contributed to more accidents in 1961 than any year since.

Certainly the air traffic controller strike was important to the deregulatory era. Before the strike, 17,275 worked in air control. As a result of the strike, 11,400 were fired (*16*). Deregulation dramatically increased air travel; there were 26 percent more departures in 1985 than in 1981, and the number of air controllers was still 15 percent less than before the strike (*14*).

Deregulation's influence on air traffic control and on safety is obscure. Congestion, increased staffing, and airspace complexity covary as much as 81 to 91 percent, according to Gifford and Sinha (*17*). In traffic control airspace surrounding large airports, they found staffing levels positively associated with near collisions, possibly because complicated airspaces get more staff, and the complexity still causes near-collision errors.

Oster and Strong (*7*) found the cost-cutting theory reversed, and instead airlines performed more safely after deregulation. In the case of air traffic control, improvement is due to FAA involvement: deregulation may mark less governing and better guidance.

RANDOMNESS

Deregulation had a positive effect on safety, but safety causality still defies identification. Even the improvement of deregulation is difficult to identify because of continual tech-

nological progress and self-improvement of the industry. Research and innovation in cabin design, metallurgy, fuels, floor lighting, evacuation slides, and airport weapon detection improved safety dramatically in the last 30 years. According to NTSB, 65 percent of crashes are survivable, and the chance of surviving "survivable" crashes grows over time. However, these changes create a trend in safety improvement that obscures the effects of deregulation.

Barnett and Higgins (*5*) assumed that accidents were random, then tried to separate deregulation and technology. They concluded that air travel is 60 percent less safe because of deregulation. They assume that new airlines since 1978 are dangerous, and the traffic they attract away from older airlines is therefore risky; therefore the aggregate safety level is 60 percent lower than what it could have been. The derivation of the 60 percent is ambiguous. Their conclusion conflicts with Kanafani and Keeler's statistical analysis of new airlines (*6*).

Barnett and Higgins created a useful safety statistic, X/N, where X is the death risk per flight and N is the chance of being involved in an accident on a particular departure. Two important components of risk are encompassed, though it is still vulnerable to departure-based criticism. They apply their measure to international safety levels and find that United States carriers are the safest in the world.

Political structure is difficult to test without comparing, and deregulation's results on safety are ambiguous. Barnett and Higgins name the ill effects of deregulation, but their proofs are logically incomplete. However, the importance of deregulation as a move toward freer markets and traveler-demanded safety levels will be canceled if travelers are not aware of safety levels.

PUBLIC AWARENESS

Public awareness may depend on who pays for accident losses. Panzar and Savage (*18*) find that if liability rules are structured so that the airline pays for losses from a crash, the airline firm will insure against crashes. Theoretically, insurance will cushion the financial impact of the crash, lessening the incentive to improve safety, a phenomenon called moral hazard. If the traveler bears the loss of the crash (caveat emptor), then the traveler will purchase flight insurance and invest in safety information. If insurance companies have limited information about safety, they will offer only one insurance policy, which means that either the patrons of safe airlines will pay too much for insurance, or travelers will refuse to fly riskier airlines. This asymmetrical information is known as adverse selection.

Either way, travelers will only pay as much as they desire to be as safe as they think reasonable. An imaginary result of this scheme would be grades of airlines: some "mostly safe," others "more safe," and so on. "More safe" airlines would cost more, only fly on sunny days, employ only perfectly seasoned pilots, and prohibit carry-on luggage.

Panzar and Savage claim that regulation forced aviation to be safer than people desired (optimum), and after deregulation, market forces pushed safety down toward its optimum, lower, level. However, the point could just as easily be made that travelers desired more safety, but regulation emasculated their desires by ensuring profits regardless of "mostly safe" and "more safe" selection. Panzar and Savage reach their conclusion by noting that fares are, on the average, lower after deregulation, and it cannot be that travelers are paying less to get more.

However, once the market is freed, a small, mobile, and aware group of consumers may be enough to create market discipline of airlines, according to Moore (*14*).

The public may in fact be hypersensitive to airline risk as opposed to other equal risks. Barnett and Higgins (*5*) suggest that the frequency of incidents creates the perception of extra risk.

Borenstein and Zimmerman (*19*) tested the traveler response to safety indicators in terms of falling demand for airline stock ownership and air travel. Accidents indicated safety levels, and dips in share price after an accident indicated public awareness, or stockholder predictions of travelers' upcoming decisions. Air travel demand is difficult to measure, since price, frequency of flight, time of year, and fullness of planes must all be reckoned. For example, after the Air Florida crashes, Air Florida's planes were fuller, which would indicate higher demand, but could indicate lower frequency of flights. Borenstein and Zimmerman approximated demand from leftovers in a statistical test: everything not already explained by the variables included was assumed to be demand. This method, though common in statistical testing, is not very reliable.

Nevertheless, their results have been widely cited, especially the 3-month period of lower stock prices after a crash, though this result was not statistically significant. Borenstein and Zimmerman attribute this lack of significance to the disincentives of insurance coverage; both travelers and airlines are cushioned from poor safety vigilance. The lack of statistical significance and imperfection in estimated demand are flaws in this widely recognized study.

The chance of being involved in a near collision is extremely small, but the public appears terrified of that tiny possibility. Consider the news media treatment: "Our Troubled Skies," *Time*, Aug. 10, 1987; "Worries in the Busy Skies," *U.S. News and World Report*, Aug. 24, 1987; "Year of the Near-Miss," *Newsweek*, July 27, 1987; "Wrong Track (Near Misses and Sloppy Safety)," *Time*, Sept. 14, 1987; "Dangers in a Crowded Sky," *Macleans*, Aug. 31, 1987; and "The Gremlins in the Sky (Near Misses)," *U.S. News and World Report*, July 20, 1987. Golaszewski (*11*) studied individuals' evaluations of risk from different sources and concluded that the public is overly frightened, relative to actual risk, of airline crashes because of their catastrophic nature.

Golaszewski noted that the chance of being involved in a near-midair collision is extremely rare. A frequent flyer would have to fly 120 flights a year for 250,000 years to equal the probability of being involved in one with certainty. Yet pilots and public are aware and concerned about their presence.

Hypersensitivity appears to have been the result when an engine fell off a DC-10 over Chicago in 1979, according to Lefer (*13*). The last time equipment failure caused an accident was 1973, 6 years and several million flights ago. According to the Air Transport Association (*20*), there had been 521 accidents from 1959 through 1978, and 71 of the 521 involved fatalities. Ten of the 71 were due to equipment failure. FAA grounded the DC-10, one the industry's most popular planes, because, according to Lefer, "Congress was prompted to legislate . . . the FAA probably overreacted . . . but probably had no choice in the face of the media storm." The accident

was later found to be caused by a time-saving maintenance procedure used by American Airlines.

A NEW SAFETY MEASURE

Commentators portray 1985 as one of the worst years for airline safety. An Aeromexico jet collided with a small aircraft above Los Angeles; FAA issued record fines; a military charter plane crashed in Newfoundland, killing all aboard. All the accidents were tragedies, yet most United States travelers do not fly on foreign airlines, military charter flights, or small private planes, or fly on them rarely. All of these are significantly more dangerous than the most common transport, United States scheduled airlines. A more germane safety measure for United States travelers must exclude foreign, charter, and military flights.

Similarly, airline passengers are not threatened by ground crew injuries, flight attendants' sprained ankles, or pilot indigestion, yet all these are included in the official accident statistics that most researchers use. A rigorous examination of direct danger to average United States passengers would be informative.

STATISTICAL ANALYSIS

Mishaps such as flight attendant injury, ground crew accident, or foreign or charter flight accidents do not indicate risk probability of United States airlines fatal accidents and should be measured on different scales. Inclusion of non-life-threatening mishaps as accidents in aggregate accident statistics is misleading. Inclusion of accidents generated by foreign safety systems, foreign pilot training, and incentives obscures the causes in the United States airline accidents. Most airline safety studies use these aggregate figures.

Aggregate accident statistics fail to discriminate between danger and potential danger. Aviation safety is made up of an overlapping system of safety nets. Though considered an accident, a single case of pilot incapacitation or engine fire is not enough to cause a crash; other factors must contribute. These incidents are poor safety indicators. Mishaps are informative if they illustrate accident causality, not just chance abnormalities.

For this analysis, accidents are defined as abnormal occurrences in which one or more passengers are seriously injured in a manner directly connected with operation of the aircraft, or instances involving collisions with the ground or other aircraft that signify real threat to the safety of passengers. This definition omits irregularities among crew or aircraft that are safely resolved yet are included in the official accident statistics.

To satisfy the preceding concerns, accident data were culled from NTSB accident reports, the source of the aggregate accident figures. Accident reporting terms also changed in 1978, 1981, 1982, and 1985 (*21*). By researching NTSB "accidents" from accident reports, years of comparable data are assembled, and equally serious accidents in 1985 and 1966 get the same classification, despite what the official reports choose to call them.

Data are derived from NTSB Annual Accident Reports, 1966 through 1990. Miles and departures are from FAA; 1989 and 1990 miles are estimated. Accident data exist from 1929, but because of continually changing reporting standards, data before 1966 could not be included for this study. To illustrate, in the early 1960s, before NTSB was formed, accidents were often attributed to "crashed while enroute."

Accidents, Departures, and Mileage

The data are used to examine first which measure is more accurate, accidents per departure or accidents per mile. It is hypothesized that if 70 percent of all accidents occur at takeoff or landing, departures will have a higher correlation with accidents than mileage.

Departures have significant explanatory power. Revenue passenger miles are negatively related and significant to annual accidents. Time (technology) trend is correlated both with departures and revenue passenger miles. Inclusion of technology lowers the significance of departures from 3.43 to 2.4 and the significance of miles from -5.1 to -1.2. Caution must be used with statistical interpretation: one reading of these results implies that longer flights are safer than shorter flights.

Tests of Accident Causes and Factors

The second investigation seeks to discover which factors influence accident risk. Risk is deflated by departures, following the preceding results, and tested against factors cited as causes in accidents, including congestion, air traffic control, and jet innovation. Deregulation and FAA activity are included to find out whether either has had an effect on safety.

FAA activity is measured by the number of airworthiness directives (ADs) issued annually. ADs are commonly issued after an airline accident. Many ADs come from the manufacturers of the aircraft, the engines, and various parts. Therefore, to the extent that they incorporate manufacturers' warnings, ADs are not a pure measure of FAA accident-prevention activity. However, those warnings reflect the liability environment surrounding air travel, which is under the purview of the federal government and influenced by FAA.

These results are reproduced in Table 1. In the test of total accidents, the R-square fit measure is .9998. The high fit number is not attributable to autocorrelation or abnormal errors common in airline accident data, since correcting for both did not change the coefficients or the R-square. Deregulation is significantly negative, indicating that deregulation is correlated with fewer accidents. The time (technology) trend is barely significant with the wrong sign. FAA ADs show significant risk mitigation but lose their effectiveness after a certain point, as expected. The 113th FAA AD achieves maximum safety; the rest are less useful.

Statistically, the error terms above may not be normally distributed because of the rarity of accidents. Consequently, the analysis is repeated using probit analysis to mitigate error abnormality. In this test, the positive or negative influences of factors mimic those of the fully specified equation above, though none of the influences are statistically significant. Perhaps accident rarity creates errors that covary with factors.

TABLE 1 RELATION OF RISK TO ACCIDENT FACTORS (EQUATIONS 1, 2, AND 3)

Equation 1: Risk = Accidents/ Departures; R-square = .9998
Equation 2: Probit of Equation 1; R-square = .5849
Equation 3: Fatals = Deaths/ Departures; Fatals R-square = .9276

Risk =	Time +	FAA AD +	Log (FAA) +	Pilot +	Mid Air Collis. +	Weather
Coef.	.713E-7	-.256E-7	.288E-5	.217E-6	-.554E-6	.142E-6
[Tstat]	[1.73]	[-3.55]	[3.89]	[4.05]	[-2.91]	[3.09]
Probit:	8.96	-1.38	154.47	16.03	-28.37	-3.35
	[.579E-5]	[-.551E-5]	[.585E-5]	[.52E-4]	[-.108E-4]	[-.868E-5]
Fatals:	-.143E-5	-----	-----	.395E-5	.492E-5	.305E-5
	[-.643]	-----	-----	[.79]	[.416]	[.677]

+ Traffic Control	+ Congestion	+ Maint.	+ Aircraft	+ Other Pilot
-.297E-6	.180E-8	.654E-6	.377E-6	.102E-6
[-2.46]	[2.94]	[4.77]	[5.7]	[3.93]
-35.62	85.11	14.01	21.58	60.96
[-.124E-4]	[.717E-5]	[.566E-5]	[.263E-4]	[.914E-5]
.909E-5	-.631E-5	.298E-5	.794E-5	-.152E-4
[.731]	[-.136]	[.265]	[1.72]	[-.878]

+ Sabotage	+ Mechanical Fatigue.	+ CoPilot	+ Crew	+ Airport	+ Seatbelt
.208E-6	-.366E-6	-.147E-5	-.135E-6	.595E-7	.585E-6
[3.27]	[-10.17]	[-11.48]	[-5.83]	[3.37]	[9.75]
7.07	-20.23	-102.49	-3.912	4.83	29.04
[.633E-5]	[-.708E-5]	[-.183E-4]	[-.382E-5]	[.684E-5]	[.703E-5]
.746E-5	-.89E-5	-.215E-4	.831E-5	.491E-5	-.588E-5
[1.51]	[-1.184]	[-.507]	[-1.639]	[.843]	[-.538]

+ Alaska	+ Birds	+ Evacuation	+ Deregulation	+ Jet Innovation
.193E-6	.143E-5	.181E-6	-.135E-5	-.146E-6
[10.75]	[15.45]	[5.03]	[-10.33]	[-.528]
1.807	74.82	10.28	-130.96	67.624
[.171E-5]	[.232E-4]	[.893E-5]	[-.776E-5]	[.409E-5]
-.283E-5	.208E-5	-.467E-6	.147E-4	.191E-4
[-.417]	[.0822]	[-.0666]	[.527]	[.2758]

It has been a puzzle whether the fuller planes after deregulation lead to more fatalities in a crash. Crashes are less frequent since 1978, yet each may have more fatalities because of higher load factors. Testing passenger fatalities per departure, or death rate, against accident factors indicates how deregulation affected the death rate. Seating before and after deregulation must be assumed to be random and have no effect on the death rate. The test indicates an insignificant relation between deregulation and the death rate: deregulation had no effect.

Because of the suspicion of abnormal errors in the test on accident causes, a second data set from more diverse sources was tested. Annual rainfall proxies for weather, annual passengers for congestion, aviation industry's hourly wage for maintenance cost, and airline profits are included. The results have their expected signs, and autocorrelation and abnormal error correction did not change the results (see Table 2). Time trend decreases risk, congestion increases it, and the introduction of jets reduced risk. Deregulation and FAA ADs are ambiguous. There appears to be a trade-off between time and deregulation. Depending on the specific equation used, one or the other is significant.

Congressional Activity and FAA Effectiveness

Observers have asserted that Congress passes laws and puts pressure on FAA to act in the wake of an accident. Ott (*22*) writes of "short-term, hastily prepared technology programs that Congress has required in wake of aviation accidents." Congressional concern is understandable. In testing this concern, accidents and hearings should be correlated. If FAA, in response, acts in a knee-jerk fashion, hearings and ADs should be correlated. However, FAA may be acting immediately after accidents to keep Congress off its back, and an AD would immediately follow every accident. The influence of FAA on safety and Congress on FAA is examined.

Eight years and 216 observations of congressional hearings, FAA AD activity, and accidents indicate little evidence of the relations expected. FAA issued ADs 2 weeks after an accident, and not significantly at any other time (lags of up to 16 weeks were tested). Hearings also follow 2 weeks after accidents, though in all cases, the *T*-stats are less than 1. Though the results are not significant, they imply that both Congress and FAA react simultaneously to accidents and do not pull each other's strings explicitly (see Table 3).

TABLE 2 RISK AND FACTORS REVISITED (EQUATION 4)

R-square = .8294

Risk =	Rainfall +	Time +	Transport wage +	Airline Profit +	# Passengers
Coef.	.738E-8	-.917E-6	.966E-6	-.111E-6	.196E-13
[Tstat]	[.0679]	[-1.53]	[.877]	[-.843]	[1.44]

+ Deregulation	+ Jet Innov.	+ FAA ADs	+ log(FAA ADs)
.457E-7	-.253E-5	-.128E-7	.211E-5
[.0339]	[-1.85]	[-.436]	[.684]

TABLE 3 ACCIDENTS, FAA ACTIVITY, AND CONGRESSIONAL HEARINGS; ALSO, ACCIDENTS AND THE AIR TRAFFIC CONTROL STRIKE (EQUATIONS 5, 6, AND 7)

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Equations 5-6: Relation of Air Safety, FAA ADs and Congressional Hearings
R-square = .0518
(Figures are for two week periods; Accident-2 are accidents three and four
weeks ago, and FAA ADs+2 are ADs two weeks in the future.)

Hearings =  Accident + Accident-2 + Accident-4 + Accident-6 + Accident-8
Coef.         .1933     -.03378      -.0579       -.06301      -.0915
[Tstat]      [.7494]   [-.4061]     [-.7034]     [-.7655]     [-1.11]

           +Accident-10  + Time + FAA ADs+2  +  FAA ADs+4
            -.03228      -.0258   .002698        .03885
           [-.3875]     [-2.056] [.09898]       [1.4346]

R-square = .0695
FAA ADs = Accident  + Accident-2 + Accident-4 + Accident-6 + Accident-8
          -.0606     .0208        -.2885       -.07537      -.2858
          [-.274]   [.0936]      [-1.315]     [-.3435]     [-1.299]

          + Accident-10 + Accident-12 + Accident-14 + Accident-16
            -.3365        -.2646        -.00209       .471
            [-1.51]       [-1.19]       [-.00937]    [2.095]

          + Hearings  +  Time
            -.1275      -.06286
            [-.6565]   [-1.805]

Equation 7: Relation of 1981 Air Traffic Controllers and
            Air Traffic Control Related Accidents
R-square = .7411

ATC accidents = Strike + Time + Log(Time) + FAA ADs + log(FAA)
Coef.           .139E-7   .25E-6  -.207E-4   -.298E-8   .375E-6
[Tstat]         [.182]    [2.14]  [-2.36]    [-1.19]    [1.5]

             + Jet Innovation + Deregulation
               .578E-7          .588E-7
               [.67]            [.825]
```

CONCLUSIONS

Literature Survey

From the literature survey, it appears that accidents may be random or occur so infrequently that they approximate randomness, for lack of a better-fitting distribution. There is a size-safety relation, though it holds only across groups of carriers and is weak. Technological progress has steadily improved air safety, and deregulation does not appear to have hampered that time trend, and perhaps has improved it.

Probably the biggest contribution of this study was the debunking of the financials-safety myth. Deregulation has not caused cost-cutting to win out over reputation effects and endanger safety: in fact, the opposite appears true.

Regulation emasculated a strong public interest and safety discipline mechanism. Testimonies before and after deregulation indicate that before deregulation, passengers assumed all airlines were alike, presumably because they were all regulated alike. Since deregulation, passengers follow safety records and remember accidents.

Statistical Analysis

This inquiry developed a much-needed new definition of an accident useful to United States air travelers. This measure provides a purer, more error-free measurement of flight safety. Future studies should extend the meter to United States passengers on foreign and charter flights.

The safety rate was tested against departures and miles, rather than assuming one measure was best for all purposes. The effect of deregulation on load factors and death rate, long ignored, was tested and found to be insignificant.

Two data sets were collected and used with the new accident definition. Accidents are randomly generated but tend to occur more under certain circumstances. Deregulation was a positive safety innovation. Profit and maintenance expenditures have no uniform or significant effect on safety.

FAA has played a significant role in air traffic control innovation, though deregulation indicates that less government control is better. FAA exhibited decreasing returns to effectiveness statistically; other studies indicated that fines and regulations were statistically insignificant. A significant knee-jerk relation with Congress failed to appear. Assuming that ADs are a proxy for overall FAA activity, FAA has improved aviation safety, notably in its technology leadership.

Historical Observations

Civil Aeronautics Authority, Civil Aeronautics Board, and NTSB reports over 60 years point to certain factors correlating with higher accident rates. Rain, night flights, smaller planes, turboprops (as opposed to bigger jets), international flights, and territorial flights all increase risk.

The 1960s witnessed a high number of equipment failures, particularly landing gear collapse, with landings on foamed runways (see Figure 1). Midair collisions in the early 1960s occurred with frightening frequency, creating risk that dwarfs

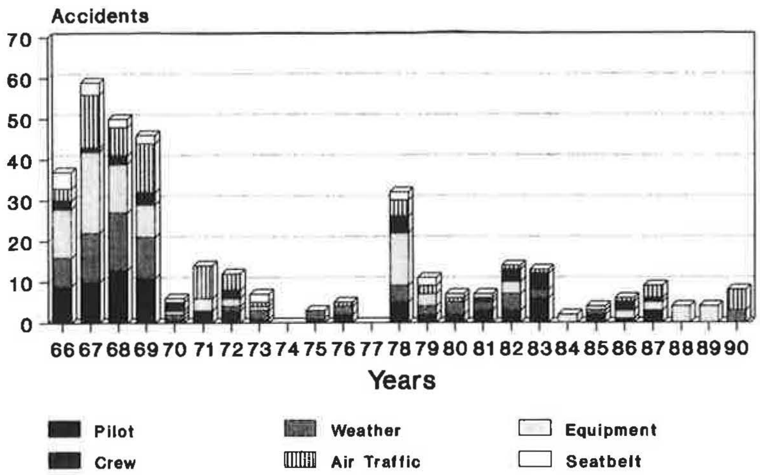

FIGURE 1 Accident causes over time.

the modern odds. Congestion and air traffic control error contributed to many of the 1960s collisions. The 1970s showed the rise and fall of unseated passenger and flight attendant injuries. The 1980s saw increasing crew communication and better and more aircraft equipment. The power of the time and technology trend lies in ongoing safety improvements.

Safety levels achieved in the 1960s made commercial flight in the 1930s appear reckless; similarly, 1990 safety levels make the 1960s flights appear dangerous. Paradoxically, because of deregulation, travelers are now more concerned with danger levels; that in turn raises vigilance. Deregulation may be seen as one in a set of continuing safety improvements. It is a sweet failing that these improvements make accidents so rare that it is hard to statistically prove that result.

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