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Aircraft Cabin Turbulence Warning Experiment

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April 2006

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ABSTRACT

New turbulence prediction technology offers the potential for advance warning of impending turbulence encounters, thereby allowing necessary cabin preparation time prior to the encounter. The amount of time required for passengers and flight attendants to be securely seated (that is, seated with seat belts fastened) currently is not known. To determine secured seating–based warning times, a consortium of aircraft safety organizations have conducted an experiment involving a series of timed secured seating trials. This demonstrative experiment, conducted on October 1, 2, and 3, 2002, used a full-scale B-747 wide-body aircraft simulator, human passenger subjects, and supporting staff from six airlines. Active line-qualified flight attendants from three airlines participated in the trials. Definitive results have been obtained to provide secured seating–based warning times for the developers of turbulence warning technology.

NOMENCLATURE

ACTWE	Aircraft Cabin Turbulence Warning Experiment
AERF	Advanced Evacuation Research Facility
AvSP	Aviation Safety Program
CAMI	Civil Aerospace Medical Institute
D	deployed
FA	flight attendant
FAA	Federal Aviation Administration
LAV	lavatory
lidar	light detection and ranging (an infrared spectrum–based radar-like technique for detecting clear-air turbulence)
NAS	National Air Space (The air space over the continental United States beginning at the surface and extending to as high as commercial aircraft typically fly, over which the FAA has responsibility for maintaining aircraft separation)
pax	passenger(s)
PIREP	pilot report
S	stowed
TPAWS	Turbulence Prediction and Warning Systems

INTRODUCTION

Atmospheric turbulence has long been a difficult issue for the aviation community. Early turbulence experience and associated effects led to the formation of the Turbulence Prediction and Warning Systems (TPAWS) element within the Aviation Safety Program (AvSP), a joint program between NASA and the Federal Aviation Administration (FAA). The TPAWS element focuses on providing warning of turbulent conditions during commercial aircraft flights so that appropriate action can be initiated to minimize injuries and damage. The Aircraft Cabin Turbulence Warning Experiment (ACTWE) within TPAWS is based on the need to establish a warning time requirement for recently developed in-flight turbulence warning technology.

Turbulence Encounter Costs

Turbulence encounters cause injuries, resulting in fiscal costs directly associated with the injuries and other financial drains on the airline industry. Turbulence is the leading cause of in-flight injuries. During the past 16 years, 3 fatalities, 176 serious injuries, and 544 minor injuries have occurred as a result of turbulence (ref. 1). During a recent average year, commercial aircraft passengers and crew sustained 75 serious injuries and 350 minor injuries resulting in 15,000 lost workdays (ref. 1) for the crew members involved. The airline industry's average annual costs associated with turbulence-related injuries and fatalities are estimated at $26 million (ref. 2).

Several sources have produced estimates of the airline industry's annual fiscal costs. Consequently, various assumptions and cost factors were considered, resulting in a wide variation of estimates. A recent study sponsored by the Commercial Aviation Safety Team (CAST) estimated that from 1988 to 2001, turbulence cost the industry $31 billion (ref. 2), an annual average of $2.4 billion. An incomplete list of cost elements includes insurance, damage claims, employee medical expenses, lost work time, aircraft inspections, aircraft out-of-service time, routing disruption, and increased fuel.

Approach to Injury Reduction

National Transportation Safety Board (NTSB) records provide a compelling argument that the most effective approach to reducing injuries during a turbulence encounter is to require that all cabin occupants are seated and securely belted prior to the encounter. In this report the term "securely seated" or "secured seating" refers to a situation in which occupants or a class of occupants (that is, passengers or flight attendants) are seated and belted. To ensure that occupants are secured, an appropriate warning must be available in time for occupants to return to their seats and fasten their seat belts. This warning must be reliable (that is, it must have both a low missed detection rate and low false alarm rate) to build confidence with aircraft crew and persuade passengers to respond appropriately to turbulence warning announcements.

Turbulence Warning Technology

The AvSP, as part of the effort to reduce the airline in-flight turbulence accident rate, has supported the development of in-flight turbulence detection technology that would provide warning of impending turbulence encounters. This development has been pursued through a government and industry collaboration involving NASA and private sector technology development companies, airlines, and avionics manufacturers. The private sector manufacturers produce enhanced weather radar sets for commercial airlines and the development companies perform research to develop infrared-based lidar remote turbulence detection technology. Airlines provide in-service evaluation of new technology and enhanced commercial products to assess effectiveness and develop operational standards for use. New enhanced weather radar technology developed in the AvSP recently was tested in flight. During the in-flight testing, the radar technology provided 80 seconds (ref. 2) of warning time of an impending turbulence encounter, with a low false alarm rate. Although these results are promising, 80 seconds of warning time without additional situational awareness to determine an escape path is not sufficient to maneuver for turbulence avoidance. Researchers are hopeful that increased warning times eventually will be possible with enhanced technology, but establishing realistic operational warning requirements is important for focusing research activities and measuring technological performance.

Warning Time Requirement

Operational warning requirements provide the basis for estimates of injury reduction and cost savings that would result from a reliable turbulence warning system. A realistic warning time requirement is needed for the development of turbulence warning technology. Postulating a reliable sensor with a close-to-zero false alarm rate is expected to reduce the time necessary to secure the cabin. This expectation is based on the belief that both passengers and flight attendants will take the warning seriously, but data are not available to support this hypothesis. The AvSP Executive Committee endorsed the ACTWE trials to determine the cabin preparation time. United Air Lines, Inc. (Chicago, Illinois), offered an out-of-service aircraft to use in the experiment.

The objective of turbulence warning technology is to provide as much warning time as possible. Until the trials were held at the FAA Civil Aerospace Medical Institute (CAMI) facility, no definitive set of requirements was available for minimum pre-encounter warning time that would allow all cabin occupants to be securely seated. The primary purpose of the trials was to determine the time necessary for passengers and flight attendants to be securely seated. Several knowledgeable airline staff members had estimated secured seating times ranging from 2 minutes to more than 8 minutes. The trials provided estimated secured seating time based on a realistic set of the most difficult in-flight scenarios commonly encountered under existing cabin procedures.

Cabin Procedures

Ideally, the trials would establish a required secured seating time under an existing procedure (called the baseline procedure). That seating time then would be compared to the seating time under a different procedure (called the expedited procedure), in which an announcement (more urgent than that used in the baseline procedure) is made and flight attendants seat themselves as quickly as possible. Attendants apply brakes on the serving carts and leave the galleys unsecured. Use of the expedited procedure is increasing among the major airlines, and secured seating is believed to be accomplished more quickly with this approach.

Experiment Goals

The primary goal of the ACTWE was to determine the time required to configure a commercial aircraft cabin for safe transit through atmospheric turbulence and in turn reduce turbulence-related injuries. In addition, three additional objectives were established: provide an accurate secured seating time estimate for use in the development of turbulence warning technology, understand the variables affecting the cabin configuration process, and establish a benchmark for future reference.

On October 1, 2, and 3, 2002, the ACTWE was conducted at the FAA CAMI in a full-scale wide-body aircraft cabin configured as a revenue service aircraft. Staff from six airlines, two flight attendant unions, and two government agencies participated in the trials.

BACKGROUND

Atmospheric turbulence occurs in varying degrees at all altitudes and poses a hazard to all flight vehicles. From the earliest days of manned flight, air was recognized as extremely turbulent in the areas of convective activity. In fact, turbulence was the subject of the first report (published in 1917) by the National Advisory Committee for Aeronautics (NACA), the predecessor to NASA. To this day, flight crews try to avoid thunderstorms and associated turbulent airflow.

Turbulence Sources and Visual Clues

Turbulence generated by convection is associated with visual clues in the form of clouds, which the pilot can use to avoid turbulence encounters. The processes that cause convective storms are commonly known to generate high levels of turbulence within cloud formations. Less commonly known is the fact that substantial turbulence exists (as much as 50 miles) outside the cloud boundaries of convective storms in the clear air at the base and above convective buildups.

In the early days of electronic weather information gathering, pilots reported the presence of turbulence without any associated weather system. The term clear-air turbulence (CAT) was coined to describe turbulent air that is present without visible weather activity. This type of turbulence (generated from jet-stream or mountain-wave activity) is particularly troublesome, because it provides no visual clues to warn pilots, except under very special circumstances.

Turbulence Encounter Warnings

The lack of a reliable turbulence warning system is one reason that commercial aircraft cabin crews are not able to effectively prepare for turbulence encounters. Without reliable turbulence warning technology, flight crews have little or no confidence in the alerting process and consequently have little incentive to rapidly reconfigure aircraft cabins for safe transition through turbulence. Instead, flight crews often ignore the warnings. General passenger lack of education of the potential for turbulence-related injury historically has resulted in considerable lead time to secure the cabin, averaging several minutes. Experienced passengers also lack confidence in the warnings and often ignore them.

Some knowledgeable members of the aviation safety community have estimated that 8 minutes would be required to prepare an aircraft cabin for a turbulence encounter. Others have estimated that with a reliable warning system and new procedures, a substantial percentage of the passengers and flight attendants might be securely seated in as little time as 2 minutes. This wide span of estimates and insufficient data pertaining to cabin preparation time provide a required warning time prediction that is unacceptably vague. Without a more reliable warning time estimate, performance and cost estimates for the development of turbulence warning technology cannot be determined. This lack of specificity creates uncertainty for the technological development, which will delay the readiness and installation of warning technology and cause the high rate of turbulence-related injuries to continue.

Turbulence Encounter Warning Mechanisms

A major contributing factor to the absence of a reliable turbulence warning system is the difficult challenge of consistently detecting turbulence with the confidence expected from other weather detection aids (such as weather radar) or weather forecasts. High-altitude wind shear is a basic hazard element that causes injuries mostly in the climb out, cruise, and descent phases of flight. Wind shear can be created by several atmospheric phenomena, such as convective thunderstorms, jet-stream interactions, mountain-wave activity, and wake vortices from leading aircraft. Unfortunately, no common indicator can be used to reveal the presence of wind shear. Doppler shifted radar returns from atmospheric moisture can be used when sufficient moisture is present, but this approach cannot be used in clear-air conditions when moisture is insufficient. Likewise, Doppler shifted returns from naturally occurring atmospheric aerosols are detectable with lidar technology when sufficient aerosol concentrations are available. Lidar has potential for future use but is currently at a low maturity level and will not be available for some time. Forecasts endeavor to identify atmospheric conditions that are conducive to the development of wind shear. Turbulence onset may be extremely abrupt and a gradual buildup of turbulence intensity often is not present. Pilot reports (PIREPs) provide in-situ warnings but often lack objectivity and do not account for aircraft-specific response variations. Major turbulence warning mechanisms include weather radar, forecasts, and PIREPs.

Weather Radar

The turbulence warning technology in current onboard weather radar produces high false alarm rates and primarily detects turbulence within thunderstorms, which flight crews already avoid as a matter of procedure. Many pilots disable the warning feature to avoid distraction from unreliable information.

Forecasts

Currently available turbulence forecasts provide limited assistance for pilots seeking to avoid turbulence encounters. Typically, large areas of the National Air Space (NAS) are identified where conditions exist that are likely to produce turbulence. Areas as large as several states and sometimes as large as half or more of the continental United States (CONUS) may be included. Forecasts are more useful when specific altitude regions are included, and turbulence forecasts for large areas are not very useful. State-of-the-art turbulence forecasting technology continues to improve as more highly resolved weather information with more complete coverage becomes available and improved modeling concepts are developed; however, in the foreseeable future, turbulence forecasts are not expected to reliably predict specific aircraft turbulence encounters.

Pilot Reports (PIREPs)

For many years, pilots encountering unexpected turbulence have used the voice communication channel to provide verbal reports to other nearby aircraft and to air traffic control. Turbulence situational awareness received in this manner generally provides the longest warning time of all the warning mechanisms. The PIREP is arguably the most current and most accurate source of turbulence information, often providing sufficient time to execute an avoidance maneuver or alert the cabin if changing altitude or direction is not an option. Because turbulence is often stratified in altitude bands, the PIREP may be less reliable, especially when the reporting and receiving aircraft are flying at different altitudes. Unfortunately, relaying PIREP information to aircraft in flight often is a very low priority of flight controllers. As a result, valuable information often is not conveyed in sufficient time to allow the pilot an opportunity to avoid turbulence.

Turbulence Structure

Some turbulence structures have light turbulence intensity at the periphery, and the intensity increases as the center of the structure is approached. In this situation, when light turbulence is encountered, an alert pilot will give a warning to passengers and flight attendants to be seated, which will protect cabin occupants if the turbulence intensifies to a moderate or severe level. Other turbulence structures give no warning, thus the severe effects are experienced without warning immediately upon penetrating the structure.

Warning Communication

When available, warnings of expected turbulence encounters are communicated to cabin occupants according to airline procedures through pilot announcements and communication with the cabin crew. When the warning is received only a short time before the encounter, the information must be transmitted to the cabin occupants with minimal delay to allow maximum time for secured seating. Passengers receive warning information from announcements and the “Fasten Seat Belt” sign.

Turbulence Encounter Effects

Aircraft response to high-altitude wind shear can cause severe motion that may adversely affect cabin occupants and damage the aircraft. The adverse effects on cabin occupants include physical injuries and emotional trauma.

Aircraft Motion

The primary effect of a turbulence encounter is acceleration experienced in the aircraft vertical axis caused by vertical gusts in the turbulent region. Vertical gusts cause occupants to loose footing and severe vertical gusts may propel unbelted occupants into the cabin ceiling. Lateral and roll accelerations also are present but are not as much of a hazard as vertical accelerations, although side-to-side aircraft motion is dangerous for standing cabin occupants who may be knocked off balance, thereby causing ankle or knee breaks and sprains.

During a turbulence encounter, vertical acceleration effects are not experienced uniformly throughout the aircraft and may vary with an occupant's location inside the aircraft. As an aircraft enters a vertical gust, it experiences a combination of overall vertical acceleration and a pitching moment, which is the result of uneven vertical forces as the aircraft transitions through the gust front. Because an aircraft is designed with a forward center of gravity, vertical acceleration effects usually are moderate in the front of the aircraft and more severe in the tail position. Theoretical analysis and anecdotal evidence support this observation (ref. 3).

Injuries

Flight attendants experience a disproportionately large percentage of turbulence-related injuries. They are at higher risk of injury, because they must continually move around the cabin to perform service activities and safety functions to ensure that passengers are protected from turbulence effects.

The risk of injury increases when the aircraft motion causes zero or negative vertical acceleration (known as a weightless condition). Under this weightless state, unconstrained objects (including cabin occupants) can be thrown upward violently and could impact the aircraft ceiling. During severe turbulence encounters, more than one cycle of high vertical acceleration often is experienced, hurling objects and unbelted cabin occupants into the ceiling and back onto the floor (or onto unyielding seat arms) several times, thus posing a serious safety hazard with a high probability for serious injuries.

Passenger Fears

Many travelers are terrified of turbulence encounters. Some travelers, after experiencing turbulence, will travel by air only when absolutely necessary. In some cases, people will not travel by air under any circumstances. Although no studies are known to exist on the general problem of passenger fear of turbulence, it is believed to discourage a large number of potential air travelers.

Aircraft Damage

Aircraft damage caused by turbulence rarely is serious enough to necessitate diversion to an alternate landing site; however, before the aircraft can be returned to service, regulations require that a hull inspection be performed to ensure airworthiness. Only moderate or severe turbulence encounters, in which a specific acceleration threshold has been exceeded, require inspections.

Safety Program Development

In August 1996, a White House Commission on Aviation Safety and Security was established to study aviation safety issues. The Commission concluded that the overall accident rate for major air carriers and commercial aviation is low and has been nearly constant in the recent past, and the growth in traffic has resulted in an increase in the absolute number of accidents. Aviation accidents can negatively affect public view and confidence, potentially slowing the anticipated growth of commercial air travel. In February 1997, a national goal was set by the Commission to reduce the aviation fatal accident rate by 80 percent within 10 years.

To establish a focused safety program, a major program planning effort was instituted to gather information from the aviation community regarding the appropriate research to be conducted by NASA. The resulting NASA Aviation Safety Investment Strategy Team (ASIST) conducted industry and government workshops to identify research that could have the greatest impact on accident reduction. The ASIST activity recommended the establishment of a project within the AvSP to reduce injuries from atmospheric turbulence, even though relatively few associated fatalities have occurred.

EXPERIMENT APPROACH

To ensure an accurate estimate of required seating time, emphasis was placed on achieving the highest level of realism possible within the resource constraints of the program. Emphasis also was placed on conducting trials that closely represent commercial airline in-flight situations in which turbulence is encountered.

Experiment Setup

To ensure representative results based on the performance of a cross section of the flight attendant population, flight attendants from three major airlines participated in the ACTWE trials. Although differences were expected among the crews, competition was strongly discouraged and participants were requested to base their actions on the training and experience that they had received at their respective airlines.

Three scenarios were developed to simulate commonly encountered in-flight commercial aircraft situations that present the most difficult and challenging conditions for responding to a turbulence encounter. Although secured seating times were expected to vary with each scenario, different scenarios were used to ensure representative results. Scenarios were not expected to be a major experiment variable, although discoveries from trials with different scenarios would provide insight.

Two procedures were applied for each scenario. The type of procedure, a major experiment variable, was expected to affect secured seating times and reveal clues for improved practices in the airline industry.

Passenger subjects were drawn from the same pool of candidates for all three days of the experiment. The same subset of passengers was used to conduct each scenario. To minimize learning curve effects and ensure an impromptu performance, the role for each passenger was changed between each trial.

Schedule

Three days (one day for each flight attendant crew) were allocated for the experiment. Six trials were conducted every day, and each procedure was applied to each scenario. A total of 19 trials were completed; 18 were used to acquire data, and 1 was used as a photo opportunity for the press.

Staffing

The flight attendants were chosen by the participating airlines from their active line crews to ensure that all had recent line experience and were familiar with current airline procedures. Passenger subjects were selected from individuals who responded to advertisements. To ensure consistency with accepted practice in other human subject testing, Federal Aviation Regulations (FAR), Part 25, Paragraph J, "specification for passenger subject demographics," was used. This section of the FAR specifies the demographics for aircraft cabin evacuation drills. It states that a representative passenger load of persons in normal health must be used as follows:

1. At least 40 percent of the passenger load must be female.
2. At least 35 percent of the passenger load must be over 50 years of age.
3. At least 15 percent of the passenger load must be female and over 50 years of age.
4. Three life-size dolls, not included as part of the total passenger load, must be carried by passengers to simulate live infants 2 years old or younger.

Cabin Logistics

The Advanced Evacuation Research Facility (AERF) at CAMI was selected for the experiment. The AERF is a decommissioned B-747 aircraft (Boeing Company, Seattle, Washington) that has been reconfigured to support the staging of cabin evacuation drills (fig. 1). The facility was configured to represent the layout of a line B-747 aircraft to ensure a valid outcome. To simulate an actual aircraft situation, the following activities were included in the trial procedure:

- Active line cabin crews were used to perform the normal duties of cabin service and passenger control during the trials.
- Flight attendants were seated according to two accepted procedures currently used by major airlines.
- Passengers were conditioned to respond to a reliable turbulence encounter warning.
- Passengers submitted boarding passes and brought carry-on baggage as part of the passenger boarding process (because no cabin motion was involved in this activity, it is not a factor in turbulence encounters and was done only to increase the realism of the experience).
- Normal passenger safety briefings were provided before the trial began.

Figure 1. Advanced Evacuation Research Facility (AERF).

Support Resources

A team of private companies, employee organizations, and government entities jointly supported the experiment as follows:

- Delta Air Lines, Inc. (Atlanta, Georgia), United Air Lines, Inc., and US Airways, Inc. (Arlington, Virginia), supplied the flight attendant crews.

- Delta Air Lines, Inc., United Air Lines, Inc., US Airways, Inc., American Airlines, Inc. (Fort Worth, Texas), JetBlue Airways (Salt Lake City, Utah), and Southwest Airlines Co. (Dallas, Texas), contributed planning and support staff.
- FAA CAMI provided planning and support staff, in addition to design, labor, and materials to configure the AERF.
- Flight attendant employee organizations (the Association of Flight Attendants, and the Association of Professional Flight Attendants) contributed planning and support staff.
- Aviation Research, Inc. (Laguna Beach, California), assisted with activity planning and provided a perspective of the aviation community to ensure that the experiment would address current major issues.
- NASA supplied passenger subjects, airline safety consultants, and general management oversight.

Processes and Instructions

Cabin instructions to participants were designed to ensure that the stated goals of the exercise were achieved and that all participants clearly understood the processes. Appendix A presents a detailed description of the subject instructions.

Flight Attendant Processes

Flight attendants were brought to the test site the evening before the trials to receive a briefing on medical issues associated with the experiment and were offered the opportunity to ask questions about the experiment process. The legal rights of the participants were explained, and each flight attendant voluntarily signed a legal release to permit the use of data recordings for research and public reporting purposes.

Each host airline uses a very specific approach for setting up the serving equipment. The flight crews configured their serving carts and galleys according to their respective airline training.

Because each airline has a unique galley layout, duplicating the exact configuration of each host airline was not possible. The galleys were configured with a generic layout similar to that used in all the host airlines, but they were not exact representations of any specific host airline galley. Cart availability and stowage arrangements were similar for all the host airlines, and the cart installations resembled those of the host airlines with only minor variations. Airline crews stocked the galleys with serving equipment and supplies from their respective airlines and gained familiarity with the galley layout and cart configuration before the trials. The slight variations between galley representations and actual galley layouts are not believed to have measurably affected the results.

Flight crews were instructed to perform normal duties according to their training. After the captain's warning announcement, the announcements made by the lead flight attendant (purser) were constructed according to the individual airline policy and customary practices and procedures.

Passenger Processes

Passengers assembled at an off-site location and were transported by bus to the CAMI facility headquarters building located near the Will Rogers World Airport (Oklahoma City, Oklahoma). Testing and administrative processing were completed at this location, and the passenger subjects then were transported to the AERF.

Passenger subjects were advised of their rights as required by the U.S. Department of Health and Human Services. Full disclosure of the risks associated with the experiment was provided with historical injury statistics from similar CAMI activities. All subjects voluntarily signed a legal release to allow the use of personal experiment video data images for research and limited public releases. All images are suitably de-identified.

A role was defined for each passenger in each location and scenario. For example, some passenger subjects were sleeping or reading, and others were working on laptop computers. Some subjects were in the lavatories, waiting for the lavatories, or standing in the aisles conversing with other passengers or the cabin crew. The role instructions for each passenger were contained on a boarding pass that was issued during the boarding process and were linked to a vest number assigned to each passenger subject. To enhance realism, passenger subjects in lavatories were asked to wait 20 seconds before exiting. To avoid biasing the passenger subjects, the general instructions were limited to the minimum necessary to accommodate simulated cabin situations.

Passengers were provided with typical carry-on equipment including luggage, books, and simulated laptop computers. Anthropomorphically accurate dummies were used to simulate children.

Food Service

To avoid the problem of food spills and cleanup time delays, nonedible imitation food was used. Food service was provided for the unoccupied seats (these seats contained cardboard boxes) to make conditions realistic for a full load situation.

Recorded Announcements by Line Pilots

To ensure that the warning announcements of an impending turbulence encounter and instructions to return to seats were consistent and realistic, a recording of the announcement from a line pilot was prepared and broadcast at the beginning of each trial. Appendix B contains the narrative of the pilot announcement.

Timing Procedure

The timing procedure for the trials started the clock at the beginning of the warning announcement. To get a total warning time estimate for an actual in-flight situation, it was necessary to add the time required for the pilot-in-command to receive the warning information and make the decision to alert the passengers. For further discussion, refer to the "Results" section, under "Implications of Results."

Nonparticipants

To ensure that the passenger and flight attendant subjects were not distracted, all persons not a part of the actual experiment were removed from the cabin trial area. This rule was strictly enforced.

Cabin Configuration

The cabin configuration represented the layout of a line B-747 aircraft. A total of 210 passenger seats were installed in the cabin area. In addition, five jump seats were installed for flight attendant use. Galley and cart stowage configurations and service classes replicated those of an actual aircraft. The cabin was configured to support both first class and coach class levels of service. As shown in figure 2, first class seating was installed in zone 2, and coach class seating was installed in zones 3 and 4.

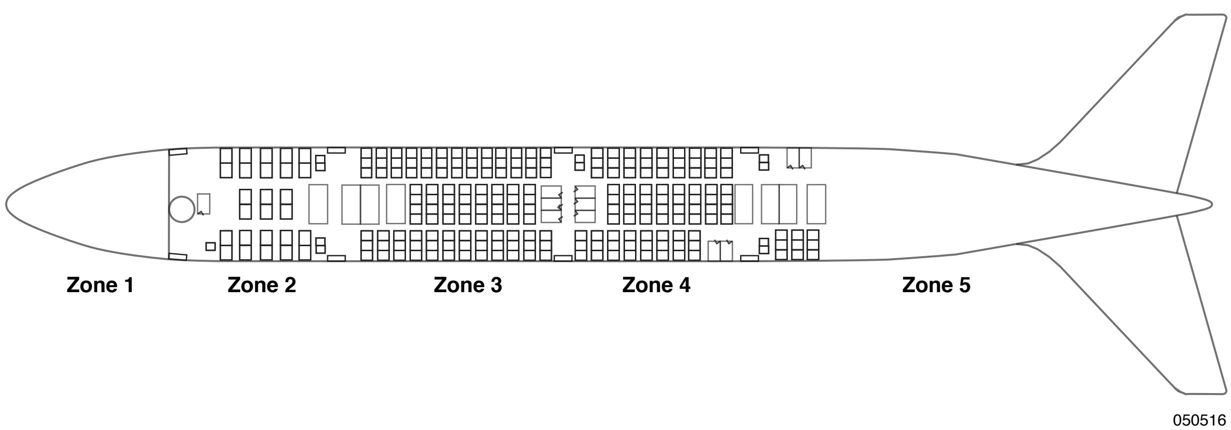

Figure 2. Advanced Evacuation Research Facility (AERF) seating layout.

Full Passenger Load (Worst-Case Condition)

Reseating passengers in preparation for a turbulence encounter is most difficult under conditions of a full passenger load. Pathways available for returning to assigned seats are most congested in a full load situation. For all loads, approximately the same percentage of passengers are roaming at any one time; however, with a full load, a greater number of passengers are out of their seats, hindering quick returns to assigned seats, because additional moving passengers must be avoided. Under full load conditions, the reduced space available per passenger is believed to induce roaming tendencies, because passengers must move muscles to avoid cramping or other unpleasant effects caused by confinement in a small space.

Scenarios

Based on flight attendant experience, three scenarios were selected that present very challenging situations when in-flight turbulence is anticipated. Scenario A takes place midway through an international flight after a movie presentation. Scenario B takes place on a domestic flight during pickup from snack service 30 minutes before landing. Scenario C takes place midway through a domestic flight during a meal service.

Challenges included reseating a large group of roving passengers and reseating a smaller group during a meal service when serving equipment was blocking routes to assigned seats. Line flight attendant experience was used to determine the number of roaming passengers for each scenario. Fewer passengers were roving during the food service scenarios, and relatively more passengers were up during the "after movie" scenario. Approximately 15 percent of passengers were roving in the worst-case condition.

Table 1 and the subsequent narratives describe specific details of each scenario. Appendix C provides the details of scenario A as an example of the scenario structure.

Table 1. Scenario conditions.

Scenario	Initial conditions		Cabin complement					
	Roving pax	Seated pax	Total pax	Total boxes	Total load	Infants	Child restraints	Flight crew
A	20	48	68	147	210	2	3	5
B	33	35	68	147	210	5	3	5
C	13	55	68	147	210	1	2	5

Scenario A

Scenario A takes place midway through an 8-hour international flight, after a movie, at an altitude of 42,000 feet. Normal activities occurring in the cabin include passengers working on computers, reading, sleeping, and stretching their legs; passengers occupying every lavatory and waiting in line; and flight attendants working in the galleys. Cabin lights are dimly lit, and most window shades are closed.

Scenario B

Scenario B takes place on a 2.5-hour domestic business flight, 30 minutes before landing, at an altitude of 35,000 feet. This scenario represents the most common in-flight situation and has the largest number of roving passengers. Normal activities occurring in the cabin include passengers finishing breakfast; passengers occupying every lavatory and waiting in line; flight attendants returning personal items in the first class section; flight attendants picking up breakfast supplies; and galley flight attendants securing items. Cabin lights are brightly lit, and most window shades are open.

Scenario C

Scenario C takes place midway through a 5-hour domestic flight, during the meal service, at an altitude of 37,000 feet. Normal activities occurring in the cabin include passengers eating lunch; a few passengers using the lavatories; and flight attendants in the aisles serving beverages from the carts. Cabin lights are brightly lit, and most window shades are open.

Cabin Procedures

To capture the current standard operating approach for cabin preparation, a baseline procedure was employed that has been used for some time in commercial airline operations. In addition, an expedited procedure (increasingly used by the major airlines) was used that emphasizes rapid seating of both passengers and flight attendants. These two procedures were used to assess the effects of various secured seating approaches and the time required to attain secured seating.

Baseline Procedure

The baseline procedure emphasizes serving equipment stowage and galley clearing and cleanup. If serving is in progress, carts are returned to the storage cabinets. Utensils are retrieved, trash is collected, and galley equipment is cleaned and stowed to achieve an orderly cabin cleanup. The attainment of a neat and tidy cabin is emphasized rather than a partial cleanup and rapid seating. The baseline procedure represents a "classical" approach to preparing an aircraft cabin for a turbulence encounter. The baseline procedure typically is used as an early preparation for landing, because turbulence often is encountered during the descent to landing.

The captain's announcement is: "Ladies and gentlemen, this is your captain speaking. We will be encountering a line of thunderstorms in about 10 minutes as we begin our descent into the Oklahoma City airport. At this time, all passengers please be seated as the flight attendants begin an early preparation of the cabin for landing." The tenor of the captain's announcement does not imply a high degree of urgency.

Expedited Procedure

The expedited procedure emphasizes rapid seating of both passengers and flight attendants. If serving is in progress, brakes are applied on the carts, which are left in the aisles and not returned to storage. No attempt is made to retrieve utensils or trash, stow galley equipment, or clean up the galley.

The expedited procedure considers the cabin crew safety responsibilities and closely represents the practice evolving in many airline operations in which emphasis is placed on rapidly seating and belting all cabin occupants to avoid injuries. If the crew is injured in a turbulence encounter, performing safety responsibilities is difficult or impossible. Protecting the cabin crew during the encounter (that is, ensuring that they are securely seated), therefore, is a high priority. As such, flight attendants take their assigned seats after only limited equipment preparation (for example, applying the cart brakes). The decision to leave the carts in the aisles is a compromise between two options, neither of which is ideal, but it is one that is based on the most likely situation and will achieve the desired outcome under the most probable conditions.

Under the expedited procedure, the captain's announcement stresses that a turbulence encounter is imminent: "Ladies and gentlemen, this is your captain speaking. We are about to encounter some moderate turbulence. All passengers and flight attendants please be seated immediately." This announcement has an urgent tone.

The B-747 Advanced Evacuation Research Facility (AERF)

The wide-body aircraft cabin simulator, AERF, was the primary facility required for the ACTWE trials. It was developed from an out-of-service B-747-100 aircraft that had been obtained by the FAA CAMI and modified for use as a cabin evacuation simulation facility. The AERF interior had been stripped of the original flight hardware, and a power supply, air conditioning system, public address system, and fire simulation equipment had been installed.

Configuration

The AERF was configured to closely represent the configuration of a line B-747 aircraft that had been used in the past (none are currently flying). The AERF was divided into five zones, as shown in figure 2. The installed equipment (air conditioning system, public address system, and system control panels) was located in the aircraft nose cabin compartment (zone 1), so this area of the simulator was unavailable for use in the trials. First class seats were installed in zone 2, and coach seats were installed in zones 3 and 4. Because the number of available seats were sufficient to accommodate the needed passenger subjects, zone 5 (the cabin tail area) was not needed and was closed off during the trials. Figure 3 shows the AERF seating configuration.

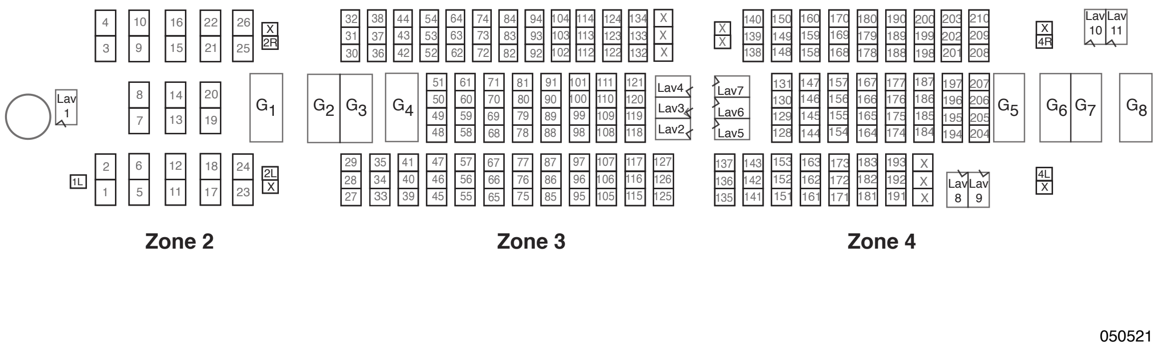

Figure 3. Advanced Evacuation Research Facility (AERF) seating configuration.

Data Recording

The exact time of passenger and flight attendant seat belt connection was required to analyze the experiment results. This information was acquired from two completely separate data systems.

Flight Attendant Data System

The five flight attendants used jump seat belts equipped with switches to indicate the exact time of belt fastening. Seat belt status was displayed in the control room and recorded for data analysis. Seat belt status was estimated within an uncertainty of ±0.2 seconds or less. Time readout was provided to the nearest 0.5 seconds.

Passenger Data System

Passenger secured seating times were obtained from a video system with 16 cameras configured to provide a clear view of each passenger seat. Figure 4 shows the video camera layout. The video camera outputs were recorded with experiment time code on tape for each trial. Secured seating times for each passenger subject were obtained through the manual viewing of the recordings and identification of the time code value for each belt fastening. Freeze-frame video playback equipment allowed forward-backward jogging to establish the best estimate of the frame in which the seat belt was fastened. The frame time code then became the fastening time. Fastening times were estimated within an uncertainty of ±0.2 seconds.

Compromises

Because of budgetary constraints, some compromises were necessary to limit costs. For example, not all areas of the aircraft simulator were used. An approximate B-747 aircraft configuration was used based on incomplete layout information from the B-747-100 version of the simulator facility. Because no known B-747-100 aircraft versions were still in active service at the time of the trials, verifying cabin layout through drawings or observation was not possible. Instead, the recollections of flight attendants with experience on B-747-100 aircraft were used to configure the cabin.

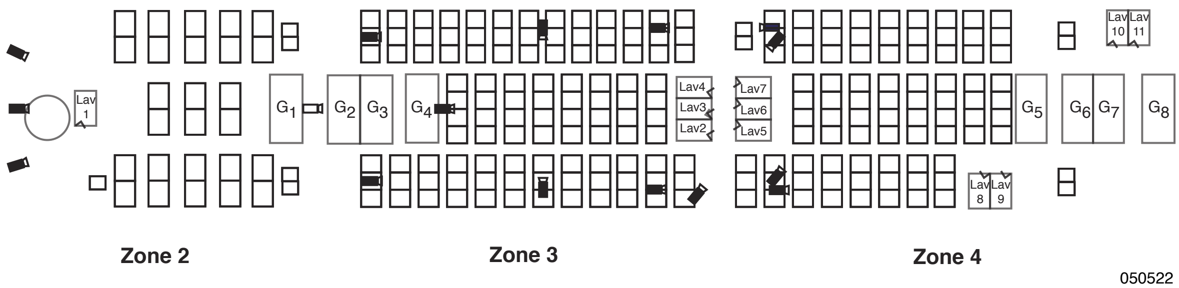

Figure 4. Advanced Evacuation Research Facility (AERF) camera locations.

As another budgetary compromise, only 70 passenger subjects were used in the trials, although seating was available for 210 passengers. Cardboard boxes were placed in the unoccupied seats to block the seat and simulate a full load condition. The same pool of passenger subjects was used for all 3 days of the trials. Concern was expressed that the subjects would learn the most effective techniques to quickly return to their seats, such as walking rapidly and taking the most direct route to the assigned seat. To limit the direct route issue, passenger subject role assignments were changed for each scenario. No evidence of learning curve effects was noted in the trial results.

EXPERIMENT PROCESS

The experiment process included cabin preparation and subject preparation, both of which involved a crew of experiment staffers operating in various roles. The final step in the process involved conducting the experiment to obtain the data necessary to satisfy the goals of the ACTWE.

Cabin Preparation

As part of the cabin preparation process, seating configurations were completed and verified for each scenario. Before each trial, the seat block crew installed and verified the seat blocks according to the cabin seat map developed for each scenario.

In addition, the galleys and carts were prepared for use prior to each trial. The flight attendant crew gained familiarity with the galleys during the introductory sessions held the evening before the trials. To prepare the galleys for the scenarios, the flight attendant crew boarded the aircraft approximately 30 minutes before the passenger subjects boarded. Between each trial, the galley and carts (if required by the specific scenario) were configured according to the requirements of the upcoming scenario.

Subject Preparation

Following the flight attendant and passenger processes, the final step was to prepare the subjects to participate in the trial. The flight attendants arrived at the facility in time to prepare the galleys and then were positioned to receive the boarding passenger subjects and assist with seating. The passenger subjects began boarding in a reserved area near the AERF. At the bottom of the boarding ramp, each subject was given a boarding pass and carry-on equipment. Subjects then proceeded up the ramp and were assisted to their assigned seats by the boarding agents and flight attendant crew.

Experiment Roles

Conducting the experiment required the support of several members of the ACTWE team serving in identified roles. A crew leader and crew were assigned to perform each of the roles. Trials were initiated only after a "thumbs up" report from each of the crew leaders. Appendix D describes these roles and responsibilities.

Press Accommodation

Although several members of the press were present during each day of the experiment, the majority arrived on the first day. An unofficial trial was conducted on the first day so that reporters could observe the experiment, acquire video footage, and prepare articles. No data were acquired during this trial. Media escorts were assigned to assist the reporters and videographers in obtaining news information.

RESULTS

The results of the ACTWE trials are based entirely on measured secured seating times for passengers and flight attendants. The passengers and flight attendants are analyzed separately. Note that in every trial, the passengers and flight attendants received from the captain an announcement of impending turbulence and instructions to be seated, and were to assume that the turbulence warning system was reliable. The trial results are believed to be representative of similar in-flight situations in which passengers and flight attendants receive warning of impending turbulence. Situations in which a less specific announcement is made, or the "Fasten Seat Belt" sign is illuminated without an announcement do not represent the conditions used in the ACTWE trials, and other than preliminary speculation, should not be directly compared to these results.

The results are described in terms of time (independent variable) and percent of securely seated occupants (dependent variable). The time begins at the start of the captain's announcement. The percent of securely seated occupants is defined as the ratio of the roving occupants at a point in time during the trial (those at risk of injury in a turbulence encounter) to the roving occupants at the start of the trial. Although the objective of the seating effort was to reach a 100-percent secured seating condition, behavior realities had to be accommodated when subjects forgot to fasten their seat belts or, because of inattention or distraction, did not complete the belt fastening process to reach the 100-percent secured seating condition. Therefore, a 95-percent belted metric was adopted as the basis for comparing passenger secured seating times. For flight attendants, the basis for comparison was the 100-percent belted condition.

Time values in this report are obtained from experiment measurements. In some cases, the experiment measurement value is cited. More often, a time composite is cited to convey the results in terms of a "best estimated time" value that represents the collective outcome of the experiment as a single value.

Some trials resulted in fast seating times (during one trial 95 percent of the subjects were seated in 61 seconds), and some trials resulted in slow seating times (during another trial 101 seconds were necessary to seat 95 percent of the subjects). Passenger and flight attendant secured seating times are presented separately. The effects of procedures, scenarios, and differences among flight attendant crews are discussed where appropriate. Table 2 summarizes the results for passengers and flight attendant crews.

Table 2. Secured seating time for passengers and cabin crews.

Subjects	Procedure effects, s	Scenario effects, s	Cabin crew effects, s
Passengers	(Substantial) Expedited, 86 Baseline, 101	(Minor) Random effects, 79–99	(Minor) Random effects, 89–98
Cabin crews	(Major) Expedited, 240 Baseline, 606	(Major) Expected effects, 262–606	(Major) Expedited, 75–240

Passenger Secured Seating Time

The passenger secured seating times, as a group, are remarkably consistent, as shown in figure 5. The data in this figure include the results from all the trials (483 data points covering all procedures, scenarios, and flight attendant crews). Individual trial data points are represented by small solid symbols. Composite data, represented by large open circles, are the combined results of the other individual trial data points displayed on the chart. For example, the round open symbol at the 95-second, 95-percent point in figure 5 shows that 95 percent of the passengers in all trials (each trial individually represented by a small data point on the chart) were securely seated within 95 seconds. The 95-percent secured seating time is believed to be a more representative result than the 100-percent time, because anomalies in secured seating times were avoided, which would unduly impact the results when the vast majority of passengers were securely seated. The trial end point at 148 seconds and several points greater than 100 seconds demonstrate that passengers can be distracted and delayed in fastening seat belts even during an experiment designed to determine secured seating times.

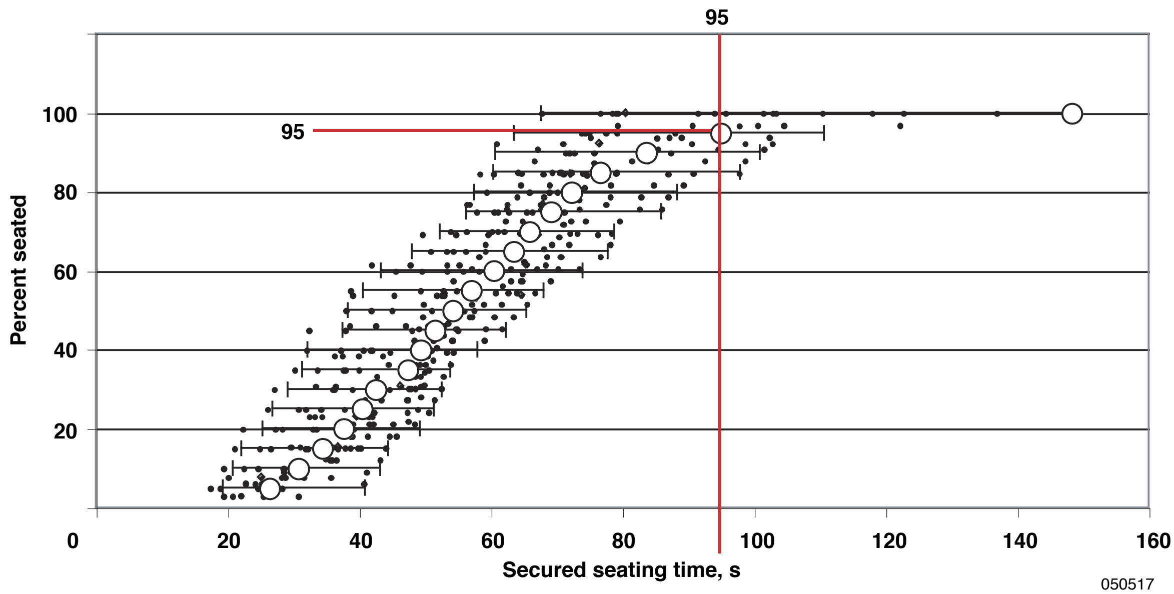

Figure 5. Passenger secured seating times under all procedures.

Effect of Procedure on Passenger Secured Seating Time

As might be expected, the expedited and baseline procedures each resulted in a different composite time for achieving a 95-percent secured seating condition (table 3). The composite time for a specific procedure is the combined passenger secured seating time resulting from all scenarios and crews.

The urgency of the pilot announcement coupled with the pretrial instructions and crew behavior is believed to have influenced these results. Although differences between procedures do not represent a major variation, these results suggest that the use of the expedited procedure could reduce the passenger secured seating time by approximately 15 seconds.

Table 3. Composite passenger 95-percent secured seating time by procedure.

Procedure	Time, s
All procedures	95
Baseline	101
Expedited	86

Effect of Scenario on Passenger Secured Seating Time

Each scenario resulted in a different composite time for achieving a 95-percent secured seating condition, as shown in table 4. The composite time for a specific scenario is the combined passenger secured seating time resulting from all crews and procedures.

Table 4. Composite passenger 95-percent secured seating time by scenario.

Scenario	Time, s
A	79
B	99
C	96

The variations in secured seating times are minimal and are thought to result from certain factors in the scenarios. Scenario B had the largest number of roving passengers, which could account for the longest delay in secured seating. Scenario C took place during a full meal service, which may have influenced the delayed secured seating times for this scenario.

Effect of Crew on Passenger Secured Seating Time

The composite passenger 95-percent secured seating time varied by crew, as shown in table 5. The composite time for a specific crew is the combined passenger secured seating time resulting from all scenarios and procedures.

Table 5. Composite passenger 95-percent secured seating time by crew.

Crew	Time, s
1	95
2	98
3	89

Variations in secured seating times among the different crews are normal variations that occur in experimental situations. Because the standard deviation of these results is 6.9 percent, these variations are not considered significant and are within the expected scatter.

Flight Attendant Secured Seating Time

Flight attendant secured seating times among the cabin crews vary substantially according to some measures but vary minimally according to other measures. The reason for this variability is unknown but probably originates from differences in training and experience among the three airlines.

Effect of Procedure on Flight Attendant Secured Seating Time

The baseline and expedited procedures each placed different expectations on the cabin crew and not surprisingly, the baseline procedure resulted in longer flight attendant secured seating times. The baseline procedure required that the cabin be cleaned and organized before the turbulence encounter, which required more time to complete. As shown in table 6, the composite time for achieving a 100-percent secured seating condition varied between the baseline and expedited procedures. The composite time for a specific procedure is the combined flight attendant secured seating time resulting from all crews and scenarios.

Table 6. Composite flight attendant 100-percent secured seating time by procedure.

Procedure	Time, s
Baseline	606
Expedited	240

Effect of Scenario on Flight Attendant Secured Seating Time

Each scenario placed different requirements on the flight attendant tasks and therefore influenced the flight attendant secured seating times. As shown in table 7, each scenario resulted in a different composite time for achieving a 100-percent secured seating condition. The composite time for a specific scenario is the combined flight attendant secured seating time resulting from all procedures and crews.

The differences in flight attendant secured seating times may have been caused by factors similar to those influencing the passenger secured seating times. Scenario B had the largest number of roving passengers, which could account for some of the delay in secured seating. The flight attendants were required to clean up the cabin after lunch, which also could have contributed to the secured seating delays for scenario B. Scenario C took place during a full meal service and the need to retrieve serving equipment undoubtedly contributed to the secured seating delays for this scenario.

Table 7. Composite flight attendant 100-percent secured seating time by scenario.

Scenario	Time, s
A	262
B	402
C	606

Effect of Crew on Flight Attendant Secured Seating Time

The overall composite flight attendant 100-percent secured seating time under the baseline procedure generally are uniform across the participating crews, as shown in table 8. The composite time for a specific crew is the combined flight attendant secured seating time resulting from all scenarios and just the baseline procedure.

Table 8. Composite flight attendant 100-percent secured seating time for each crew under the baseline procedure.

Crew	Time, s
1	507
2	554
3	606

The flight attendant secured seating times under the expedited procedure revealed the largest differences among the participating flight crews. Because of these differences, a more detailed analysis is presented for this set of conditions. The reasons for these differences are speculative and probably originate primarily from differences in the experience and training of the crews. As a benchmark, the passengers achieved a composite 95-percent secured seating condition in 86 seconds (see table 3). Table 9 shows the composite flight attendant 100-percent secured seating time for each crew under the expedited procedure. The composite time for a specific crew is the combined flight attendant secured seating time resulting from all scenarios under the expedited procedure only.

Under the expedited procedure, the flight attendants are expected to be seated shortly after the passengers, or possibly before some of the passengers. Table 9 shows that crew 1 did not achieve a 100-percent secured seating condition until 240 seconds had elapsed (more than 2 minutes after the passengers had achieved a 95-percent secured seating condition). Crew 2 achieved a 100-percent secured seating condition in 116 seconds, which is 30 seconds after the passengers had achieved a 95-percent secured seating condition. Crew 3 attained a 100-percent secured seating condition within 75 seconds, 11 seconds before the passengers had attained a 95-percent secured seating condition.

Table 9. Composite flight attendant 100-percent secured seating time for each crew under the expedited procedure.

Crew	Time, s
1	240
2	116
3	75

Figure 6 and table 10 reveal a similar pattern among the crews with respect to the time that the first flight attendant was securely seated under the expedited procedure. For crew 1, the first flight attendant was securely seated in 105 seconds (the longest time of all the crews), which is consistent with the longest composite flight attendant 100-percent secured seating time of 240 seconds shown in table 9. The seating time delay is consistent with the late start that crew 1 encountered in the secured seating process. For crews 2 and 3, the first flight attendant was securely seated in 30 and 22 seconds, respectively. These times also are consistent with the 100-percent secured seating times of 116 and 75 seconds for crews 2 and 3, respectively. When crews began the secured seating process early, the final 100-percent secured seating time also was less.

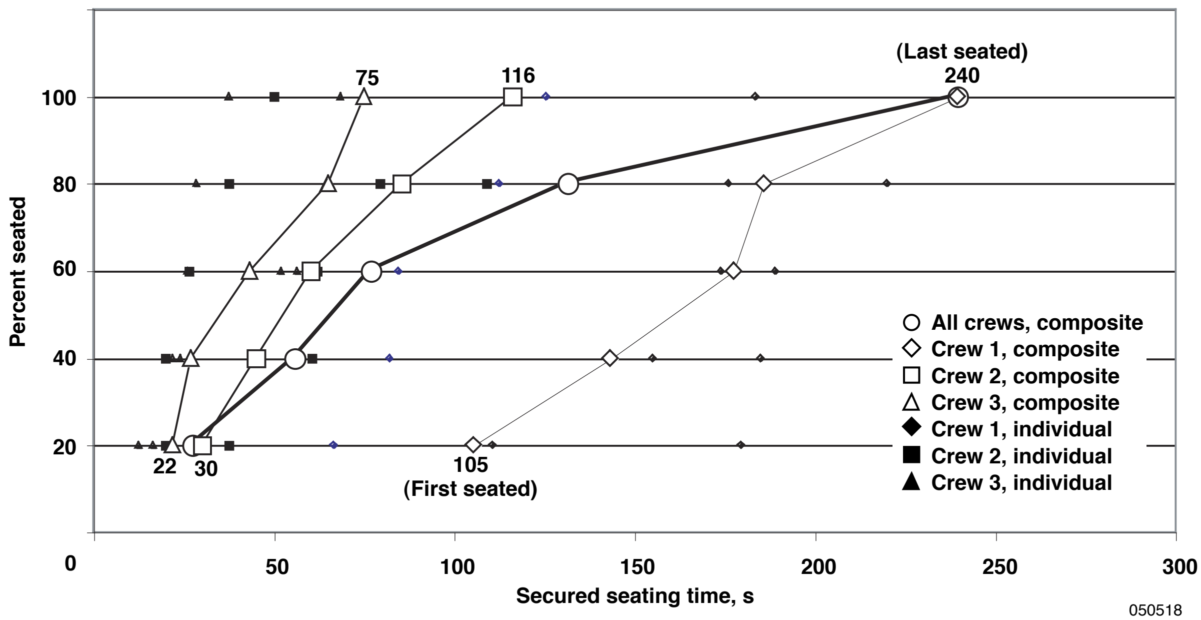

Figure 6. Flight attendant secured seating time by crew.

Table 10. Time that the first flight attendant was securely seated in each crew under the expedited procedure.

Crew	Time, s
1	105
2	30
3	22

Implications of Results

The observations address the secured seating behavior of both the passenger subjects and flight attendants. The behavior of the passenger subjects and flight attendants was affected in substantially different patterns by the scenarios, procedures, and crews.

Implications of Passenger Secured Seating Time

The passenger secured seating times are very consistent and do not appear to have been strongly affected by the different crews. All scenario A trials (for all procedures and crews) required 79 seconds to achieve a composite 95-percent secured seating condition; scenarios B and C (for all procedures and crews) required 99 and 96 seconds, respectively, a spread of 20 seconds. When the expedited procedure was used, the composite 95-percent secured seating time consistently improved by 15 seconds compared to the seating time under the baseline procedure (see table 3).

During the trials passengers occasionally became distracted for unknown reasons and delayed fastening their seat belts for an extended time after being seated. The metric used in these trials is the secured seating time, which was consistently applied in the data reduction process, although in some cases the distracted passenger subject could have fastened the belt much earlier (approximately 1 minute earlier in the worst case observed). This anomaly is believed to represent actual situations in which passengers may become distracted.

The consistency of the passenger secured seating times is an encouraging result in the sense that this variable in the overall secured seating process is probably the least controllable. In an aircraft cabin setting, passenger behavior cannot be substantially modified by training or any other influence, thus the consistency in the results of an uncontrollable variable is good news.

Implications of Flight Attendant Secured Seating Time

The flight attendant secured seating times are much less consistent than the passenger secured seating times. Because the flight attendant crews came from three different major airlines, each with distinct training programs, cabin policies, and procedures (including the definition of turbulence), behavior is expected to vary under similar circumstances.

The procedure (expedited or baseline) used in the individual trials had the most compelling effect on flight attendant secured seating times. Because of the time necessary to methodically retrieve and stow serving equipment and arrange the cabin in an orderly manner before being seated, the baseline procedure required substantially more time than the expedited procedure. On average, an additional 366 seconds (6.1 minutes) were required for flight attendants to retrieve and stow equipment and achieve a 100-percent secured seating condition (see table 6). The secured seating time under the expedited procedure is 40 percent less than the secured seating time under the baseline procedure.

The 100-percent secured seating times under the baseline procedure generally are uniform among the crews (see table 8). A standard deviation of 8.8 percent among the three values indicates minimal variability with the overall performance of the crews.

Conversely, under the expedited procedure, the secured seating times vary significantly among the three crews. As shown in table 9, the composite flight attendant 100-percent secured seating times range from 75 to 240 seconds with a standard deviation of 60 percent. An examination of the time that the first flight attendant was securely seated in each crew shows secured seating times ranging from 22 to 105 seconds with a standard deviation of 86 percent. The large standard deviations suggest major differences in crew behavior under the expedited procedure. The seating times of crew 1 are significantly longer than those of crews 2 and 3.

A comparison of the actual experiment results with the pre-experiment estimates (2 and 8 minutes, as discussed in the introduction) reveals that both estimates were reasonable depending on the secured seating procedure. The baseline procedure resulted in a flight attendant 100-percent secured seating time of 606 seconds (10 minutes, 6 seconds) compared to an estimate of 8 minutes. Under the expedited procedure, composite passenger 95-percent secured seating was achieved in 86 seconds (1 minute, 26 seconds), and the flight attendant 100-percent secured seating was achieved in 240 seconds (4 minutes) compared to an estimate of 2 minutes.

Although the variability in the secured seating times among the cabin crews appears to be somewhat troubling, this variable in the cabin secured seating process is one of the more controllable. Flight attendants undergo extensive initial and recurring training, and with an industry-wide assessment of the experiment results, flight crew training can be developed to substantially improve secured seating time. When an optimal practice permeates the industry, flight attendant secured seating can be expected to converge to a much shorter average time than that identified in the experiment trials.

Time Line for Passenger and Flight Attendant Warning and Secured Seating

Figure 7 presents a time line for the turbulence detection, recognition, warning, and secured seating process on a commercial aircraft. The figure shows that the advance warning time is consumed by an interval for the pilot to assess the situation and conclude that a warning announcement is appropriate. According to a recent AvSP safety benefit analysis report (ref. 4), 10 seconds are required for the pilot to complete this process. Therefore, the available passenger secured seating time is 10 seconds less than the advance warning time. During flight testing of an advanced weather radar system, a warning time of 80 seconds was achieved in one turbulence encounter, thereby leaving 70 seconds available for passenger secured seating. The secured seating results for all procedures show that 76 percent of the passengers were securely seated at the end of the 70-second window. Nearly identical results were obtained for both the expedited and baseline trials.

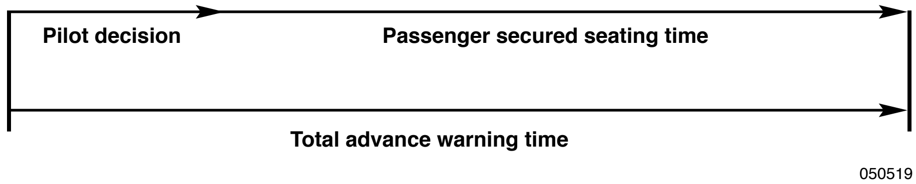

Figure 7. Time line for turbulence detection, recognition, warning, and secured seating.

Figure 8 presents the secured seating times of various occupant categories combined with the procedures used. Probably the most important finding is the first bar on the chart showing a 67-percent secured seating condition accomplished in 70 seconds for all cabin occupants under all procedures. One interpretation of this result is that 67 percent of the roving cabin occupants can be removed from the risk of injury from a turbulence encounter. The remaining chart information and observations are preliminary findings and should not be considered as definitive until the warning time is more clearly identified and additional test results are available to assess the statistics of the warning process.

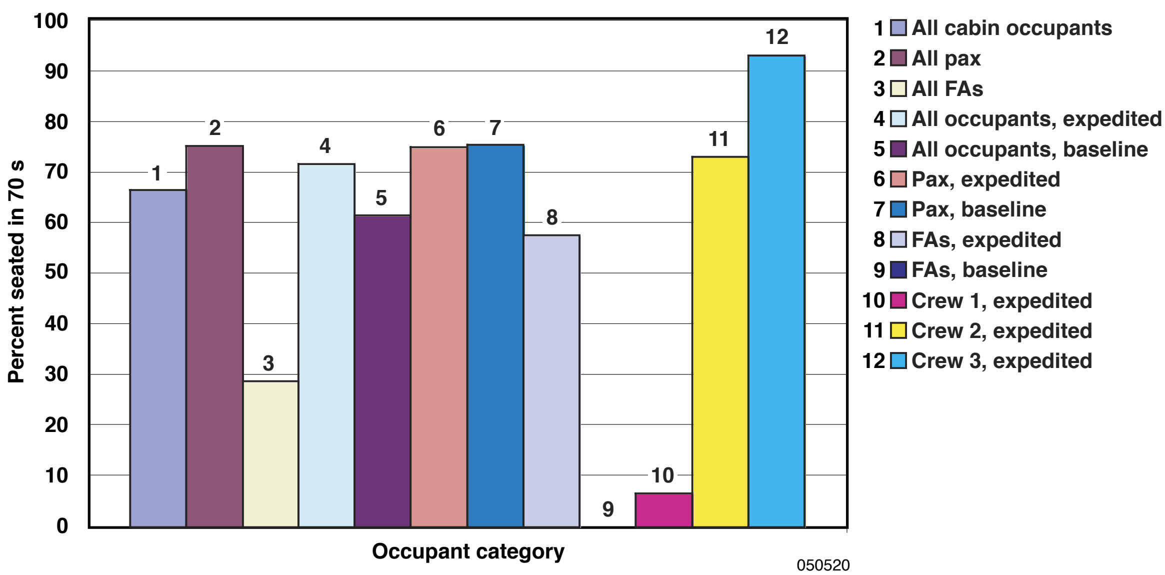

Figure 8. 70-second secured seating performance.

All passengers (represented by the second bar) achieved a 75-percent secured seating condition, and flight attendants (represented by the third bar) achieved a 29-percent secured seating condition. The low percentage of flight attendants that were securely seated is undoubtedly the result of cabin cleanup requirements. The next two bars represent the seating performance of all occupants under the expedited (72 percent) and baseline (62 percent) procedures. Under the expedited procedure, urgency and proactive facilitation of passenger secured seating by the flight attendants are believed to have improved the results in this case. Passenger secured seating results under the expedited and baseline procedures are almost identical at the 70-second point, although the expedited procedure produced better results for completed secured seating time. The next two bars show flight attendant performance under the expedited and baseline procedures. Under the expedited procedure, 58 percent of the flight attendants were securely seated at the 70-second point. Under the baseline procedure, no flight attendant was securely seated at the 70-second point. As previously discussed, substantial variations were observed among the crews when the expedited procedure was used. Crews 1, 2, and 3 achieved 7-, 73-, and 93-percent secured seating, respectively. Because similar relative performances were observed under other measures of performance, these results are consistent. The advance warning time is a single value with no results to provide estimates of uncertainty, so no statistical analysis has been performed.

CONCLUDING REMARKS

No known studies have been conducted that are similar to the Aircraft Cabin Turbulence Warning Experiment (ACTWE), thus guidelines from previous research are not available to assist with the study approach or data analysis. Many in the aviation community have supported the need for this experiment to understand the requirements for reliable and timely warning of impending turbulence encounters (the largest source of in-flight injuries) to reduce accidents and injuries. Whatever safety benefits may be derived from the results of the ACTWE are expected to be realized in safer flight conditions for the traveling public.

Achievement of Experiment Goals

The primary goal of the ACTWE was to determine the time required to configure a commercial aircraft cabin for safe transit through atmospheric turbulence and in turn reduce turbulence-related injuries. As a result, the ACTWE has produced an estimate of the time required for passengers and flight attendants to be securely seated in preparation for a turbulence encounter under common in-flight scenarios. An estimated 95 seconds are required for passengers to achieve a 95-percent secured seating condition. Under the expedited procedure, an estimated 240 seconds are required for flight attendants to achieve a 100-percent secured seating condition.

Another goal of the ACTWE was to provide an accurate secured seating time estimate for use in the development of turbulence warning technology. Results from the data assessment suggest that under expedited procedures passengers can achieve a composite 95-percent secured seating condition within 86 seconds. One flight crew achieved a composite 100-percent secured seating condition in 75 seconds under the expedited procedure. Improved procedures are expected to shorten the secured seating time.

Another goal was to understand the variables affecting the cabin configuration process. The ACTWE revealed that the procedure used by the flight attendants to prepare the cabin has the most significant effect on cabin preparation time. Changing from a baseline to an expedited procedure can reduce the cabin preparation time by 60 percent. Furthermore, crew training and experience can substantially alter the cabin preparation time. More information is needed on this subject.

The final goal of the ACTWE was to establish a benchmark for future reference. The support that the ACTWE has received from the aviation safety community is expected to establish this activity as a benchmark. The fact that this experiment is the first of this type also will strengthen the claim to benchmark status.

Recommendations

To improve the turbulence warning process, the use of the expedited procedure is recommended. Based on the ACTWE results, this procedure is expected to reduce passenger secured seating time by an estimated 15 seconds. In addition, a process must be established within the airline community to identify optimal practices for turbulence warning, and all airlines must be urged to adopt these practices.

Preliminary Benefit Assessment

Considering the preliminary advance warning times achieved in flight testing combined with the ACTWE results and disclaimers regarding the preliminary nature of the results, an estimated two-thirds of injuries could be avoided with turbulence prediction and warning technology under the conditions experienced in the flight test. Further technological development should increase the advance warning time, thus this two-thirds estimate is expected to improve with time.

Further Research

Further tests are needed to confirm (or modify) the ACTWE results (for example, testing should be extended to narrow-body aircraft). Independent review is needed to confirm the ACTWE methodologies and establish future directions.

Unquantifiable Factors

As with most experiments, especially those involving human subjects, several unquantifiable factors are present that add uncertainty to the results; for example:

1. Anthropomorphically accurate dummies representing children younger than 2 years of age cannot demonstrate the cooperative mentality of real children in that age range.
2. No allowance is made in the demographics for elderly and disabled passengers.
3. Cooperative passenger subjects who are given specific instructions are likely to be more responsive to announcements and perform better than actual passengers.
4. The cleanup of simulated nonedible food and drinks is likely to require less time than the cleanup of real food.

All of these factors tend to bias the secured seating times to the longer ranges, although the actual bias amount is speculative and no estimates have been proposed for these effects.

Dryden Flight Research Center
National Aeronautics and Space Administration
Edwards, California, November 4, 2004

APPENDIX A

INSTRUCTIONS TO SUBJECTS

Flight Attendant Instructions

You will be participating in a series of exercises that are designed to study the effects of several variables on the time required for passengers and flight attendants to return to their assigned seats in anticipation of a turbulence encounter.

You will use your airline's existing turbulence procedures as a guideline to prepare the cabin for turbulence. Throughout the day we will be conducting six exercises that will be broken down into three scenarios. We will conduct each of the scenarios using two different types of preparations: an expedited preparation (think of it as "sit and strap," getting to your jump seat and fully fastened in) and a baseline (or normal) preparation for landing. Please remember that this is not a race or competition. The three scenarios are as follows:

1. A domestic business flight with a flying time of 2.5 hours. The exercise occurs at 30 minutes before landing at 35,000 feet. You will be picking up snack lunches.
2. An international flight with a flying time of 8 hours. The exercise occurs mid-flight after the movie has finished. The flight is at 42,000 feet.
3. A domestic flight of 5 hours. The exercise occurs mid-flight during the meal service at 37,000 feet.

You will each be given a "boarding pass" with your exact location on the aircraft simulator and what your duties will include at the time the experiment begins. The experiment will begin when the "captain's PA" is made and a buzzer sounds. In the expedited or sit-and-strap exercise, you will assume that severe turbulence will be encountered momentarily. Consider that there is a guaranteed turbulence warning system that is 100-percent reliable. Your goal will be to use your company's procedures as a guideline while ensuring that you get to your jump seat, fully strapped in with your lap belt and harness fastened. When all flight attendants and passengers have successfully strapped in, a buzzer will signify that the exercise is over. In the baseline or normal cabin preparation, you will prepare your cabin as if you have a few minutes before the turbulence is encountered and ensure that the cabin and passengers are fully prepared for turbulence and landing. Again, when all flight attendants and passengers have successfully strapped into their jump seats and fastened both harness and lap belt, a buzzer will signify that the exercise is finished.

You will always be using the aisle-side seat (inboard seat). The seat belts will not adjust, so please do not try to. Just fasten them. In an actual emergency or if you determine there is any reason to stop the experiment, place your arms over your head and cross them in view of a camera. Additionally, next to each door is a red emergency stop button that will also signal that the experiment must stop. You should push this button under the above conditions.

Passenger Subject Instructions

Initial General Safety Briefing

Ladies and gentlemen, welcome to the B-747 Advanced Evacuation Research Facility located at the Mike Monroney Aeronautical Center. We will be conducting a trial in support of a very important experiment today and your safety is the most important factor in the completion of the work we will do. Please listen very carefully as this safety brief is like no other briefing and your attention is paramount.

The floor here in the B-747 is 16 feet above the ground. Please no not open or attempt to open any door.

In case of a situation in which you would be required to evacuate the simulator, you should follow the instructions of the flight attendants and staff within the B-747.

The available exits are the door that you boarded the simulator and the over-wing door that will be manned by a flight attendant who will give you instructions.

In case of an emergency, you will hear a continuous bell (sound bell), which will serve as your alarm to evacuate. Once you have evacuated the simulator, proceed in the direction of the back of the simulator to the containment fence and wait for assistance. If there are any questions, please direct them immediately to the flight attendant staff after this presentation.

On behalf of the National Aeronautics and Space Administration and the Federal Aviation Administration, and all of your host organizations, I wish to thank you very much for your participation today.

Subject/Safety Briefing

The experiment that we will be conducting today is very important to the future of aviation safety. To insure that you receive all the information that you will need, please remain quiet at all times while you are in this facility and wait for instructions from the researchers.

Aircraft cabin preparation for a turbulence encounter requires passengers to return to their assigned seats and buckle seat belts for their own safety. Consider that there is a guaranteed turbulence warning system that is 100-percent reliable. Please do not trample anyone when you return to your assigned seats. Even though these tests only simulate a real turbulence encounter, the potential hazards are similar to those you could experience prior to an actual turbulence event. While we have taken every foreseeable precaution to insure your personal safety, occasionally the unexpected happens. If a potentially unsafe condition occurs, a member of the research team will stop the exercise by sounding this alarm bell (sound alarm). If you hear this alarm at any time during the experiment, immediately stop moving and wait for further instructions.

In preparation for the trial, please make sure your seatbelt is fastened securely around you. To fasten your seatbelt, insert the metal fitting into the buckle (demonstrate). Tighten the belt by pulling on the loose end of the strap. To release the belt, lift up on the buckle flap. Please make sure that you can fasten your seatbelt, as you will be required to do this again when you return to your seat during the trial.

As you can see, there are uniformed flight attendants present in the cabin today. They are in charge of the cabin. Please follow any instructions that they may give you.

In a short time, those of you who have roles requiring you to move will be asked to assume the preassigned positions described on your boarding pass. The rest of you will remain seated and will move only to allow another passenger to pass your seat position to reach his assigned seat. Shortly, after you have reached your assigned cabin pretrial position, an announcement will be made urging you to rapidly return to your seats to avoid injury in the impending turbulence encounter. After all of you are securely seated, sit back in your seat and relax. This buzzer will sound (sound buzzer) signifying the end of the current trial. If you are still up and moving around the cabin, please continue on and take your seat. If you have any questions, please ask one of the researchers or flight attendants. At the end of the experiment, we ask you to wait for further instructions.

Please make certain that your cellular phones and pagers are turned off. Also, please do not bring any food or beverages onboard the aircraft.

Please take this time to read the instructions, which are provided on the backside of your boarding pass.

Now we'd like to point out the location of the lavatories and galleys onboard this aircraft:

- Lavatory 1 is in the forward cabin.
- Lavatories 2–7 are in the middle cabin.
- Lavatories 8–11 are in the last (aft) cabin.
- Galleys 1–4 are found in the forward cabin.
- Galleys 5–8 are located in the very back of the aft cabin.

APPENDIX B

CABIN ANNOUNCEMENT NARRATIVES

Post-Boarding Announcements

Scenario A Briefing

Our first scenario is a 2.5-hour domestic business flight, and this exercise begins approximately 30 minutes before landing.

Now, we kindly ask you to proceed to your initial starting position and activities, which again can be found on the back of your boarding pass.

If you are seated, please fasten your seatbelt unless your boarding pass instructions specifically tell you to leave your seatbelt unbuckled.

You will hear an announcement urging you to return to your seat. When you do reach your seat and are belted in, sit back in your seat and relax. A buzzer will sound indicating the end of the exercise. If you are still moving towards your seat when the buzzer sounds, please continue to your seat.

Now please move to your initial position and activity as indicated on the back of your boarding pass. Once the exercise is completed, please wait for further instructions.

Baseline Procedure Briefing

Ladies and gentlemen, thank you very much. Our next scenario is the same as the first. It's about 30 minutes before landing on a 2.5-hour domestic business flight. Once again, please return to your initial starting position and activity. Once the exercise is completed, please wait for further instructions.

In Between Scenarios, Exit Aircraft Instructions

Ladies and gentlemen, we will now ask you to exit the aircraft. Please take this time to gather all of your belongings including your boarding pass, which will be collected as you exit the aircraft.

Scenario B Briefing

Welcome aboard once again. Please take a moment to read over the instructions, which are provided on the back of your boarding pass.

For our next scenario, imagine yourself onboard an 8-hour international flight. Our exercise occurs in the middle of the flight, after the movie has ended.

You will again hear an announcement urging you to return to your seat. When you do reach your seat and are belted in, sit back in your seat and relax. A buzzer will sound indicating the end of the exercise. If you are still moving towards your seat when the buzzer sounds, please continue to your seat.

Now please move to your initial position and activity as indicated on the back of your boarding pass. Once the exercise is completed, please wait for further instructions.

Baseline Procedure Briefing

Ladies and gentlemen, thank you very much. Our next scenario is the same as the one we just did. It's the middle of an 8-hour international flight and the movie has just ended. Once again, please return to your initial starting position and activity. Once the exercise is completed, please wait for further instructions.

In Between Scenarios, Exit Aircraft Instructions

Ladies and gentlemen, we will now ask you to exit the aircraft. Please take this time to gather all of your belongings including your boarding pass, which will be collected as you exit the aircraft.

Scenario C Briefing

Welcome aboard once again. Please take a moment to read over the instructions, which are provided on the back of your boarding pass.

For our next scenario, imagine yourself onboard a 5-hour domestic flight. Our exercise occurs during the middle of the flight during the meal service.

You will again hear an announcement urging you to return to your seat. When you do reach your seat and are belted in, sit back in your seat and relax. A buzzer will sound indicating the end of the exercise. If you are still moving towards your seat when the buzzer sounds, please continue to your seat.

Now please move to your initial position and activity as indicated on the back of your boarding pass. Once the exercise is completed, please wait for further instructions.

Baseline Procedure Briefing

Ladies and gentlemen, thank you very much. Our next scenario is the same as the one we just did. It's the middle of a 5-hour domestic flight during the meal service. Once again, please return to your initial starting position and activity. Once the exercise is completed, please wait for further instructions.

In Between Scenarios, Exit Aircraft Instructions

Ladies and gentlemen, we will now ask you to exit the aircraft. Please take this time to gather all of your belongings including your boarding pass, which will be collected as you exit the aircraft.

Captain's Announcements

Expedited Procedure Announcement

"Ladies and gentlemen, this is your Captain again. We are about to encounter some moderate turbulence. All passengers and flight attendants please be seated immediately."

Baseline Procedure Announcement

"Ladies and gentlemen, this is your Captain. Our radar is indicating a line of thunderstorms in front of us so we would like to secure the cabin. At this time please take your seats, and I would like to ask the flight attendants to secure the cabin for turbulence and take their jump seats."

APPENDIX C

EXAMPLE SCENARIO A SUBJECT ROLES

Three scenarios were selected that present very challenging situations when in-flight turbulence is experienced. Tables C-1 (cabin crew specifications) and C-2 (passenger specifications) present the details of scenario A as an example of the scenario structure.

Table C-1. Cabin crew specifications.

Cabin crew	Cabin assignment	Equipment	Assigned seat	Initial crew position	Initial activity	Notes
1	Purser	Tray with napkins and five small bottles of water	Door 1L	In first class, aisle 14R	Offering water and taking beverage requests	
2	First class	Dinner tray and beverage	Door 2L	In the G1/G2 galley complex	Standing while eating dinner	
3	Coach	Dinner tray and beverage on lap	Door 2R	Seated door 4L outboard	Eating dinner and talking to FA No. 4	Tray on lap

Table C-1. Concluded.

Cabin crew	Cabin assignment	Equipment	Assigned seat	Initial crew position	Initial activity	Notes
4	Coach	Cup of coffee	Door 4L	Seated door 4L inboard	Holding a beverage and talking to FA No. 3	Carry-on item open on floor next to FA
5	Coach and galley	Tray of water glasses	Door 4R	Coach aisle right 52	Offering water	

Note: Multiple service items on the G1/G2 galley counters include two bottles of wine, one large bottle of water, and a cart insert. Two cart doors are open in housing. Items on the G5 counter include five open soda cans, stack of plastic glasses, ice bucket, coffee cups, sugars and stirrers, and a milk carton. Two cart doors are open in housing. Items on the G6 galley counter include one large bottle of water and two empty dinner trays. Collection trash bags are on the floor. One cart door is open in housing.

Table C-2. Passenger specifications.

Ref. seat	Pax ID/vest	Gender	Age	Personal equipment	Pax link	Tray table	Initial pax position	Initial activity	Notes; seatbelt fastened or unfastened
5	7	F	55	NA	NA	S	In LAV 1	In LAV 1	NA
6	5	M	55	NA	NA	D	Seated	Dozing	Seatbelt unfastened
7	9	M	30	NA	NA	D	Standing in G1	Talking to FA No. 2	NA
13	8	F	40	NA	NA	S	In LAV 2	In LAV 2	NA
14	1	F	30	Computer	NA	D	Seated	Working on computer	Seatbelt fastened
17	6	M	54	NA	NA	S	In LAV 3	In LAV 3	NA
18	2	F	55	Book	NA	D	Seated	Reading	Seatbelt fastened
25	4	M	51	Book	26	S	Seated	Reading	Seatbelt fastened
26	3	F	41	Child on lap	25	S	Seated	Playing with child	Seatbelt unfastened; will have to fasten seatbelt while holding child
36	10	F	30	NA	NA	S	In LAV 4	In LAV 4	NA
48	38	F	35	Infant, child restraint, diaper bag, bassinet	49	S	Seated	Changing diaper while infant is in bassinet	Seatbelt unfastened; must move infant from bassinet to child restraint
49	39	F	6 mo.	NA	48	S	Seated in bassinet		Seatbelt fastened

Table C-2. Continued.

Ref. seat	Pax ID/ vest	Gender	Age	Personal equipment	Pax link	Tray table	Initial pax position	Initial activity	Notes; seatbelt fastened or unfastened
56	28	M	30	Headphones	57	S	Standing outside LAV 10	Stretching	NA
57	29	F	30	Child on lap	56	D	Seated	Playing with child	Seatbelt unfastened
60	40	F	40	Carry-on bag	NA	S	Seated	Searching through carry-on bag	Seatbelt unfastened; carry-on bag on lap
64	42	M	47	1 Pillow	NA	D	Lying down	Lying across seats 63 and 62	Seatbelt unfastened
65	34	F	12 mo.	NA	66, 67	S	Seated	Playing	Seatbelt unfastened; in child restraint
66	11	F	30	Infant, infant restraint, baby bottle, diaper bag	65, 67	S	Standing in G4	Filling baby bottle	NA; diaper bag on seat
67	36	M	32	Toys	65, 66	S	Seated	Playing with infant	Seatbelt unfastened
72	41	F	45	Computer	NA	D	Seated	Working on computer	Seatbelt fastened

Table C-2. Continued.

Ref. seat	Pax ID/ vest	Gender	Age	Personal equipment	Pax link	Tray table	Initial pax position	Initial activity	Notes; seatbelt fastened or unfastened
75	43	F	57	Book	NA	S	Seated	Reading	Passenger is deaf; seatbelt unfastened
78	35	F	60	Magazine	NA	D	Seated	Reading	Seatbelt fastened
79	16	M	60	Cane	NA	S	In LAV 5	In LAV 5	NA
81	44	M	18	Headphones with CDs	NA	D	Seated	Listening to music	Seatbelt unfastened; stack of CDs on tray table
84	45	F	60	2 pillows, blanket, shoes	NA	S	Lying down, sleeping	Lying across seats 82, 83, and 84	Seatbelt unfastened; shoes off, sound asleep
87	46	M	39	Briefcase, jacket	NA	D	Standing in aisle at seat 87	Opening overhead bin for jacket	NA
88	47	F	75	NA	NA	S	Seated	Sleeping	Seatbelt unfastened
99	48	F	35	2 pillows, blanket, beverage	NA	D	Lying down	Lying across seats 98 and 99	Seatbelt unfastened; beverage on tray table
101	49	F	62	Small pet carrier	NA	D	Seated	Playing with “Bootsy”	Seatbelt unfastened; small pet carrier is on tray table

Table C-2. Continued.

Ref. seat	Pax ID/ vest	Gender	Age	Personal equipment	Pax link	Tray table	Initial pax position	Initial activity	Notes; seatbelt fastened or unfastened
103	17	F	55	NA	NA	S	In LAV 6	In LAV 6	NA
106	50	M	70	2 pillows, blanket, shoes, briefcase	NA	S	Sleeping	Looking through open briefcase on lap	Seatbelt unfastened; sound asleep with shoes off
118	51	M	51	Computer	119	D	Seated	Working on computer	Seatbelt unfastened
119	15	F	55	NA	118	S	In LAV 7	In LAV 7	NA
120	52	M	48	2 empty glasses, book	NA	D	Seated	Reading book	Seatbelt fastened; empty glasses on tray table
121	53	M	25	Carry-on bag, bottle of water	NA	D	Seated	Carry-on bag on lap, removing water bottle	Seatbelt unfastened; just retrieved carry-on bag from overhead bin
125	54	M	75	Oxygen tank	NA	D	Seated	Breathing from oxygen tank	Seatbelt unfastened

Table C-2. Continued.

Ref. seat	Pax ID/ vest	Gender	Age	Personal equipment	Pax link	Tray table	Initial pax position	Initial activity	Notes; seatbelt fastened or unfastened
129	55	M	25	Headphones, two pillows, blanket, jacket, beverage	NA	D	Seated	Sleeping	Seatbelt unfastened; beverage on tray table of seat 130, jacket over head
137	56	M	37	Carry-on bag	NA	S	Seated	Stretched out with feet propped on carry-on bag	Seatbelt fastened; carry-on bag in aisle
139	57	M	34	Headphones, carry-on bag	NA	D	Seated	Listening to music	Seatbelt fastened; carry-on bag under legs
145	58	F	37	Blanket	NA	S	Lying down	Lying across seats 144, 145, and 146	Seatbelt unfastened
148	19	M	64	NA	150	S	Seated	Resting, eyes closed	Seatbelt unfastened
150	31	F	55	NA	148	S	Standing outside LAV 8	Waiting for LAV 8	NA
151	33	M	9 mo.	NA	152	S	Seated	Sleeping	Seatbelt unfastened from child restraint

Table C-2. Continued.

Ref. seat	Pax ID/ vest	Gender	Age	Personal equipment	Pax link	Tray table	Initial pax position	Initial activity	Notes; seatbelt fastened or unfastened
152	32	F	30	Infant, child restraint, diaper bag, book	151	S	Seated	Reading book	Seatbelt unfastened
159	59	M	55	Book	160	D	Seated	Reading book	Seatbelt unfastened
160	18	M	70	NA	159	S	In LAV 8	In LAV 8	NA
165	60	M	46	NA	NA	D	Seated	Sleeping soundly	Seatbelt unfastened
166	26	M	35	NA	167	S	Standing at jump seat 5	Talking to vest 27	NA
167	25	F	30	Beverage	166	D	Seated	Drinking	Seatbelt unfastened
172	12	M	30	NA	NA	D	Seated	Talking to vests 13 and 14	Seatbelt fastened
173	13	M	30	NA	NA	D	Seated	Talking to vests 12 and 14	Seatbelt unfastened

Table C-2. Continued.

Ref. seat	Pax ID/ vest	Gender	Age	Personal equipment	Pax link	Tray table	Initial pax position	Initial activity	Notes; seatbelt fastened or unfastened
174	62	F	30	Carry-on bag	175,176	S	Seated	Carry-on bag is placed on seat 175; pulling books out	Seatbelt unfastened
175	30	F	30	NA	174,176	S	In LAV 10	In LAV 10	NA
176	63	F	30	Several books	174,175	D	Seated	Reading	Seatbelt unfastened
184	21	F	60	Book	NA	D	Seated	Reading	Seatbelt unfastened
185	21	F	30	NA	212	S	In LAV 9	In LAV 9	NA
186	64	F	40	Computer	NA	S	Seated	Working on computer	Seatbelt fastened
188	65	F	25	Book	NA	S	Seated	Waiting for seat 190 to return from LAV	Seatbelt unfastened
189	66	M	75	Carry-on bag with medication	190	S	Seated	Searching through bag	Seatbelt unfastened; carry-on bag on lap; needs 190 to return bag to overhead bin

Table C-2. Continued.

Ref. seat	Pax ID/ vest	Gender	Age	Personal equipment	Pax link	Tray table	Initial pax position	Initial activity	Notes; seatbelt fastened or unfastened
190	23	F	55	NA	189	S	In LAV 12	In LAV 12	NA
196	27	M	40	Papers	NA	S	Standing at jump seat 5	Talking to vest 26	NA
198	67	M	60	Book	NA	D	Seated	Reading book	Seatbelt unfastened
199	68	M	60	2 beverages	NA	D	Seated	Drinking	Seatbelt unfastened
200	24	M	45	NA	NA	S	In LAV 11	In LAV 11	NA
203	69	F	37	2 pillows under head	NA	S	Lying down	Lying across seats 201, 202, and 203	Seatbelt unfastened; head on seat 203, feet on seat 201
205	70	F	70	3 pillows, blanket	NA	S	Seated	Sleeping	Seatbelt unfastened
209	71	M	28	DVD player with headphones	NA	D	Seated	Watching and listening to movie	Seatbelt unfastened
210	72	M	27	CD player with headphones	NA	D	Seated	Listening to music	Seatbelt unfastened

Table C-2. Concluded.

Ref. seat	Pax ID/ vest	Gender	Age	Personal equipment	Pax link	Tray table	Initial pax position	Initial activity	Notes; seatbelt fastened or unfastened
211	20	F	30	Purse with contents	NA	D	Seated	Cleaning out purse	Seatbelt unfastened
212	14	M	40	NA	185	S	Standing at 173	Talking to 172 and 173	NA

APPENDIX D

OPERATIONAL CREW ROLES

Conducting the experiment required the support of several members of the Aircraft Cabin Turbulence Warning Experiment team serving in identified roles. These roles and responsibilities are as follows:

- Flight Attendants: The flight attendants serviced and operated cabin equipment and facilitated the passenger secured seating process.
- Flight Attendant Briefer: The flight attendant briefer developed and delivered briefings to flight attendant crews.
- Passengers: The passengers followed instructions to board the cabin simulator, occupy the assigned seats, and perform assigned roles.
- Passenger Briefer: The passenger briefer developed and delivered briefings to passengers.
- Cabin Configuration Monitor: The cabin configuration monitor verified cabin readiness and configuration (passenger and flight attendant starting positions) before the start of the exercise and notified the safety officer when the cabin was ready to begin the exercise.
- Boarding Agent: The boarding agent boarded the passenger subjects and made sure that the proper vest numbers and seat assignments were communicated to the subjects.
- Safety Officer: The safety officer monitored the progress of the exercises and advised the test conductor if unsafe conditions developed.
- Test Conductor: The test conductor was responsible for the overall satisfactory progress of the test. The test conductor received advice from the safety officer and was able to halt the trial(s) on the basis of safety issues or other detrimental conditions that may have developed.
- Very Important Person (VIP) Tent Monitor: The VIP tent monitor was responsible for monitoring the conditions of the VIP tent and working with VIPs to ensure that their questions were answered, needs were met, and safety and comfort was maintained.
- Corrugated Box Engineers: The corrugated box engineers ensured that each unoccupied seat contained a box representing a passenger.
- Galley Setup Crew: The galley setup crew stocked the galleys with supplies from participating airlines and scheduled this activity to ensure readiness on the day of the airline participation.
- Media Escort: The media escort was responsible for meeting and escorting on-site media staff to ensure appropriate positioning during the trial sequence and appropriate interface with experiment staff.

APPENDIX E

EXPERIMENT TEAM AND SUPPORTING ORGANIZATIONS

Table E-1 lists the members of the experiment planning and support team. Many members of the core team (identified by an asterisk) were involved in the planning effort for more than 2 years. Table E-2 lists the individuals and corporations that provided support.

Table E-1. Experiment planning and support team.

Name	Title	Organization
Brenda Fuhrman*	Manager, In-flight Service Health and Safety Policies	Delta Air Lines, Inc.
Christopher Hanlon	Flight Attendant	JetBlue Airways
Lisa Juenger	Supervisor, Cabin Health and Safety	TWA-LLC STC
Annick Kiernan	Safety Chair and Flight Attendant	United Air Lines, Inc./ Association of Flight Attendants (AFA)
Candace Kolander*	Air Safety and Health Coordinator	AFA
Lisa Kolodner*	Aviation Safety Inspector (Cabin Safety)	Federal Aviation Administration (FAA)
Ken Larcher*	Cabin Safety Research/ Protection Survival Lab	FAA Civil Aerospace Medical Institute (CAMI)
Julie Larcher*	Aircraft Accident Research Team	FAA CAMI
Kathy Lord-Jones	Flight Attendant Advisor	Aircraft Cabin Safety Services (ACSS), Inc.
Brian Manubay*	Manager, In-flight Operations and Planning (core team)	JetBlue Airways
Jack O’Brien*	In-flight Safety	United Air Lines, Inc.
Anthony Palombo	Manager, Cabin Safety	US Airways, Inc.
Kimberly Peart	Health, Safety, and Security Specialist	Delta Air Lines, Inc.
Debbie Roland*	Flight Attendant Advisor	ACSS, Inc.
Barbara Reyes	Supervisor, Initial Training	Southwest Airlines Co.
David Ruppel	Cabin Safety Research/ Protection Survival Lab	FAA CAMI
Renae Stephenson	Supervisor, Initial Training	Southwest Airlines Co.

Table E-1. Concluded.

Name	Title	Organization
Joan Strow*	Senior Administrator, Cabin Safety and Flight Operations	American Airlines, Inc.
Lori Szopinski	Flight Attendant	American Airlines, Inc.
Robert Valenta	Cabin Safety, Flight Attendant	Association of Professional Flight Attendants (APFA)
Chris Yi	Safety Analyst	American Airlines, Inc.

* Member of the Aircraft Cabin Turbulence Warning Experiment core team.

Table E-2. Corporate support.

Name	Title	Organization	Contribution
Bill Bosen	Vice President for Safety	US Airways, Inc.	Provided cabin crew and planning assistance
Laura Burnett	Managing Director for Flight Operations	American Airlines, Inc.	Helped staff planning and support team
John Marshall	Vice President, Safety and Quality Assurance	Delta Air Lines, Inc.	Provided cabin crew and planning assistance
Joann Mately	National Safety Coordinator	APFA	Helped staff planning and support team
Robert Shaffstall	Manager, Protection and Survival Laboratory	FAA CAMI	Provided liaison with CAMI staff for planning
Ed Soliday	Vice President, Safety and Quality Assurance (retired)	United Air Lines, Inc.	Provided cabin crew; staffed planning and support team
Al Spain	Vice President for Operations	JetBlue Airways	Staffed planning and support team
Bob Sutton	President	Aviation Research, Inc.	Provided strong support and garnered Commercial Aviation Safety Team (CAST) support
Gary Thompson	General Manager, In-flight Service Health and Safety	Delta Air Lines, Inc.	Provided planning assistance
Dr. James Whinnery	Manager, Aerospace Medical Research Division	FAA CAMI	Marshaled CAMI support

APPENDIX F

EXECUTIVE SUMMARY

New turbulence prediction technology offers the potential for advance warning of impending turbulence encounters, thereby allowing necessary cabin preparation time prior to the encounter. The amount of time required for passengers and flight attendants to be securely seated (that is, seated with seat belts fastened) currently is not known. To determine secured seating–based warning times, a consortium of aircraft safety organizations have conducted an experiment involving a series of timed secured seating trials. This demonstrative experiment, conducted on October 1, 2, and 3, 2002, used a full-scale B-747 wide-body aircraft simulator, human passenger subjects, and supporting staff from six airlines. Active line-qualified flight attendants from three airlines participated in the trials. Definitive results have been obtained to provide secured seating–based warning times for the developers of turbulence warning technology.

Background

Aircraft encounters with atmospheric turbulence are by far the largest cause of in-flight injuries. Although all commercial airlines have operational procedures designed to reduce injuries in turbulence encounters, the lack of a timely reliable system to warn of impending turbulence is a major obstacle. Resolving this warning issue has been elusive and as a result, the turbulence accident rate remains unacceptably high for both flight attendants and passengers. The pervasive nature of atmospheric turbulence occurrence, the frequent lack of visual clues that reveal its presence, and the variety of atmospheric conditions that may trigger turbulence formation suggest that the development of a reliable warning system will require advances in many areas. Improvements are beginning to develop in turbulence warning technology, turbulence-forecasting skills, and remote atmospheric sensing, which together may provide a more definitive and comprehensive picture of the turbulence hazard. With these expected improvements in situational awareness, more information is needed about time requirements for seating passengers and flight attendants so that the appropriate strategies can be developed to reduce in-flight turbulence injuries. The Aircraft Cabin Turbulence Warning Experiment (ACTWE) was designed to quantify cabin occupant seating times and explore the effect of various seating procedures on seating times.

Experiment Requirements

Accident records from the National Transportation Safety Board show that seated and belted cabin occupants overwhelmingly avoid injuries in turbulence encounters. A critical issue in avoiding turbulence injuries is providing a reliable warning in sufficient time for cabin occupants to be seated and belted before the encounter. The ACTWE objective, therefore, was to realistically identify the time required to seat the vast majority of cabin occupants under the most difficult conditions. All conditions simulated a full-load seating situation.

Variables

To ensure that realistic results were obtained from the experiment, variations in cabin conditions were used to address a variety of difficult cabin situations. Three in-flight scenarios were devised that presented very challenging situations for preparing an aircraft cabin for a turbulence encounter. One scenario took place on a flight after a movie presentation, one took place after a snack service, and the other took place during a full meal service. Two cabin procedures representative of common airline practices were used to judge the effects on seating time and provide an opportunity to assess results for future industry best practice recommendations. Three days were allocated for the experiment, and a different cabin crew (from three airlines, United Air Lines, Inc., Delta Air Lines, Inc., and US Airways, Inc.) was used each day.

Realism

All subjects were encouraged to behave normally to promote a realistic environment. To simulate an actual aircraft environment, passengers were provided with carry-on baggage and boarding passes with seat assignments. Anthropomorphically accurate dummies were used to simulate children in numbers consistent with Federal Aviation Regulations (FAR), Part 25, Paragraph J. Full load conditions were simulated with either a passenger or a box in every available seat. Passengers seated in window or middle seats were required to negotiate passage around other seated passenger subjects when they returned to their assigned seats. Turbulence warning announcements were recorded by line aircraft pilots and broadcast at the beginning of each trial. Cabin crews used the training from their respective airlines to define their approach to facilitating passenger seating. Each crew, therefore, used its own announcement with familiar procedures to enhance crew realism during the trials.

Equipment realism also was strongly emphasized. The cabin of the B-747 Advanced Evacuation Research Facility (AERF) was configured to represent a cabin layout typical of the Model 100 aircraft. Cabin galleys and serving carts were representative of those commonly used by the major airlines. Individual flight crews brought serving equipment and supplies to set up the galleys and carts to conform to the standard configuration of the host airline. For the food service, nonperishable imitation food and standard trays and cups were used.

Repeatability

Duplicating trial conditions was considered critical for consistent results. Each trial used the same announcement schedule with accommodations by the cabin crew to address different scenarios and procedures. A corresponding turbulence warning announcement from the captain had been previously recorded and was repeated for each trial. Passenger learning (through practice in successive seating trials) was minimized by randomly reassigning subject roles for different scenarios. All nonparticipating individuals were removed from the cabin during the trials to avoid influence on the results.

Compromises

Because of budgetary constraints, some compromises were necessary to limit costs. The same pool of passenger subjects was used for all 3 days of the experiment. Because each scenario required a different number of passengers, specific participants varied for each scenario. The AERF had been modified such that use of the nose zone and rearmost zones was impractical. Therefore, the trials were confined to the middle three cabin zones.

Experiment Findings

The results are described in terms of time (independent variable) and percent of securely seated occupants (dependent variable). The time begins at the start of the captain's announcement. The percent of securely seated occupants is defined as the ratio of the roving occupants at a point in time during the trial (those at risk of injury in a turbulence encounter) to the roving occupants at the start of the trial. Although the objective of the seating effort was to reach a 100-percent secured seating condition, behavior realities had to be accommodated when subjects forgot to fasten their seat belts or, because of inattention or distraction, did not complete the belt fastening process to reach the 100-percent secured seating condition. Therefore, a 95-percent belted metric was adopted as the basis for comparing passenger secured seating times. For flight attendants, the basis for comparison was the 100-percent belted condition.

Passenger Secured Seating Time

The composite of all trials resulted in a passenger 95-percent secured seating condition within 95 seconds under all scenarios, procedures, and participating flight attendant crews. Under the expedited procedure, 86 seconds were required to achieve the 95-percent secured seating condition. The consistent results suggest that under full load conditions, varying scenarios and flight crews minimally affect seating time. As noted, a slight improvement in seating time was observed when the expedited procedure was used (possibly because of a more urgent implication from the pilot announcement and crew behavior). For the passenger seating results, please refer to figure 5 of the main report.

Flight Attendant Secured Seating Time

Flight attendant secured seating times among the three cabin crews varied substantially according to some measures but varied minimally according to other measures. The reason for this variability is unknown, but probably originates from differences in training and experience among the three airlines.

Procedure Effects

The baseline and expedited procedures each placed different expectations on the cabin crew and not surprisingly, the baseline procedure resulted in longer flight attendant secured seating times. Because the baseline procedure required that the cabin be cleaned and organized before the turbulence encounter, 606 seconds were required for flight attendants to reach the 100-percent secured seating condition. Under the expedited procedure, 240 seconds were required to reach the same condition.

Scenario Effects

The scenarios each placed different requirements on the flight attendant tasks and therefore influenced the flight attendant secured seating times. Each scenario resulted in a different composite time, ranging from 262 to 606 seconds. The differences in seating times undoubtedly resulted from different situations within the scenarios (such as the number of roving passengers and meal service cleanup requirements). These differences are expected and not believed to be significant in the experiment results.

Crew Effects Under the Baseline Procedure

Flight attendant seating times under the baseline procedure generally were uniform among the participating crews, ranging from 508 to 606 seconds. This range represents a standard deviation of 6.4 percent, which is within a normal, expected variability.

Crew Effects Under the Expedited Procedure

The flight attendant secured seating times under the expedited procedure revealed the most significant differences among the participating flight crews (please refer to figure 6 of the main report). The reasons for these differences are speculative and probably originate primarily from differences in crew experience and training.

As a benchmark, the passengers reached a composite 95-percent secured seating condition in 86 seconds. The individual crew 100-percent secured seating times ranged from 75 to 240 seconds, representing a standard deviation of 61 percent, which is a very substantial variability.

Under the expedited procedure, the flight attendants were expected to be seated shortly after the passengers, or possibly before the last passengers. The data in figure 6 show that crew 1 did not reach a 100-percent secured seating condition until 240 seconds had elapsed (more than 2 minutes after the passengers had reached a 95-percent secured seating condition). Crew 2 achieved a 100-percent secured seating condition in 116 seconds (30 seconds after the passengers had achieved a 95-percent secured seating condition). Crew 3 reached a 100-percent secured seating condition in 75 seconds (11 seconds before the passengers had reached a 95-percent secured seating condition).

A review of the time that the first flight attendant was securely seated in each crew under the expedited procedure reveals a similar pattern. For crew 1, the first flight attendant was securely seated in 105 seconds (the longest time of all the crews), which is consistent with the longest composite flight attendant 100-percent secured seating time of 240 seconds. The seating time delay is consistent with the late start that crew 1 encountered in the secured seating process. For crews 2 and 3, the first flight attendant was securely seated in 30 and 22 seconds, respectively. These times also are consistent with the 100-percent secured seating times of 116 and 75 seconds. When crews began the secured seating process early, the final 100-percent time also was less.

Implications of Findings

The passenger secured seating time of approximately 95 seconds is consistent with early results from radar-based turbulence warning technology, which demonstrated a warning time of 80 seconds. The consistency of the passenger secured seating times is an encouraging result in the sense that this variable in the overall secured seating process is probably one of the least controllable. Passenger behavior cannot be substantially modified by training or any other influence, thus the consistency in the results of an uncontrollable variable is good news.

The flight attendant secured seating times are much less consistent. The major factor is the variability among crews and the effect of the cabin procedure (expedited as opposed to baseline). Including cabin cleanup in the procedure for turbulence encounter preparation obviously will require more time, as indicated by the experiment results. The expedited procedure required 40 percent less time than the baseline procedure. The variability among the crews is thought to result from training differences among the host airlines.

Although the variability in the flight attendant secured seating times is considerable, this factor in the secured seating process is one of the more controllable. Flight attendants undergo extensive initial and recurring training, and with the adaptation of industry-wide best practices for crew seating and improved training procedures, most crews can be expected to improve the 75-second seating time demonstrated by the trial crews.

Using the radar-based turbulence warning technology advance warning time of 80 seconds, and assuming that pilot processing of the warning requires 10 seconds, 70 seconds remain for passenger and flight attendant seating. The results for all cabin occupants for all scenarios, procedures, and crews show that 66.8 percent of the cabin occupants were seated within 70 seconds. These results suggest that for atmospheric conditions equal to those experienced in the radar technology flight test, two-thirds of cabin occupants could be removed from risk of injury in a turbulence encounter.

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14. ABSTRACT

New turbulence prediction technology offers the potential for advance warning of impending turbulence encounters, thereby allowing necessary cabin preparation time prior to the encounter. The amount of time required for passengers and flight attendants to be securely seated (that is, seated with seat belts fastened) currently is not known. To determine secured seating–based warning times, a consortium of aircraft safety organizations have conducted an experiment involving a series of timed secured seating trials. This demonstrative experiment, conducted on October 1, 2, and 3, 2002, used a full-scale B-747 wide-body aircraft simulator, human passenger subjects, and supporting staff from six airlines. Active line-qualified flight attendants from three airlines participated in the trials. Definitive results have been obtained to provide secured seating–based warning times for the developers of turbulence warning technology.

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