Evaluation and Mitigation of Aircraft Slide Evacuation Injuries

DETAILS

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 2

Evaluation and Mitigation of Aircraft Slide Evacuation Injuries

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AIRPORT COOPERATIVE RESEARCH PROGRAM

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FOREWORD

By Christine L. Gerencher
Staff Officer
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ACRP Report 2: Evaluation and Mitigation of Aircraft Slide Evacuation Injuries provides guidance on reducing injuries and improving safety and coordination during aircraft slide evacuation events. This report examines available data regarding commercial aircraft slide deployments with particular focus on injuries to aircraft crew and passengers incurred during aircraft slide evacuations. As a result of encountering gaps in the data on commercial aircraft slide deployments, this report also encourages more consistent reporting of injuries incurred in commercial aircraft slide deployments. A better understanding of the types and potential causes of aircraft slide evacuation injuries will help airport first responders, such as Aircraft Rescue and Fire Fighting personnel, and airport and aircraft operators to better prepare for commercial aircraft slide deployments and possibly prevent some injuries from happening.

Aircraft operating in accordance with Title 14, Federal Aviation Regulation (FAR), Part 121, of the *Code of Federal Regulations* are required, under §121.310, to provide a means for emergency evacuation that meets certain requirements. In order to meet these requirements, manufacturers developed a system incorporating inflatable slides at multiple points of entry and exit in the aircraft. As the requirement implies, the use of these slides is intended for situations in which quick egress is needed, and the aircraft crew and passengers are unable to exit through normal means (e.g., via jetbridge or stairs). When an emergency situation arises at an airport involving an aircraft evacuation via inflatable slides, the airport's Aircraft Rescue and Fire Fighting (ARFF) department is typically the first to respond to the incident and provide assistance to the aircraft crew in evacuating the passengers.

Emergency situations provide unique challenges that the aircraft crew, ARFF, and other airport personnel must address in order to provide the most expedient evacuation of the aircraft in the safest possible way. In these evacuation situations, injuries to passengers can occur. In this research, numerous records of previous aircraft slide evacuation events were examined to gain a better understanding of the rate of injury in these events and the types of injuries that have occurred. Data associated with the introduction of the newest generation of large commercial aircraft were also examined to better understand the potential impact of higher evacuee speeds during a slide evacuation.

ACRP Report 2 concludes with a presentation of issues identified through a survey of ARFF personnel throughout the country—issues that should be taken into account when preparing for and responding to an aircraft slide evacuation event. Guidance on improving coordination of the response to slide evacuation events to further minimize the risk of evacuation injuries is also provided.

CONTENTS

SUMMARY

Evaluation and Mitigation of Aircraft Slide Evacuation Injuries

This report contains results of a study conducted by the George Washington University Aviation Institute under a contract from the Airport Cooperative Research Program (ACRP) of the Transportation Research Board. The purpose of the study was to examine events and injuries occurring during emergency evacuation of commercial aircraft operated under provisions under Title 14, Part 121, of the *Code of Federal Regulations* when inflatable slides were used. The study identified a number of issues regarding emergency evacuations. A number of recommendations are also made that may mitigate injuries incurred during emergency evacuations using inflatable slides.

Emergency evacuation events matching the scope of this study for the period of January 1, 1996, to June 30, 2006, were identified. During the stated timeframe, 142 emergency evacuation events were found. The collection of data presented a number of challenges associated with the details of events and the consistency of recorded information; this was particularly the case for events in which minor injuries were incurred. Multiple data sources, including databases from FAA and NTSB, commercial databases, and records from airlines and Aircraft Rescue and Fire Fighting (ARFF) units were used for the data analysis. Considering the volume of flights within the U.S. air transport system, the number of emergency evacuation events is low—approximately 1 event per million departures. The data show that over the study period, about 50 percent of emergency evacuations result in injuries. However, nearly 90 percent of these injuries are minor. In this study, the injuries incurred during emergency evacuations were analyzed using the AIS (Abbreviated Injury Scale), and the injury mechanisms are discussed when adequate information was available from the accident investigation. Only about 10 percent of the injuries examined in this study may be classified as AIS 3, serious; the remaining 90 percent would be classified as AIS 1 and 2, minor and moderate, respectively.

As a part of this study, the performance of slides during high winds was examined within the scope of required regulations for evacuation using slides. Since the total number of events is very low, there are no statistically significant effects that can be deduced from the existing data. Existing literature also points to a very low probability of mean wind speeds exceeding 25 knots—about 6 instances per billion departures, as derived from measurements at 601 airports. Nevertheless, because delayed landing or diversion may not be an option in an emergency, use of evacuation slides during conditions of high wind must be addressed. Given the conditions possible during an emergency evacuation (i.e., immediate hazard, panic, confusion, structural or cabin change and destruction, fire and smoke, and so forth), the only recommendations made in this regard are for the first responders to (1) practice the initial stabilization and proper orientation of the slide, particularly during windy conditions, and (2) realize that continued stabilization may be needed under such conditions.

In addition, the emerging issue of emergency evacuation of Very Large Transport Aircraft (VLTA), which is receiving a lot of public interest, was addressed in this report by examining the very few events involving B747 aircraft (some outside the stated scope of this study) and the very recent certification test of A380 aircraft. A mathematical model was developed to study the key issue of the speed at which a passenger comes down a slide. No attempt was made to quantitatively evaluate the accuracy of this model, but a qualitative comparison with A380 evacuation has good results. The model shows that the evacuation rate and speed of passenger down the slide from the upper deck of an A380 is essentially the same as it is in an evacuation from the upper deck of a B747.

A number of survey instruments were used to gather information on evacuation events. Based on a survey of ARFF units in the United States, a list of issues and key recommendations has been developed. The purpose of these recommendations, summarized and prioritized in this study, is to decrease injuries during emergency evacuations. The key elements of the stated recommendations are the following:

- Communication, coordination, and action planning among rescue personnel at airports, flight crew, and airline operation personnel should be improved.
- Rescue personnel training should be improved by conducting training programs with airlines and defining the role of ARFF personnel during evacuations.
- An EMS team to handle injuries should be included as part of the response.
- Installation of lighting or reflective markers along the length of the slide should be considered for better visibility of deployed slides for ARFF crews.
- Developing standard operating guidelines that include uniform documentation of emergency evacuation events at a national level should be considered by ARFF groups.
- The AIS system should be considered for classifying injuries in aviation accident and incident events.

CHAPTER 1

Background

This final report details the findings for Airport Cooperative Research Program (ACRP) Project 11-02/Task 3. This study was focused on evaluation and mitigation of injuries due to use of inflatable slides during emergency evacuation of commercial aircraft. Exits that are required to have an inflatable slide are defined in Title 14, "Aeronautics and Space," of the *Code of Federal Regulations* (CFR) at 14 CFR § 25.810 and include both over-the-wing and fuselage exits. This report also addresses evacuation of large aircraft and the effect of wind on the stability of slides.

Motivation

Rapid and safe evacuation of aircraft during proven or perceived emergencies is a very important component of aviation safety. Although the U.S. air transport system has enjoyed a very low accident rate over the past decade, there is still room for improvement. The reduction of aircraft crashes overall in recent decades has allowed attention to turn to areas of safety that were previously not as high a priority, such as the reduction and mitigation of injuries during emergency evacuation.

Studies of past emergency evacuations have shown that during the use of inflatable slides, problems can occur that pose a threat to lives of passengers and crew members during evacuation (NTSB 1974; NTSB 2000; TSB 1995; Fedok 2001).

This study builds on an NTSB study published in 2000 by examining the issue over a longer time period with a narrower focus: evaluating the relevant processes and procedures used by airlines, Airport Rescue and Fire Fighting (ARFF) units, and airports, as well as examining injury mechanisms (NTSB 2000). External factors—such as wind, fire, and smoke outside the aircraft, as well as large aircraft characteristics—are considered as well.

This study is focused on the following:

- Accurate identification of all relevant events that have involved the use of inflatable slides for aircraft evacuation;
- Collection of all available information regarding each event;
- Evaluation of any injuries during or due to evacuation, using the best available information and the Abbreviated Injury Scale (AIS);
- Overview of particular issues regarding Very Large Transport Aircraft (VLTA) (not limited to the time period); and
- General evaluation of the effect of wind on the stability and performance of inflatable slides.

Scope of Study for Slide Evacuation Events

The study period was set for nearly 10 years to provide a reasonably large database of operations and a potentially significant number of events. Since some time must elapse to ensure incident and accident reports are compiled, working back from a latest possible date of June 2006, the period of January 1, 1996, to June 30, 2006, was selected. To be included in the compilation, events had to fall within the following parameters:

- Involve U.S. air transport operated under provisions of 14 CFR, Part 121 (both scheduled and non-scheduled);
- Involve deployment of inflatable slides during emergency evacuation; and
- Be defined as accidents and/or incidents by NTSB and FAA (for these definitions of accidents and incidents, see http://www.ntsb.gov/aviation/report.htm).

Definitions and Categories of Evacuation

The sections that follow provide definitions and categories of evacuation.

Definition of Accidents and Incidents

An *accident,* as defined by NTSB, is an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage. An *incident* is an occurrence other than an accident that affects or could affect the safety of operations.

Regulatory Requirements for Evacuations and Reporting

There are three types of exits described in 14 CFR § 25.810—Type A, Type B, and Type C. Type A is a floor-level exit with a rectangular opening of not less than 42 in. wide by 72 in. high, with corner radii not greater than 7 in. Type B is a floor-level exit with a rectangular opening of not less than 32 in. wide by 72 in. high, with corner radii not greater than 6 in. Type C is a floor-level exit with a rectangular opening of not less than 30 in. wide by 48 in. high, with corner radii not greater than 10 in.

As dictated by 14 CFR § 25.810, the assisting means for emergency evacuation should be a self-supporting slide or the equivalent, and, in the case of Type A or Type B exits, the assisting means for emergency evacuation must be capable of carrying two parallel lines of evacuees simultaneously. In addition, the assisting means must meet the following criteria:

- It must be automatically deployed;
- It must be automatically erected in 6 sec (except for assisting means installed at Type C exits);
- It must be such length after full deployment that the lower end is self-supporting on the ground and provides safe evacuation of occupants to the ground after collapse of one or more legs of the landing gear;
- It must have the capability, in 25-knot winds directed from the most critical angle, to deploy and, with the assistance of only one person, to remain usable after full deployment to evacuate occupants safely to the ground; and
- All passengers and crew must evacuate the plane in 90 sec through half of the available aircraft exits.

Precautionary Evacuation (Security-Related)

Precautionary emergency evacuations are evacuations that are ordered by the crew, or are sometimes initiated by passengers, because of the perceived threat of fire, although no fire actually develops. (Hynes 1999)

Uncommanded Evacuation

Uncommanded evacuations are evacuations that passengers may initiate if they perceive an emergency or if there is a communication breakdown.

Emergency Evacuation

Emergency evacuation of commercial aircraft is an important part of operational safety of an airline. Such evacuations can occur under a number of circumstances ranging from survivable crash scenarios to precautionary emergency landings or ground emergencies occurring while an aircraft is positioned at the gate or taxiing on the airport surface.

There are significant numbers of flight diversions that occur due to "smoke in the cabin" that may lead to emergency evacuations as well. Finally, security-related events may also lead to diversions and possibly to emergency evacuations.

Literature Survey

There have been several studies and papers written on different aspects of commercial passenger aircraft evacuation (Hynes 1999, 2000; NTSB 2000). The study conducted by NTSB in 2000 was very thorough and covered all aspects of evacuation and regulatory issues as well as providing detailed analysis of 46 cases of emergency evacuation occurring between September 1997 and June 1999. The NTSB study (2000) also provided the "first prospective study of emergency evacuations of commercial airplanes" and described aircraft type, crew training and response, passenger surveys, and details of the incidents for the 46 cases mentioned (NTSB 2000, vii). It further contains 20 safety recommendations to the FAA. The study and safety recommendations were focused on certification issues related to airplane evacuation, the effectiveness of evacuation equipment, the adequacy of evacuation procedures and operational guidelines for ARFF personnel, and guidance and communication issues related to evacuations. In addition, there are two studies conducted by Michael Hynes that focus on the frequency and costs of transportation airplane precautionary emergency evacuation and evacuee injuries and demographics in such evacuations (Hynes 1999, 2000).

Hynes' first study, published in December 1999, looks at precautionary emergency evacuations during the period of 1988 to 1996. According to this study, such events occur about 58 times per year. Hynes claims that in about 18 percent of precautionary emergency evacuations, aircraft emergency escape systems were deployed without being reported to the FAA, and approximately 80 percent of such incidents were not reported to the NTSB (Hynes 1999). In the current study, it was determined that when no injury or damage to the aircraft occurred, many incidents of this type may have been reported to the FAA and NTSB by airlines with a simple telephone call rather than documented through a formal reporting process. This also explains some of the discrepancies in data on emergency evacuations and slide deployment.

Hynes' second study, published in March 2000, looks into evacuee injuries during precautionary emergency evacuations. During the period of the study (December 1994 to

November 1996), 109 precautionary evacuations were identified; 19 of these resulted in injuries. The 19 precautionary evacuations that resulted in injuries involved 190 passengers and 3 crew members. However, information on the injury mechanisms is not reported.

The current study builds on the NTSB study (2000) by examining the issue over a longer time period with a narrower focus, evaluating relevant processes and procedures used by the airlines, ARFF, and the airports, as well as examining the injury mechanisms.

CHAPTER 2

Research Approach

Databases

The databases and sources consulted in compiling the evacuation incident and accident data were the following:

- The FAA's *Accident/Incident Data System (AIDS),* part of the *Aviation Safety Information Analysis and Sharing (ASIAS)* System;
- NTSB's *Aviation Accident Database & Synopses;*
- The *CASE* database produced by Airclaims;
- The RGW Cherry & Associates Limited *Accident Database,* designed on behalf of the airworthiness authorities participating in the Cabin Safety Research Technical Group (a group formed by the aviation authorities of Canada and the United States, Europe, and Japan in the early 1990s to bring together their respective cabin safety research efforts. For additional information visit http://www.fire.tc.faa.gov/cabin.stm);
- Service Difficulty Reports (SDRs);
- The Aviation Safety Reporting System (ASRS);
- A direct survey of the ARFF groups of 30 major U.S. airports; and
- A direct survey of airlines that are Air Transport Association (ATA) members.

The authors of this report have also examined the potential use of SDRs and the ASRS. The very large number of SDRs means that data-mining tools may be required for searching, and this is outside the scope of this project. However, examination of SDRs has allowed the authors make some qualitative assessments of the extent of information available. The ASRS is difficult to use since much of the information is de-identified and therefore cannot be correlated with identified events.

Each of the databases in the list above was queried separately, using the parameters outlined in the project scope and parameters for aircraft that have inflatable slides. Those aircraft that are not large enough to have such slides are not included in this study.

Challenges with the Accuracy of the Data

Title 49 of the CFR (49 CFR § 830.5) requires operators to notify the NTSB of any deployment of inflatable slides. This includes inadvertent, uncommanded, and maintenance-related deployment or actual emergency deployment. According to Hynes (2000), such accidents or incidents do not always get reported to the NTSB. Based on discussions with airline safety officers conducted as part of this research, it seems that such reporting may take the form of a phone call to the NTSB, and, if the event has not resulted in damage or injuries of any kind, it may not be even logged by NTSB and would certainly not be investigated. That some forms of reporting may not be documented makes it difficult to establish a total base number of slide deployments or occurrences of emergency evacuations using slides. Even more challenging, the review of databases for this research revealed that not all incidents (as opposed to accidents) are included in FAA's *Accident/Incident Data System (AIDS).* While, as expected, all accidents were noted in NTSB's *Aviation Accident Database & Synopses,* a few accidents were not included in *AIDS.* It was expected that all incidents involving slide deployment would be recorded in NTSB's *Aviation Accident Database & Synopses* because of the reporting requirement. However, perhaps due to the less formal reporting mechanism noted above, incidents that did not involve major injuries are not recorded. Surprisingly, some of these types of incidents were included in the FAA's *Accident/Incident Data System (AIDS);* however, there were only a few discrepancies of this nature.

Since there were discrepancies among the four databases used (FAA's *Accident/Incident Data System (AIDS),* NTSB's *Aviation Accident Database & Synopses,* Airclaims' *CASE,* and RGW Cherry & Associates Limited *Accident Database*), this research was supplemented by direct contact with airlines and airport fire and rescue units. The compilation of information from all of these sources makes it reasonable to assume that nearly all cases of passenger and crew evacuations using inflatable slides for the period under study (January 1, 1996, to June 30, 2006) have been identified.

In order to accurately identify cases resulting in injuries and, more importantly, to examine the injury mechanisms, additional information from any record of the incident/accident or investigation was sought. In cases that were identified as accidents and involved NTSB investigation, the report and narratives—particularly those compiled by the Survivability Factors Group at NTSB—contain very useful information. Unfortunately, most narratives do not contain enough detail, particularly with regard to injury mechanisms. The most critical issue is that not every accident has been investigated; therefore, it is almost impossible to obtain enough detailed information on all injury mechanisms.

Surveys

Three separate surveys were conducted. The first survey was designed to obtain additional details on identified incident or accident cases as well as to discover events that may not have been captured in the review for this research. The second survey was similar to the first one, but was designed to solicit information regarding the type, location, and severity of injuries that may have been recorded by ARFF units. The third survey was developed to solicit specific information about conditions faced by first responders during aircraft emergency evacuation and to seek their recommendations.

The first survey was designed in consultation with ATA's Director of Safety (see Appendix A). The survey was distributed among the 18 member airlines of ATA. The airlines were requested to provide as much information as possible on the emergency evacuation events collected by the research team. The airlines were also asked to provide a list of any emergency evacuation events that had been missed by the researchers. FedEx, United, and Delta responded to the survey. FedEx provided information on the evacuation cases collected by the research team as well as a separate list of events that were missing from the collected data. The supplemental data provided by FedEx are indicative of a gap in data capture owing to the circumstances previously described. Other airlines either lacked the resources to conduct a thorough review or did not retain descriptive data after complying with all reporting requirements and adjudicating any legal matters pertaining to incidents. Most responses simply confirmed the list of events collected by the research team and did not provide additional detailed information on injury mechanisms.

A second survey was designed and sent out to the ARFF working units of about 100 airports throughout the United States (see Appendix B). The ARFF units were asked to provide detailed information on any injuries incurred during slide evacuation of commercial aircraft. Forty-one ARFF units responded to the survey; 12 of the responding ARFF units were at large airports.

Finally, a third survey was also sent to the ARFF units of about 100 U.S. airports. The ARFF units were asked to list the three top issues encountered during aircraft emergency evacuations using slides. The ARFF units were also asked to list their top three recommendations for ARFF personnel for improving emergency evacuation. Out of the total distributed surveys, 11 responses were received. The complete list of issues and recommendations can be viewed in Appendix C.

The researchers visited Delta Airlines headquarters in Atlanta. A meeting was held with the Vice President of Safety and Security and Quality Assurance and his staff. Their facility was visited, and the research team participated in a mock slide emergency evacuation. The research team was also briefed on Delta's cabin safety program. A list of all the emergency evacuation events during the period being researched was provided by Delta. There were three incidents that were not included in the NTSB and FAA accident/incident databases. Delta Airlines has a procedure for reporting to NTSB and FAA that is similar to the reporting procedures of other airlines. As previously noted, in minor incidents, the immediate reporting may take the form of a phone call to the NTSB field office.

CHAPTER 3

Findings and Applications

Using different databases, a total of 142 emergency evacuation events involving slides were collected; in these events, there were 441 minor injuries and 35 serious injuries. A complete list of the 142 events is included in Appendix D. The ultimate goal of this research was to identify the predominant injury mechanism(s) during emergency slide evacuation of commercial aircraft and to propose a list of recommendations for emergency responders that would mitigate occurrences of those injuries. A complete list of available information on injury types and number of occurrences has also been included in Appendix E.

Analyses of the collected data are illustrated in Figures 1 through 8. Figure 1 shows that there is a significant annual variation in the number of emergency evacuation events involving slides. By examining the annual rate of emergency evacuation, one can observe that there seems to be a general reduction, but given the low number of total events, such observation is not statistically significant.

Although the overall number of cases is low, on average, about 50 percent of the emergency evacuation events involving slides in the study period resulted in injuries, as shown in Figure 2. The nature of the injuries varies significantly, depending on the cases and conditions of evacuation. Table 1 lists the predominant minor and serious injuries incurred in emergency evacuation events involving slides, based on the available detailed reports.

The total number of reported injuries caused by emergency evacuation events involving slides identified in this study, broken down by year, is illustrated in Figure 3. The highest number of injuries due to emergency slide evacuation occurred in 1998, and the lowest number occurred in 2004. There is no particular trend or underlying reason for such variations because the size and type of aircraft (e.g., operation cargo versus passenger) and behavior of passengers and crew members are significant factors in risk exposure levels. Furthermore, in some cases, it is difficult to ascertain if all injuries have occurred on, or in conjunction with the use of, inflatable slides. This uncertainty is due to the poor documentation of injuries incurred during evacuation of commercial aircraft and is especially the case for minor injuries. Since the number of incidents is much larger than the number of accidents, as illustrated in Figure 4, lack of documentation of minor injuries is prevalent. While the downward trend in number of emergency evacuation events involving slides shown in Figure 4 is not statistically significant, it is clear from Figure 1 (in terms of rate) and Figure 4 that there has been an appreciable reduction in emergency evacuations since 1996.

The detailed reports of the emergency evacuation events collected for this research suggest that nearly 90 percent of the reported injuries due to use of inflatable slides during emergency evacuation have been minor injuries. However, in 2004, there were only two injuries reported, and the 50-percent split between minor and serious injuries shown in Figure 5 is entirely insignificant.

The percentage of serious injuries due to use of inflatable slides during emergency evacuation of commercial aircraft is illustrated in Figure 6. Except in 2004, when only two events resulted in injury, less than 20 percent of emergency evacuation events involving inflatable slides caused serious injury in any given year during the study period.

Figure 7 shows a comparison of the rate of emergency evacuation events on commercial aircraft involving slides per 100,000 departures for flights operating under provisions of 14 CFR Part 121 and the accident rate per 100,000 departures for flights operating under 14 CFR Part 121 on an annual basis. The rate of emergency evacuation is lower than the total accident rate despite the fact that the emergency evacuation rate involves both accidents and incidents. Note that the emergency evacuation events classified as accidents are, on average, less than a third of the total events (see Figure 4).

Figure 8 shows the number of emergency evacuations by airport. Airports with a high number of events are those with large operations. Nevertheless, it is interesting to note that some very high-volume airports, such as Los Angeles International Airport (LAX), do not report a single event during this period.

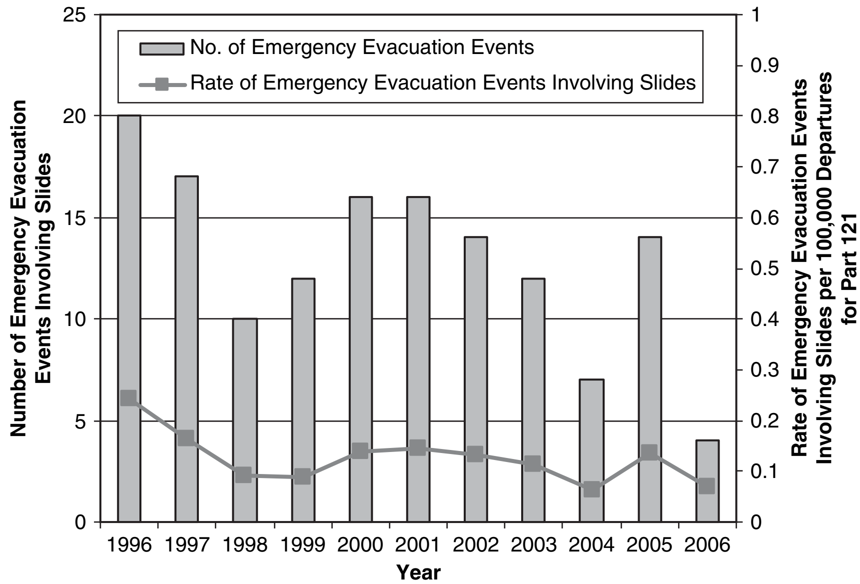

Figure 1. Annual number of emergency evacuation events involving slides.

The high number of events reported by airports such as Dallas/Fort Worth International Airport (DFW), Hartsfield-Jackson Atlanta International Airport (ATL), Washington Dulles International Airport (IAD), and George Bush Intercontinental Houston Airport (IAH), while a function of volume of operation, may also be an indication of having tracking and documentation systems that are better at capturing emergency evacuation events than such systems at other airports. Many of these airports—for instance, ATL, DFW, and IAH—are hubs for major U.S. air carriers.

Categorizing Injuries

In the automotive safety realm—where, according to NHTSA's *Motor Vehicle Traffic Crash Fatality Counts and Estimates of People Injured for 2006,* 2.575 million people were injured and 42, 642 were killed—the AIS has long been used for classifying the severity of injuries and determining the probability of fatality based on injury severity (NHTSA 2007). The AIS is an anatomical scoring system first introduced in 1969 (U.S. DOT 1990). Since that time, it has been revised and updated against survival data so that it now provides a reasonably accurate way of ranking the severity of injury. The latest incarnation of the AIS score is the 1990 version (Copes et al. 1989). The AIS is monitored by a scaling committee of the Association for the Advancement of Automotive Medicine.

In AIS classification, injuries are ranked from 1 to 6. Injuries ranked "1" are minor; injuries ranked "5" are severe; and injuries ranked "6" are not survivable. The ranking represents the "threat to life" associated with an injury and is not meant to represent a comprehensive measure of severity. The AIS is not an injury scale, so the difference between AIS 1 and

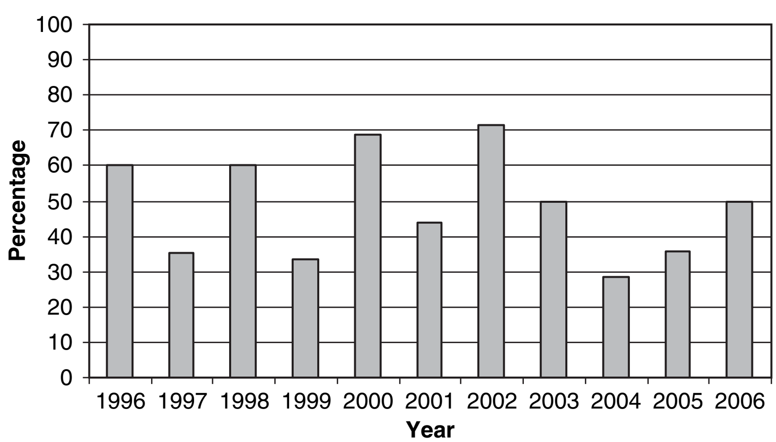

Figure 2. Percentage of emergency evacuation events involving slides resulting in injury.

Table 1. Predominant minor and serious injuries incurred in emergency evacuation events involving inflatable slides.

Minor Injuries	Serious Injuries
Sprain	Fractured ankle
Friction abrasions	Broken leg
Scrapes from slides	Major bruises
Strain	Laceration
Abrasions	
Contusion	

AIS 2 is not the same as that between AIS 4 and AIS 5. Table 2 shows the AIS severity code.

On the basis of the available information on injuries incurred during slide evacuation for identified cases in this study, it appears that all injuries caused solely by use of inflatable slides during an emergency evacuation can be classified as AIS 1 and AIS 2. Note that serious injuries are typically fractured bones, broken legs, and laceration, which fall under AIS 3.

Large Aircraft Evacuation

The review of large aircraft evacuation issues was done as part of this study because it is an emerging issue. Levels and types of injuries that are prominent in the accident and incident data for slide evacuation relate directly to speed. The primary difference for large aircraft evacuation (i.e., evacuation from the upper deck of the A380 and the B747) is the increased height, which may result in a higher speed on the slide in addition to the psychological issues associated with height. There have been several studies of emergency evacuations of large transport aircraft, especially the largest commercial aircraft, the Airbus A380 (Jungermann 2000; Jungermann et al. 2001)

A 1-year study done for the European Commission, called the *Very Large Transport Aircraft (VLTA) Emergency Requirements Research Evacuation Study*, investigated the evacuation challenges of future aircraft (Wilson et al. 2003). The Airbus A380 is categorized as a VLTA; the B747 perhaps also could be categorized as a VLTA. The examination of VLTA evacuation also includes potential future designs such as blended-wing body aircraft. A computer model for the simulation of an evacuation as well as a double-deck large cabin simulator were used to analyze these issues. The *Very Large Transport Aircraft (VLTA) Emergency Requirements Research Evacuation Study* includes results of the first evacuation research trials of large, double-deck aircraft and recommendations (Wilson et al. 2003).

Jungermann and colleagues also discuss the issues of emergency evacuation from a double-deck aircraft in several papers, one of which was presented at the 2001 International Aircraft Fire and Cabin Safety Research Conference in Atlantic City, New Jersey (Jungermann 2000, Jungermann et al. 2001). Jungermann and colleagues developed a model to analyze how factors such as slide design, visibility, and passenger safety instruction would influence an individual's performance during emergency evacuation, and they observed reactions to different situations. These researchers also studied the psychological effects of the upper deck height on people's performance. While finding that there was a need for further research, Jungermann did find a difference in hesitation time between individuals evacuating from the upper deck and individuals evacuating from the main deck.

B747 Slide Emergency Evacuation Events

Of the 142 slide emergency evacuation events identified for this study, only 2 involved B747 aircraft. One event occurred

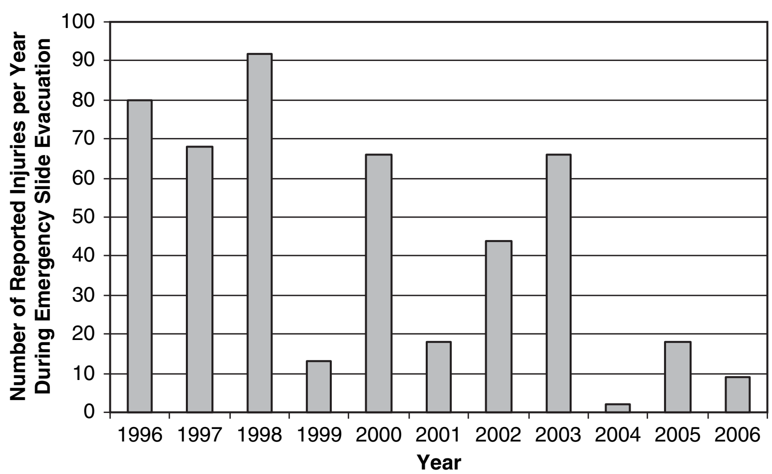

Figure 3. Number of reported injuries per year during emergency slide evacuation.

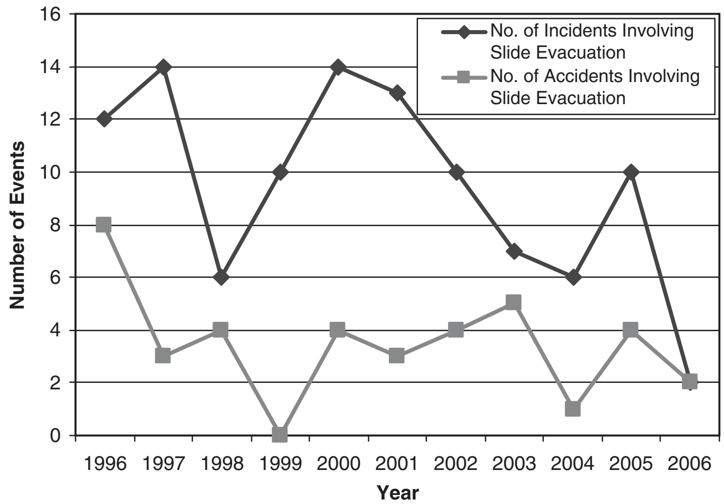

Figure 4. Number of incidents and accidents involving emergency slide evacuation per year.

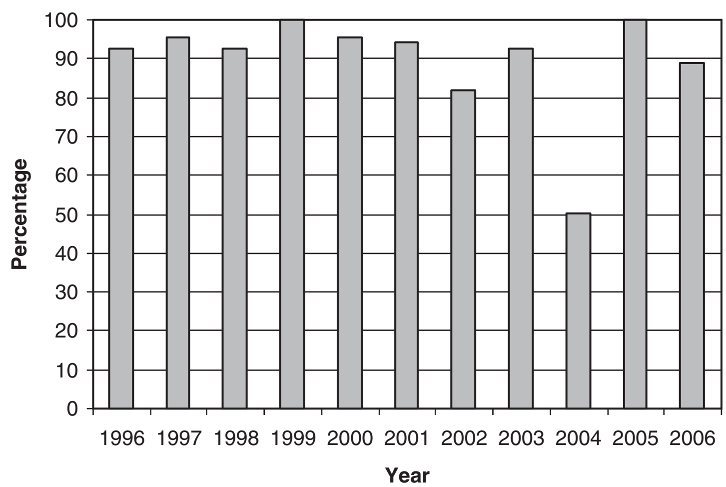

Figure 5. Percentage of minor injuries due to use of emergency slide evacuation per year.

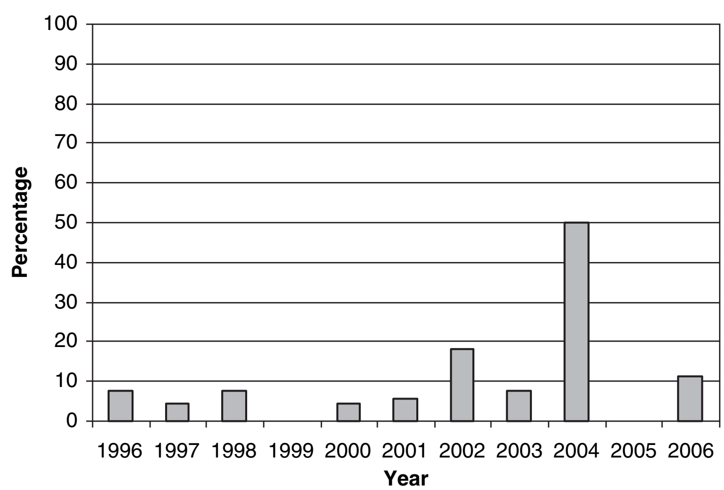

Figure 6. Percentage of serious injuries due to use of slides during emergency evacuation.

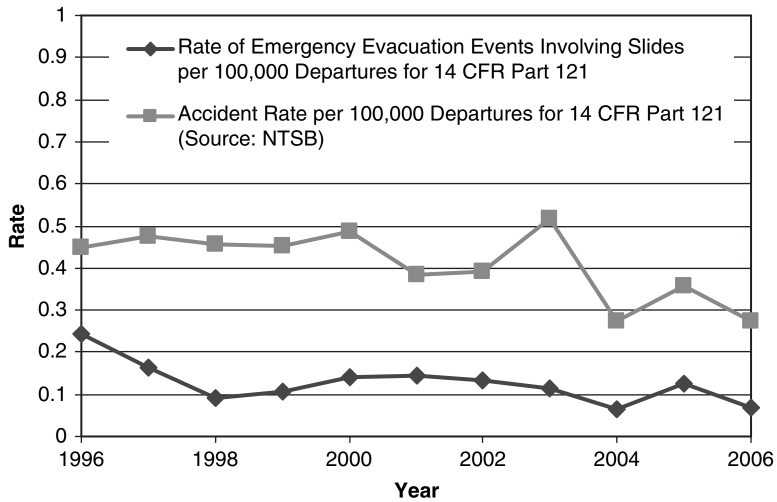

Figure 7. Comparison of rate of emergency evacuation events involving slides per 100,000 departures and accident rate per 100,000 departures for 14 CFR Part 121 as reported by NTSB (see Aviation Accident Statistics http://ntsb.gov/aviation/Stats.htm).

on August 19, 2005, in Agana, Guam. A B747-200 landed with its nose gear retracted, and an emergency evacuation was initiated. Two minor injuries occurred during the evacuation. The second event occurred in May 1998 in Tokyo and involved a B747-400. A very detailed report for this event, "Aircraft Accident Investigation Report," was produced by the Ministry of Transport of Japan (Aihara 2000).

The "Aircraft Accident Investigation Report" of the May 1988 emergency evacuation event in Tokyo states that of the 385 persons aboard (365 passengers and 20 crew members), there were 4 persons with serious injuries and 20 persons with minor injuries (Aihara 2000). The report states that the four serious injuries involved females aged 38 to 73 and consisted of different types of fractures. Minor injuries were mostly bruises, sprains, contusions, excoriations, abrasions, and so forth. A flight attendant who was injured stated that she picked up an elderly woman who was trembling at the top of the slide and took her down the slide. The flight attendant was injured on her right foot, but had no fracture. One female, aged 65, was seriously injured from sliding down the slide. She said that passengers were throwing away their belongings while she was on the slide. Her right index finger was fractured by a heavy briefcase that hit her hand. In addition to this, she hit her lower back against the ground at the bottom

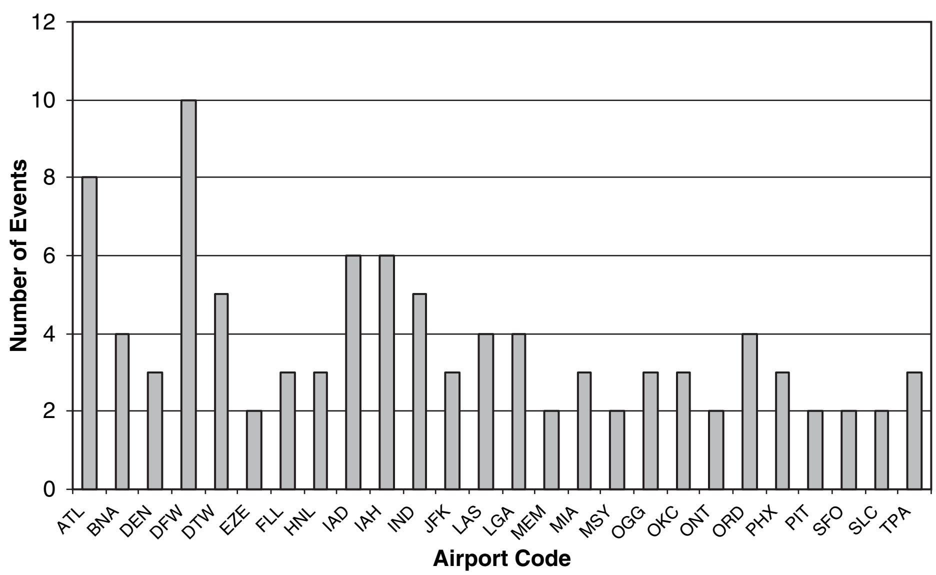

Figure 8. Number of emergency evacuation events involving slides per airport with more than one occurrence during the past 10 years.

Table 2. AIS severity code.

AIS Code	Description
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum
7	Injured (unknown severity)

of the slide, as there was no ground assistance. Another female, aged 73, sustained a serious injury at the bottom of the slide. She stated that "sliding down was so fast that I was worried about being injured by the speed." She jumped at the bottom of the slide, and while she was covering her face and head, she fractured her right arm. A passenger from the upper deck reported that he did not receive any guidance on evacuating. He mentioned that he deplaned via the ramp connected to the airplane and did not evacuate using a slide. The report estimates that all the injuries occurred sliding down, or at the bottom of, the slide (Aihara 2000).

Additional research was conducted to identify other events involving VLTA. The only event was found on NTSB's database for 14 CFR Part 129 slide emergency evacuation events involving a Boeing 747 aircraft; this event involved an aircraft operated by Iberia Airlines. The accident occurred in Jamaica, New York, on August 11, 2002. Two passengers were seriously injured and 1 flight attendant and 34 passengers sustained minor injuries. Ten passengers were transported to medical facilities for treatment. A female passenger fractured her ankle. It was noted that the slide/raft doors 4R and 5R did not work properly, and all the 369 passengers and 17 crew members evacuated using 1R, 2R, and 3R doors (NTSB 2002).

Also, an article published in *Flight Safety Australia* describes a B747-438 slide emergency evacuation event that occurred at the Sydney airport on July 2, 2003 (" 'Evacuate. Evacuate. Evacuate.' " 2005). A very detailed investigation report was done by the Australian Transport Safety Bureau (ATSB) (ATSB 2005).

In the 2003 event at the Sydney airport, the captain ordered the passengers to evacuate and deployed the aircraft's slides because of fire on the right landing gear. There were four serious injuries resulting from the evacuation. The injured people included one crew member and three passengers (out of the 350 passengers and 14 cabin crew members). Four passengers and one cabin crew member suffered from minor injuries. Figure 9 shows the Sydney incident.

The most serious injury was a fractured vertebra that required surgery. This injury was incurred by a passenger who landed heavily on the tarmac because she was on an over-wing slide at the time it deflated. Additionally, one passenger fractured her arm and foot as a result of using the evacuation slides.

The L2 and R4 escape slides on the left side of the upper deck did not deploy. The upper deck right slide was deployed, but the crew declared that it was blocked by a vehicle. The ground crew freed the slide and turned it to the right position on the ground. Upper deck passengers descended to the main deck and therefore did not use the upper deck slide to evacuate. The copilot, however, did use the upper deck slide. He descended on the upper deck right side while he was holding a 3-kg fire extinguisher. The copilot stated that he was unable to control his speed and stability. He released the fire extinguisher while sliding down, but, because of the momentum, he landed heavily on his shoulder and fractured his collar bone.

Some of the injuries incurred were cuts, abrasions, sprains, and bruises. One female passenger was injured at the bottom of the slide, where she fell and cut her right elbow. Her husband evacuated holding their infant on his right hip with his right arm. He stated that he believes he tried to slow down using his left arm. Due to his fast descent, he also fell at the end of the slide, tearing his clothes and cutting his left knee and hand.

Figure 9. Slide emergency evacuation of a Boeing 747-438 (Sydney, Australia, July 2, 2003). *(Photo Source: Australian Transport Safety Bureau)*

The cabin crew noted difficulties during the evacuation process. Some flight attendants let people take their belongings with them while others forced people to leave their belongings when evacuating. Thus, some passengers evacuated down the slides with their cabin baggage. Passengers taking luggage or wearing high-heeled shoes risk damaging the slide as they slide down. It was also observed that passengers collided with each other at the bottom of the slides as they did not know what to do next. The ground crew decided to assist the passengers by directing them away from the aircraft (ATSB 2005).

Airbus A380 Certification

Certification is needed for all new aircraft models introduced into service to ensure that the aircraft model and crew training meet safety regulations for aircraft evacuation. The main requirement is known as the "90-second rule": the maximum exit time allowed for evacuation. The list of the critical requirements needed to attain FAA certification can be found in Appendix F. Certification test results are considered proprietary to aircraft manufacturers and suppliers and cannot be disclosed to third parties. Many attempts were made to gather any type of information available to the public.

Data, such as the characteristics of A380 slides and doors and certification cabin evacuation test results, were obtained from the A380 Chief Airworthiness Engineer (J. M. Govaere, personal communication, 2007). For an evacuation test held March 26, 2006, Airbus recruited volunteers to meet the population requirements. Figure 10 is a photograph of the certification test. The A380 received joint European Aviation Safety Agency (EASA) and Federal Aviation Administration (FAA) Certification in December 2006.

The population of the aircraft was 873 persons—315 passengers on the upper deck, 538 passengers on the main deck, 18 cabin crew members, and 2 cockpit crew members.

Figure 10. Airbus A380 certification test.
(Photo source: FAA, www.Airporttech.tc.faa.gov/safety/patterson1.asp)

The A380 certification test met both 14 CFR Part 25 and 14 CFR Part 121 requirements, as well as Federal Aviation Regulation (FAR) 25.803 (c) including Appendix J and FAR 121.91 requirements, given below:

- FAR 25.803 states that "for airplanes having a capacity of more than 44 passengers, it must be shown that maximum seating capacity, including the number of crewmembers required by the operating rules for which certification is requested, can be evacuated from the airplane to the ground under simulated emergency conditions within 90 seconds."
- Appendix J to FAR Part 25 lists the certification requirements, which can be found in Appendix F of this report.
- FAR 121.91 states that "this subpart prescribes rules for obtaining approval of routes by certificate holders conducting domestic or flag operations."

The test results showed no serious injuries and only very minor injuries. None of the minor injuries was more serious than a bruise. It was stated that the number of injuries was significantly less than FAA's "official" acceptable injury rate of 5 percent.

The evacuation was performed in 78 sec, which is within the 90-sec limit. As stated from the results obtained, no difference was observed between the behavior of passengers on the main deck and passengers on the upper deck. No hesitation time on the part of passengers sliding from the upper deck was noticed.

As a part of the present study, research was conducted to examine the key parameter of VLTA slide evacuation, namely, the speed of the passenger on the slide. A dynamic mathematical model was developed to bound the problem and present a tool to perform a comparison of speeds on slides based on total length, angle of inclination, and height of the exit sill from the ground. A detailed report is presented in Appendix F.

This dynamic model was developed based on an assumed curvilinear path with friction to calculate the velocity of a person at any given location (x,y) on the inflatable slide. Several assumptions are needed to compute the velocity, including the following: initial velocity, constant coefficient of friction, constant curvature of the slide, and no deflection due to weight of individuals on the slide. The parameters required are the following: the total length of the slide, the initial velocity of an individual, and the coefficient of friction. These parameters are changed in the model to see the effect that they have on velocity. For this model, conservation of energy is employed including friction, but the air drag effect on the evacuee is neglected. A typical friction coefficient of 0.4, noted in Part 5.5.4.3.1 of TSO-C69c, was used as a starting point (FAA 1999).

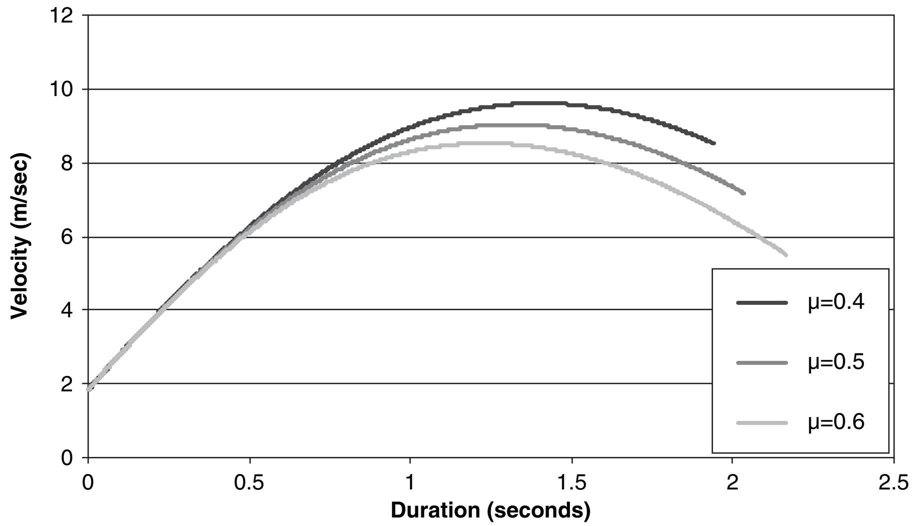

Figure 11. Velocity versus duration with three coefficients of friction for an individual sliding down the A380 upper deck evacuation slide with an initial velocity of 1.83 m/sec.

Figure 11 shows the relationship between the velocity of an individual sliding down the A380 upper deck slide and the duration of the individual's movement down the slide. It can be seen that when the coefficient of friction increases, the time it takes for an individual to slide down increases. Also, at higher coefficients of friction, the maximum velocity and velocity at the bottom of the slide are lower. With an initial velocity of 1.83 m/sec, the velocity of an individual at the bottom of the slide is 5.49 m/s for a coefficient of friction of 0.6, whereas it is 8.52 m/s when the coefficient of friction is 0.4. This dependence on the coefficient of friction is noteworthy, resulting in a terminal velocity variation of about 50 percent. The time required to move from the top of the slide to the bottom is 1.94 seconds when the coefficient of friction is 0.4 versus 2.17 seconds when the coefficient of friction is 0.6.

Figure 12 shows the evacuee speed on the slide as the function of time with varying initial velocity. The results show that the effect of initial velocity is minimal.

Figure 13 shows results for velocity versus duration on A380 and B747 upper deck slides assuming the same initial velocity and two separate coefficients of friction. Regardless of the specific accuracy of the model, the results illustrate that there is a small difference in maximum velocity and velocity at the bottom of the slide between the upper deck of the A380 and the upper deck of the B747. The time it takes to reach the bottom of the slide is about the same because of a slight dif-

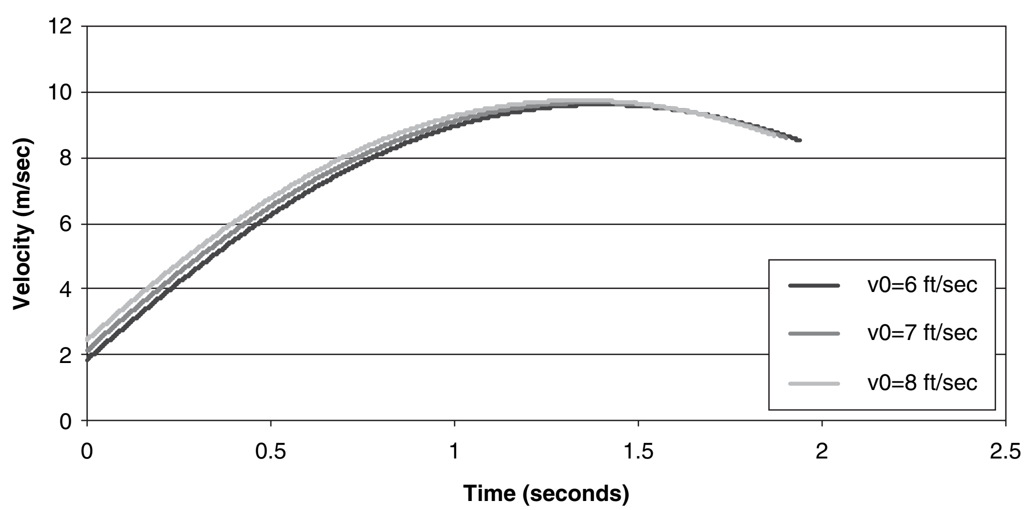

Figure 12. Velocity versus time for an individual sliding down the A380 upper deck evacuation slide with a coefficient of friction of 0.4 and different initial velocities.

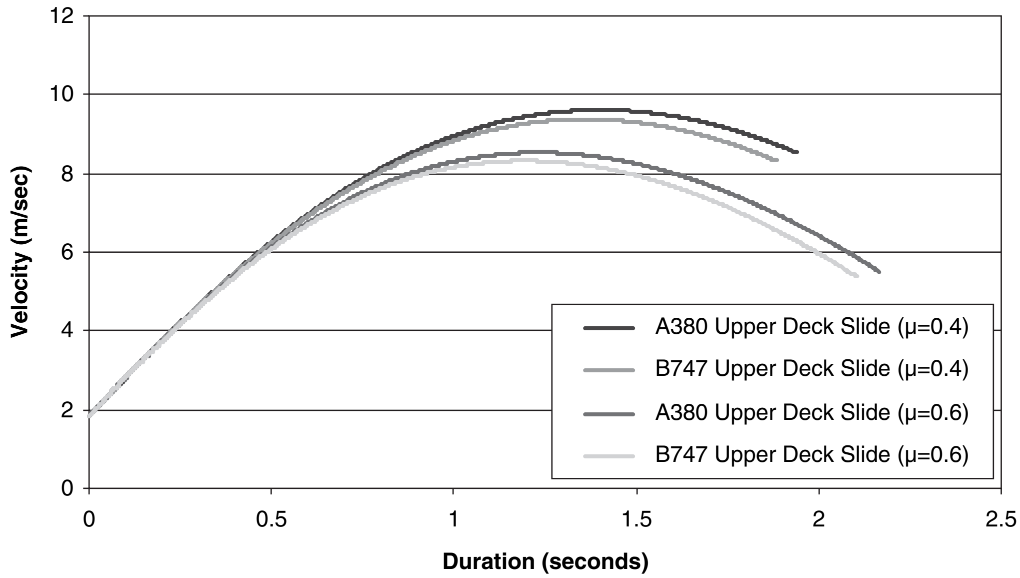

Figure 13. Velocity versus duration on A380 and B747 upper deck evacuation slides with an initial velocity of 1.83 m/sec and two coefficients of friction.

ference in the length of the slides and the distance from the top of the slide to the ground. The results indicate that at an initial velocity of 1.83 m/sec and a coefficient of friction of 0.4, it takes about 1.94 seconds to slide down from the upper deck of the A380 versus 1.88 seconds to slide down from the upper deck of the B747.

Given equal conditions, the computations show that there is very little difference between the two aircraft except the exposure of more passengers in the A380 to being evacuated from the upper deck and the fact that in a B747 passengers are generally directed to use the exits in the lower deck even in an emergency evacuation.

Effect of Wind on Stability of Inflatable Evacuation Slides

Inflatable evacuation slides and/or slide rafts provide a rapid means for evacuating passengers from commercial aircraft in the event of an emergency. These inflatable structures are normally deflated for storage in an aircraft. When the aircraft door is opened, the force of gravity can unfold or unroll the slide outside of the doorway. Once outside the doorway, the slide is rapidly inflated through the application of air pressure and in a very short period of time is ready for receiving evacuating passengers.

There are several factors that affect the performance of emergency evacuation with inflatable slides. These factors are the following:

- **The angle formed between the slide surface and the ground.** The optimum rate of descent for evacuees is usually achieved when the angle between the slide surface and the ground is approximately 30° to 50°. If the angle is much greater than 50°, the slide angle may be too steep, and this may result in evacuee injury upon impact with the ground.
- **Environmental factors.** In adverse wind conditions, slides will not be stable, and therefore it is not recommended that they be used. When an evacuation is unavoidable under these conditions, there could be an increase in the number of evacuee injuries. Other environmental conditions, such as rain or snow, could also have an impact on the performance of the evacuation.
- **Improper or failed inflation of the slides.** Malfunctions in the inflation of slides can be a major problem for the process of the evacuation.
- **Height of emergency exit.** As stated earlier, aircraft emergency exits that are higher than 6 ft from the ground are required by the *Code of Federal Regulations* to be equipped with inflatable slides. The heights of the upper decks on B747 and A380 aircraft are a major concern with regard to evacuations.

Various problems with slides have been reported since their introduction on commercial passenger aircraft. Despite recommendations from accident investigation authorities for improving slide reliability over the past 33 years, some previously identified slide problems continue to be reported (van Es and Post 2005). Researchers van Es and Post (2005) identified and analyzed 81 accidents using the Air Safety Database of the Dutch National Aerospace Laboratory (NLR). According to this research, the most significant slide problems identified in evacuation accidents are the following: slide inflation problems, aircraft attitude, wind, a burnt slide, incorrect rigging of the slide, and a ripped slide (see Table 3).

Table 3. Problems identified with the use of slides and rates of occurrence in 81 accidents listed in the NLR Air Safety Database (van Es and Post 2004).

Identified Problem	Amount (%)
Slide did not inflate	28.1
Aircraft altitude	15.7
Other	13.5
Wind	12.4
Slide burnt	11.2
Incorrect rigging	7.9
Slide ripped	6.7
Unknown	4.5

Wind had an adverse effect on slide use in 12.4 percent of the accidents. In these cases, the wind blew the inflatable slides up against the sides of the aircraft, preventing slide use. Researchers van Es and Post (2004) also studied the probability of using emergency evacuation slides in mean wind conditions of more than 25 knots in 601 airports worldwide. Based on this study, the probability of using emergency evacuation slides in mean wind conditions of more than 25 knots is estimated to be 6 per billion departures. This is a relatively low probability, but it still poses a threat to the lives of passengers and crew members since during an emergency it may not be possible to delay landing or divert an aircraft because of high wind conditions.

Three different studies, conducted by NTSB (1974, 2000) and the Transportation Safety Board of Canada (TSB 1995), have looked into the stability of inflatable slides during adverse wind conditions. In these three studies, four emergency evacuation cases (12.5%) were identified in which slides were not usable because of wind. In these emergency evacuation events, the mean wind speed varied from 13 to 20 knots.

Detailed slide design and performance requirements are contained in a Technical Standard Order (TSO) (FAA 1999). TSO C69c describes the minimum performance standards that emergency slides must meet (FAA 1999). TSO C69c requires that an inflatable slide must deploy in 25-knot winds directed from the most critical angle with the assistance of only one person, who has evacuated down the slide; furthermore, the slide must remain useable after full deployment to evacuate occupants safely to the ground. It is difficult to estimate the amount of force an individual can exert to hold down the slide because it depends largely on the gender, age, and physical condition of the person. Nevertheless, historical data show that when the wind's mean speed does not exceed 25 knots and one individual holds down the slide, the inflatable evacuation slide remains stable (NTSB 2000; Van Es and Post 2004).

CHAPTER 4

Conclusions and Recommendations

The period of study for this research—January 1, 1996, to June 30, 2006—proved to be adequate for the stated purposes of the research. As the research progressed, it became clear that most airlines or airport authorities do not retain documentation of evacuation events, particularly those events classified as incidents, and that when airlines and airport authorities do retain documentation, they typically do so for no more than 3 years. During the period of study for this research and within the stated research scope, 142 emergency evacuation events were identified. The rate of emergency evacuation events (accidents and incidents) is relatively constant at about 0.1 per 100,000 departures for 14 CFR Part 121 operations. This rate is less than one-third of the rate of accidents for the same type of operations reported by NTSB.

This research showed a clear deficiency of recorded data and detailed information on emergency evacuation events, particularly when only minor injuries are involved. The collection of data showed that not all slide deployment events are well documented, and most are not thoroughly investigated for root causes and contributing factors, even though maintenance action may involve submission of an SDR. In addition to the SDRs as a possible source of information, it may be possible to link Aviation Safety Action Program (ASAP) reports (given due consideration of the existing regulations governing the voluntary nature of ASAP) with the National Aviation Safety Information and Analysis System (ASIAS).

There is a lot of anecdotal information that indicates that there are certain events, such as maintenance-related or uncommanded events, that may not be properly reported. It is possible that a small number of events may have been both undocumented and not reported verbally to the appropriate authorities.

The data show that over the studied period, there was a significant annual variation in the number of emergency evacuation events and that, on an average, nearly 50 percent of the events resulted in injuries. The detailed reports of the emergency evacuation events collected for this research suggest that nearly 90 percent of reported injuries are minor—abrasions, bruises, cuts, and sprains. The authors of this report propose that aviation authorities use the AIS scale for classifying injuries so that reporting of injuries during aviation incidents and accidents can be more uniform. In AIS classification, 90 percent of the injuries documented in reports collected for this research would be classified as AIS 1 or AIS 2; the rest would be classified as AIS 3. No injury above AIS 3 was identified.

Surveys of ARFF groups and a number of reports have noted the stability of slides under windy conditions as an area of concern. It is important to note that the certification requirement for stability of the slide—one person should be able to hold the slide in 25-knot wind at a most critical angle—is based on slide stability *after* a full deployment. Instabilities induced by winds *during* slide deployment may be the reason for the concern expressed by ARFF groups and other reports. Quantification of the issue without accurate local measurement of wind during an event, and particularly wind gusts, is not possible. Nevertheless, such windy conditions during the initial unfolding may result in twisting and instability of the slides. It is therefore important for the first responders (1) to practice initial stabilization and proper orientation of the slide during windy conditions and (2) to realize that ongoing efforts to stabilize the slide may be needed under such conditions.

Evacuation of very large aircraft, such as the A380, has come under scrutiny and has been a matter of public interest. In this research, a mathematical model was developed to study the key issue of the speed at which a passenger comes down a slide. While no attempt has been made to quantitatively evaluate the accuracy of the model, a qualitative comparison with an A380 evacuation makes the results seem reliable. The model was used mostly as a comparison tool, and it shows that the speed at which a passenger comes down a slide from the upper deck of an A380 is essentially the same as the speed at which a passenger comes down a slide from the upper deck of a B747.

Finally, several suggestions are listed below for enhancing aircraft passenger evacuation and reducing the risk of injury during emergency evacuations using inflatable slides. These suggestions are based primarily on input by ARFF groups.

Issues

The following summary of issues is derived from a survey of ARFF personnel at airports and an analysis of the available information on emergency evacuation events. The main issues are prioritized based on frequency of occurrence and the authors' assessment of their importance.

Inflatable Slide Deployment Issues. These include challenges with the manner, location, and timing of slide deployment such as the following:

- Slides becoming twisted and caught up at the exit door;
- Failure of slides to operate or operate properly;
- Unnecessary deployment of slides; and
- Deployment in hazardous locations, such as places where fire or steep inclines exist.

It should be noted that incidents judged by flight crews to be emergencies that are later determined to be false alarms are often perceived by those outside the aircraft as unnecessary deployments. It is the position of the authors of this report that it is better for flight crews to err on the side of caution. Deployment in a hazardous location points to the fact that unfamiliarity with the surrounding conditions and terrain, particularly under adverse conditions (such as darkness), may be avoided if direct and rapid communication with those outside the aircraft can be established.

Need for Ground Assistance/Personnel. There is a clear need for first responders at the scene of an emergency evacuation who are prepared to do the following:

- Hold down slides for passengers,
- Try to calm passengers,
- Turn slides into the right position,
- Secure and manage a safe path at the bottom of the slides, and
- Effectively handle injured passengers and take them to safety.

The stability of the slides may be compromised because of uneven terrain, wind, or aircraft fuselage instability. Assisting the passengers must be done with full knowledge that touching the individuals on the slide, except at the very bottom, may result in a reaction that by itself can cause injury or disruption of the flow. For example, a person trying to catch an evacuee sliding with folded arms at the bottom of the slide may elicit an instinctive reaction to extend the arms in the evacuee, and, in extending the arms, the evacuee may inadvertently hit the assisting person.

Issues with Evacuation Speed. The flow of evacuees—their speed on the slides and at the bottom of the slides—can impact evacuation performance as well as the potential for injury. ARFF personnel noted that when there is no imminent danger, coordination between the flight crew and ARFF personnel is needed to control the flow and speed of passenger evacuation. High speed at the bottom of the slide is a function of initial speed as well as the orientation of the slide. A pile-up at the bottom of the slide can cause serious injuries, and excessive speeds on the slide can easily cause skin burns and abrasions. The challenges are to properly judge the situation and to maintain communication between the ARFF unit and the flight crew. The key issues identified by ARFF personnel are listed below:

- Initial speed of passengers on the slide,
- Slowing down the rate of evacuation if imminent danger is not present, and
- Evacuation event control in "minor" emergencies.

Slide Deployment in Wind. As noted previously, initial deployment of a slide may be difficult under windy conditions. The main challenges are the following:

- The stability of slides in wind and
- Preventing slides from turning and twisting in wind.

To keep the slide stable under windy conditions, flight crew members often instruct the first passenger down the slide to help stabilize the slide by holding it down. In practice, however, passengers often walk away, and this task falls to the first responders. Following a crash, fire, or other emergency, when all available ARFF personnel must respond to imminent hazards, assigning ARFF personnel to help with slide stability may be a problem.

Communication. Better communication between ARFF personnel and a flight crew can improve many of the situations listed above. The major issues with communication are the following:

- A lack of cockpit/ground communication and
- Communication difficulties because of a lack of secured methods (i.e., Discrete Emergency Frequency [DEF]).

Injury to Rescue Personnel While Helping Passengers. As noted earlier, unless there is adequate training and practice, particularly through simulation of adverse conditions, there is a distinct possibility that rescue personnel may incur injuries as a result of passengers sliding into them and passengers hitting them with their arms, legs, or objects that they have carried down the slide.

Recommendations

Based on the study carried out on injury mechanisms due to slide evacuation of commercial aircraft and the survey of ARFF units of major U.S. airports, the following list of recommendations to improve passenger emergency evacuation of commercial aircraft has been developed.

- Improvements are needed in communication, coordination, and action planning among rescue personnel at airports, flight crews, and airline operation personnel, including the following:
  - Airports should work with the Air Traffic Control Tower (ATCT) to design DEFs for secure and rapid communication with flight crew during emergencies.
  - Hands-on training is needed to increase coordination and communication between ARFF units and flight crews so that unnecessary evacuations can be eliminated.
- It would be beneficial for rescue personnel to train with the flight crews and operation personnel of various airlines on various aircraft. Training should focus particularly on the operation of slides during adverse conditions. The following points should be given particular consideration:
  - The numbers and locations of slides on aircraft that frequently fly to a given airport,
  - The types of emergencies that require deployment of the slide during emergency evacuation, and
  - Using an actual slide deployment or simulators during training.
- ARFF personnel assistance with slide evacuation should be concerned with the following:
  - Establishing sectors/slide zones and identifying hazards,
  - Identifying several predesignated multicasualty incident staging areas on the Air Operating Area (AOA),
  - Identifying a separate passenger area of refuge/assistance,
  - Ensuring proper slide deployment,
  - Stabilizing slides by holding them down,
  - Moving evacuees away from the slides quickly while avoiding catching or touching the passengers if their movement is stable and there is no obvious problem,
  - Assisting with passenger flow,
  - Dispersing fire-fighting agent to protect evacuees, and
  - Distinguishing controlled evacuation from emergency conditions.
- An emergency medical services (EMS) team to handle injuries would be a good addition to emergency evacuation procedures.
- The addition of lighting or reflective markers along a slide's length would provide better visibility of deployed slides for ARFF units.
- It would be helpful to develop standard operating guidelines for ARFF groups at a national level.
- ARFF groups should consider developing uniform documents to record all emergency evacuation events or deployment of slides.
- The AIS system, a well-documented classification scheme that has been established and tested by the medical community, should be considered for injury classification.

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APPENDIX A

Airline Survey on Emergency Evacuation Events

Study of Evaluation and Mitigation of Aircraft Slide Evacuation Injuries

The George Washington Aviation Institute has been tasked by the National Academies Transportation Research Board (TRB) to conduct a quick response study on aircraft slide evacuation injuries.

We are interested to examine the mechanism of ALL injuries that have occurred during slide evacuation of flights operated under provisions of 14 CFR Part 121 over the past ten years. The outcome of this study is expected to be a list of recommendations/suggestions for emergency responders to reduce the rate of evacuations and mitigate injuries due to use of slides during emergency evacuation.

We would appreciate it if you could provide us with information regarding emergency evacuation of flights operated under provisions of 14 CFR Part 121 for the period from January 1st, 1996 to June 30th, 2006 which took place at your airport. In addition, we would like to know how many of the emergency evacuation events resulted in ANY injuries directly related to slide evacuation.

Attached please find a data sheet that you can use to input the data for the emergency evacuation events. We would further appreciate it if you could provide additional information sought in the second data sheet for the individual events involving injuries.

Best Regards,

Vahid Motevalli, Ph.D., P.E.
Director, Aviation Institute

Please return your answers to the following address:

Aviation Institute
20101 Academic Way
Ashburn, VA 20147
or email it to monajemi@gwu.edu

List of flights operated by your airline under provisions of 14 CFR Part 121 **involving slide evacuation** from Jan 1st, 1996 to June 30th, 2006

Airline:

Date of event	Name of the airport	Type/Model of Aircraft	No. of Passengers onboard	No. of Crew	Total No. of Reported Injuries	No. of Fatalities	Were Slides Used?	Wind speed at the time of event (if available)

Please add additional rows if needed

Please provide us with additional information regarding each emergency evacuation event resulted in **ANY** injuries directly related to slide evacuation

Event Date:

Person No.	Crew or Passenger?	Age	Gender	Injury Severity (Minor,Serious, Fatal)	Most Probable Cause & Location of Injury	Type of injury (i.e. broken bones, burns etc.)
1						
2						
3						
4						
5						

Please add additional rows if needed

Please explain the problems experienced with exits and slides during evacuation (i.e. slide didn't inflate).

Which exits and slides where used during evacuation?

APPENDIX B

ARFF Units Survey on Emergency Evacuation Events

List of accidents/incidents involving slide evacuation for flights operated under provisions of 14 CFR Part 121 at your airport

Jan 1st, 1996 to June 30th, 2006

Airport:

Date of event	**Airline**	**Type/Model of Aircraft**	**No. of Passengers onboard**	**No. of Crew**	**Total No. of Reported Injuries**	**No. of Fatalities**	**Which Slides were Used?**	**Wind speed at the time of event (if available)**

Please provide us with additional information regarding **EACH** emergency evacuation event resulted in **ANY** injuries directly related to slide evacuation

Event Date:

Person No.	Crew or Passenger?	Age	Gender	Injury Severity (Minor,Serious, Fatal)	Most Probable Cause & Location of Injury (i.e. in cabin, slide etc.)	Type of injury (i.e. broken bones, burns etc.)
1						
2						
3						
4						
5						

Please add additional rows if needed

Please explain the problems experienced with exits and slides during evacuation (i.e. slide didn't inflate).

Were there any difficulty experienced from the perspective of emergency responders in case of adverse wind condition?

APPENDIX C

List of ARFF's Issues and Recommendations

List of Issues

- Injuries to passengers and crew would be the biggest issue. Broken or sprained ankles and/or burns, mainly on the passengers' wrists, arms and backside due to the abrasiveness of the slides.

- The speed of initial passengers evacuating down slide with no ground assistance result in back ups and injuries.

- Lack of cockpit/ground communications (at some airports)

- Using the discrete radio frequency, decreases the unnecessary deployment of slides. Ability of communicating with the pilots reduces anxiety and stress in the pilots due to the fact that the ARFF tell them what is going on behind them and what they are doing to assist them.

- If not a true emergency and slides were deployed, flight crew will not stop the process. The best we can do is hold the slides down for the passengers utilizing them and try to calm them down as they do. If the evacuation is not a true emergency, ARFF must try to slow the speed of the evacuation. The serious head injuries etc. are most often caused by passengers landing on top of one another at the base of the slide.

- Slides deployed at incidents where evacuation may not be the answer or deployed into the wrong area.

- Evacuation control - when slides are deployed flight crews are trained to evacuate passengers quickly (90 seconds) leading to behaviors and actions that result in near panic on the passengers part. This leads to injuries, disorientation and passenger control issues when the aircraft is evacuated via the slides in "minor" emergencies. Every time slides are deployed there are issues controlling the slides in windy conditions and getting passengers out of the way quickly at the bottom of the slide.

- Slides getting twisted and caught up at the door. Fire Crews on the ground can lift the slide up at the bottom taking the weight off the slide and turn the slide so it will be in the correct position.

- Failure of slides to operate - crew verbalized their concern that at least one of the slides did not deploy.

- Wind velocity (slides blow in the wind)

- Securing and maintaining safe egress paths and staging areas for ambulatory PAXs after reaching the bottom of the slide. Staffing ground operation personnel needed to secure and manage the landing zones that often are the site of PAX injury. Effectively handling injured/ infirm PAXs to safety, without compromising other emergency operations (i.e. fire suppression and control) occurring simultaneously. Communication difficulties caused by the lack of secured methods (i.e. D.E.F.) and procedures with Flight Crews to best determine crucial deployment/non-deployment decision making process.

- Deployed away from ARFF location

- When slide deployment occurs prior to our arrival, the possibility exists that they may deploy to the fire side of the aircraft. Also, when the aircraft comes to stop at a difficult angle, the escape route could be unusually unsafe to access. It is possible that in the heat of battle, aircraft occupants will exit the plane into unsafe situations.

- Deployed slides limit access to the aircraft via air stairs

- Injury to rescue personnel is a major issue. Deployment of slides usually involves in injury of emergency personnel. As much as the ARFF personnel are trained, there is always someone working who is not familiar with slide deployment rescue techniques.

List of Recommendations

- Train with various airlines on various aircraft as to how the slides operate. Get to know the numbers and locations of the slides on the aircraft that frequently fly your airport. Train them on what constitutes the need for an emergency evacuation by slide. Training with airline staff covering their evacuation procedures & ARFF concerns

- ARFF tactical plans should contain priority consideration to deployment of firefighters to assist with slide evacuation e.g. establish sectors/slide zones, identify hazards, hold slide down, assist with passenger flow, etc...

- Upon initial "size up", ARFF command should identify an area of refuge to assemble and protect passengers

- Airports work with local ATCT and design DEF to improve incident coordination and action planning. Bring pilot into the unified command structure.
- Have an emergency response team on scene to handle the injured passengers

- Discrete Emergency Frequencies (DEF) will assist ARFF to coordinate with the pilot and possibly prevent utilizing slides. Get air stairs on scene, they are cheaper for the airlines and safer for the passengers.

- Identify a "discrete" frequency that would allow the ARFF Group Supervisor, Flight Crew and Air Traffic Control. This tool can make it much easier on the flight crew in evaluating the need to evacuate the aircraft.

- Slides should only be used in a true emergency. Fire, smoke in the cabin that causes passengers and crew breathing difficulties. We have seen times when they deploy for electrical, light haze, exterior fires etc. Safety for Passenger and crew are most important concern, if you can use stairs vs. slides....use the stairs! Have air stairs on scene and visible to the flight crew to offer an alternative to slide evacuation if the situation allows.

- Provide practical training opportunities using either actual aircraft slide deployments, or simulators that allow ARFF crews to physically practice their craft. Develop/design a more ergonomic slide angle and slide termination points thus decreasing PAX injury

- Potential Lighting or reflective markers installed along slides length would allow better visibility of deployment configuration upon ARFF crews approach to the incident.

- Hands-on training with slides by ARFF and flight crews to increase coordination and communication, even if crews train with departments we believe expectations from the ARFF side are similar across the board, controlled evacuation, proper deployment, and passenger refuge.

- Enhance and improve ARFF communication w/ flight crew on incidents where the use of slides might be uncertain. While we hesitate to develop a system that slows or limits evacuation when it is called for in the flight crew's judgment, flight crews should not hesitate to call for a second opinion during those incidents when it is not clear that the use of slides is called for.

- Every ARFF Group should have Standard Operating Guidelines that pre-identify companies whose primary responsibility would be evacuation.

- Identify several pre-designated Multi-Casualty Incident staging areas on the AOA.

APPENDIX D

List of Collected Emergency Evacuation Events Involving Slides

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
1	05/30/06	Dulles, VA (IAD)	Embraer EMB-170	SCHD Part 121: Air Carrier Shuttle America Airlines (D.B.A. United Express)	1 serious (broken ankle)	During evacuation
2	05/14/06	DFW Int'l	MD 80	AMERICAN AIRLINES	2 minor	During evacuation
3	04/09/06	Washington, DC (IAD)	Airbus A319	Air Carrier United Airlines	4	
4	02/07/06	Philadelphia International Airport (PHL)	Douglas DC-8	SCHD Part 121: Air Carrier UNITED PARCEL SERVICE CO	3 minor, crew members	Unknown
5	12/12/05	Houston, TX (George Bush Intercontinental-Houston) (IAH)	0	Air Carrier Continental Airlines	3 minor, injuries were not due to use of slide	
6	12/08/05	Chicago, IL (Chicago Midway Airport) (MDW)		SCHD Part 121: Air Carrier SOUTHWEST AIRLINES CO	no injuries due to evacuation, 1 ground fatality and 12 ground injuries	Ground
7	11/8/2005	Stewart International Airport (SWF)	Boeing 727-200	Air Carrier Federal Express Corp	Unknown	Unknown
8	10/30/05	Calgary Int'l Airport (YYC)	Boeing 737-900	SCHD Part 121: Air Carrier ALASKA AIRLINES INC	no injuries	N/A
9	10/18/2005	Louisville International - Standiford Field (SDF)	Mc Donnell Douglas Boeing DC-8-73 AF	Air Carrier United Parcel Service	No injuries	N/A
10	08/19/05	Agana, GU (Guam International Airport [GUM])	Boeing 747-200	SCHD Part 121: Air Carrier NORTHWEST AIRLINES INC	2 minor	During evacuation
11	08/02/05	DFW Int'l	MD-80	AMERICAN AIRLINES	0	N/A
12	07/01/05	Houston, TX (George Bush Intercontinental-Houston) (IAH)	Boeing 737-800	Air Carrier Continental Airlines	no injuries (but 1 passenger with chest pains treated at hospital)	N/A
13	06/10/05	Oklahoma City, OK (Will Rogers World) (OKC)	Avro Bae Systems RJ Avroliner RJ 134	Air Carrier Mesaba Airlines	2 minor	Unknown
14	05/10/05	Minneapolis-St. Paul International Airport	Airbus Industrie A-319-114	SCHD Part 121: Air Carrier Northwest Airlines Inc.	1 minor due to use of slide	N/A

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
15	04/01/05	DIA	A 320	United	0	N/A
16	03/14/05	Buenos Aires, Argentina (Ezeiza International Airport [EZE])	Boeing B767	SCHD Part 121: Air Carrier UNITED AIRLINES INC	5 minor	Unknown
17	03/11/05	Buenos Aires, Argentina (Ezeiza International Airport [EZE])	Boeing B777	SCHD Part 121: Air Carrier AMERICAN AIRLINES INC	8 minor	Unknown
18	02/28/05	George Bush Intercontinental Airport-IAH	ERJ-145	Cont. Express	0	N/A
19	12/29/04	Austin, TX (Austin-Bergstrom International Airport [AUS])	Bombardier CL-600-2C10	SCHD Part 121: Air Carrier Mesa Airlines, Inc.	1 serious	During evacuation
20	12/6/2004	Bangor International Airport (BGR)	Mc Donnell Douglas Boeing DC-10-30 AF	Air Carrier World Airways	no injuries to crew of 3	Unknown
21	03/24/04	Houston, TX (George Bush Intercontinental-Houston) (IAH)	Mc Donnell-Douglas MD-80-83	Air Carrier Continental Airlines	no injuries	N/A
22	03/11/04	Fort Lauderdale, FL (Fort Lauderdale/Hollywood International Airport [FLL])	Airbus Industrie A300F4-605R	SCHD Part 121: Air Carrier FEDERAL EXPRESS CORP	no injuries	N/A
23	03/05/04	Atlanta, GA (ATL)	Boeing 717-200	Air Carrier AirTran Airways Inc	1 minor	During Evacuation
24	2/13/2004	Indianapolis International Airport (IND)	Airbus A310-220	Air Carrier Federal Express Corp	Unknown	Unknown
25	01/14/04	Dallas, TX (Dallas Forth Worth International) (DFW)	Mc Donnell-Douglas-Boeing MD-80-82	Air Carrier American Airlines	Unknown	Unknown
26	12/26/03	Indianapolis, IN (Indianapolis International) (IND)	Mc Donnell-Douglas MD-80-82	Air Carrier American Airlines	Unknown	
27	12/18/2003	Memphis, TN (MEM)	McDonnell Douglas MD-10-10F	NSCH Part 121: Air Carrier FEDERAL EXPRESS CORP	2	During evacuation
28	12/02/03	Atlanta, GA (Hartsfield-Jackson Atlanta International) (ATL)	Boeing 757-200	Air Carrier Delta Airlines	No injuries	

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
29	10/12/03	Denver, CO (Denver International Airport [DEN])	McDonnell Douglas DC-10-10	SCHD Part 121: Air Carrier (D.B.A. FedEx)	no injuries	N/A
30	10/05/03	Kahului, HI (Kahului) (OGG)	Boeing 757-200	Air Carrier United Airlines	1	
31	10/01/03	Indianapolis Intl Airport (IND)	Boeing 727-200F	Federal Express Corporation	No injuries	N/A
32	09/25/03	Dallas, TX (Dallas Forth Worth International) (DFW)	Mc Donnell-Douglas-Boeing MD-80-82	Air Carrier American Airlines	8 minor	During evacuation
33	06/23/03	Tampa Int'l Airport (TPA)	B757-232	DELTA AIR LINES INC	26 passengers sustained minor injuries, and three passengers sustained serious injuries	
34	04/22/03	Denver Int'l Airport (DEN)	MD-88	DELTA AIR LINES	one flight attendant received minor injuries	
35	04/16/03	DFW Airport, TX	McDonnell Douglas DC-9-82 (MD-82)	SCHD Part 121: Air Carrier (D.B.A. American Airlines)	1 serious, 1 minor	During evacuation
36	04/10/03	Oakland, CA (Metropolitan Oakland International) (OAK)	Airbus A300-F4	Air Carrier Federal Express Corp	No injuries	
37	03/26/03	Flushing, NY (LaGuardia Airport [LGA])	Boeing 717-200	SCHD Part 121: Air Carrier Air Tran Airways, Inc.	1 serious, 22 minor	During evacuation
38	11/09/02	Flushing, NY (LaGuardia Airport [LGA])	McDonnell Douglas MD-82	SCHD Part 121: Air Carrier AMERICAN AIRLINES INC	1 serious, 6 minors	During evacuation
39	08/28/02	Phoenix, AZ (Phoenix Sky Harbor International) (PHX)	Airbus Industrie A320-231	SCHD Part 121: Air Carrier AMERICA WEST AIRLINES (D.B.A. America West Airlines)	1 serious, 9 minors	Unknown
40	08/23/02	Atlanta, GA (Hartsfield-Jackson Atlanta International) (ATL)	Mc Donnell-Douglas MD-80-88	Air Carrier Delta Airlines	1 minor	During evacuation
41	08/10/02	Tampa, FL (Tampa Intl Airport) (TPA)	McDonnell Douglas DC-10-10	SCHD Part 121: Air Carrier (D.B.A. FedEx)	no injuries	N/A

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
42	08/03/02	Sarasota, FL (Sarasota-Bradenton International) (SRQ)	Boeing 737-306	Air Carrier Pace Airlines Inc	1 minor	During Evacuation
43	06/20/02	Memphis, TN (MEM)	Fokker F28	Air Carrier American Airlines	1 minor	
44	06/12/02	Atlantic City, NJ (Atlantic City International) (ACY)	Mc Donnell-Douglas-Boeing MD-80-82	Air Carrier Spirit Airlines Inc	6 minor	
45	06/03/02	Las Vegas, NV (Mc Carran International) (LAS)	Mc Donnell-Douglas MD-80-82	Air Carrier American Airlines	0	
46	05/05/02	Chicago O'Hare (ORD)		United Airlines	No Injuries	
47	05/31/02	New Orleans, LA (Louis Armstrong New Orleans International) (MSY)	Boeing 737-800	Air Carrier American Airlines	1 minor	
48	03/31/02	Charlotte, NC Charlotte/Douglas International Airport(CLT)	McDonnell Douglas MD-11	SCHD Part 121: Air Carrier Delta Air Lines, Inc.	5 Serious, 11 Minor	During evacuation
49	03/05/02	Chicago, IL (Chicago O'Hare International) (ORD)	Boeing 757-200	Air Carrier United Airlines	0	
50	01/24/02	Indianapolis, IN (Indianapolis International Airport) (IND)	McDonnell Douglas DC-9-41	SCHD Part 121: Air Carrier (D.B.A. Northwest Airlines)	1 serious	off plane
51	01/23/02	Fort Lauderdale, FL (Fort Lauderdale-Hollywood International) (FLL)	Boeing 727-200	Air Carrier American Airlines	0	
52	12/16/01	Dallas, TX (Dallas Forth Worth International) (DFW)	Boeing 737-300	Air Carrier Delta Airlines	3 minor	During Evacuation
53	12/14/01	Salt Lake Int'l Airport (SLC)	Boeing 727-200	Air Carrier Delta Airlines	0	
54	11/02/01	Midland, TX Midland International Airport (MAF)	Airbus Industrie A319-132	SCHD Part 121: Air Carrier America West Airlines Inc. (D.B.A. America West)	no injuries	N/A
55	10/29/01	Dulles, VA (IAD)	Boeing 757-223	SCHD Part 121: Air Carrier AMERICAN AIRLINES INC (D.B.A. American Airlines)	1 Serious, 148 Uninjured	off plane

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
56	09/17/01	Kahului, HI (Kahului) (OGG)	Boeing 717-200	Air Carrier Hawaiian Airlines Inc.	0	
57	08/09/01	Mascoutah, IL Scott Air Force Base/Midamerica Airport (BLV)	Boeing 717-200	SCHD Part 121: Air Carrier TRANS WORLD AIRLINES (D.B.A. Trans World Airlines)	no injuries	N/A
58	07/22/01	Washington, D.C (Washington Dulles International) (IAD)	Boeing 767-300	Air Carrier United Airlines	4 minor (3 passengers and 1 flight attendant)	During Evacuation
59	07/16/01	Moline, IL (Quad City International) (MLI)	Mc Donnell-Douglas Boeing DC-9-32	Air Carrier AirTran Airways Inc	no injuries	N/A
60	07/12/01	Knob Noster, MO (Whiteman AFB) (SZL)	Mc Donnell-Douglas-Boeing MD-80-83	Air Carrier	no injuries	N/A
61	06/19/01	Flushing, NY (LaGuardia Airport [LGA])	Boeing 737-400	Air Carrier US Airways	3 minor	during evacuation
62	06/15/01	Kansas city Int'l Airport, MCI	Boeing 737-200	Delta Airlines	1 minor	During evacuation
63	05/26/01	Nashville, TN (Nashville International) (BNA)	Boeing 757-200	Air Carrier Delta Airlines	3 minor	During evacuation
64	03/20/01	Phoenix, AZ (Phoenix Sky Harbor International) (PHX)	Boeing 737-300	Air Carrier Southwest Airlines	no injuries	N/A
65	03/17/01	Detroit, MI Detroit Metropolitan Wayne County Airport (DTW)	Airbus Industrie A320-200	SCHD Part 121: Air Carrier Northwest Airlines	3 Minor	Unknown
66	03/06/01	Boston (Logan International Airport)	Boeing (McDonnell-Douglas) DC-10 - 10F (M)	SCHD Part 121: Air Carrier FEDERAL EXPRESS CORP	0	N/A
67	03/02/01	Phoenix, AZ (Phoenix Sky Harbor International) (PHX)	Boeing 737	Southwest	0	N/A
68	12/22/00	Detroit, MI (Detroit Metropolitan Wayne County) (DTW)	Boeing 727-200	Air Carrier Northwest Airlines	0	N/A
69	12/01/00	Atlanta, GA (ATL)	Boeing 727	Delta Airlines	1 passenger minor injury and 1 ARFF crew minor injuries	

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
70	11/29/00	ATLANTA, GA [Hartsfield Atlanta International Airport (ATL)]	Douglas DC-9	SCHD Part 121: Air Carrier AIRTRAN AIRWAYS INC	13 Minor	Unknown
71	11/29/00	DULLES, VA (IAD)	McDonnell Douglas DC-9-82	SCHD Part 121: Air Carrier (D.B.A. AMERICAN AIRLINES)	no injuries	N/A
72	11/20/00	Miami International Airport	Airbus Industrie A300B4-605R	SCHD Part 121: Air Carrier AMERICAN AIRLINES	3 Serious, 19 Minor	During Evacuation
73	08/30/00	Pittsburgh International Airport (PIT)	MD 88/90	Delta Airlines	3 minor	Unknown
74	8/8/2000	Greensboro Piedmont-Triad International Airport (GSO)	Douglas DC-9-32	SCHD Part 121: Air Carrier AIRTRAN AIRLINES INC	3 crewmembers and 5 passengers received minor injuries from smoke inhalation. 5 passengers and one ground crewmember received minor injuries during the evacuation.	
75	07/17/00	Dallas, TX (Dallas Forth Worth International) (DFW)	Mc Donnell-Douglas-Boeing MD-80-82	Air Carrier American Airlines	4	all of injuries were due to use of slide
76	04/02/00	Federated States Of Micronesia (YAP)	Boeing 727	SCHD Part 121: Air Carrier	Unavailable	Unknown
77	03/19/00	New York, NY(La Guardia) (LGA)	Boeing 727-200	Air Carrier Delta Airlines	4	
78	03/13/00	SAN FRANCISCO, CA (SFO)	Boeing 727-232	SCHD Part 121: Air Carrier DELTA AIRLINES, INC.	No Injuries	
79	03/15/00	Tampa, FL (Tampa International) (TPA)	Boeing 737-300	Air Carrier US Airways	4 minor	Evacuation down two aft slides with engines operating
80	03/11/00	SEATTLE, WA Seattle-Tacoma International Airport (SEA)	McDonnell Douglas MD-83	SCHD Part 121: Air Carrier (D.B.A. ALASKA AIRLINES)	2 Minor	During evacuation

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
81	03/08/00	Mc Allen, TX (Mc Allen Miller International) (MFE)	Mc Donnell-Douglas MD-80-83	Air Carrier Trans World Airlines	3	injuries as result of evacuation
82	03/05/00	BURBANK, CA Burbank-Glendale-Pasadena Airport (BUR)	Boeing 737-300	SCHD Part 121: Air Carrier SOUTHWEST AIRLINES CO	2 serious injuries; 41 passengers and the captain minor injuries; At least 3 minor injuries happened during slide evacuation	On plane
83	2/18/2000	Pittsburgh International Airport (PIT)	Mc Donnell Douglas Boeing DC8-73 AF	Air Carrier United Parcel Service	No injuries to crew of 4	N/A
84	09/17/99	COVINGTON, KY Cincinnati/Northern Kentucky International Airport (CVG),	McDonnell Douglas MD-88	SCHD Part 121: Air Carrier DELTA AIR LINES	No injuries	N/A
85	09/09/99	Nashville, TN (Nashville International) (BNA)	Mc Donnell-Douglas-Boeing DC-9-31CF	Air Carrier Trans World Airlines	3 minor	Unknown
86	09/08/99	Houston, TX (George Bush Intercontinental-Houston) (IAH)	Mc Donnell-Douglas-Boeing MD-80-82	Air Carrier Continental Airlines	5 minor	Slide
87	08/11/99	Fort Lauderdale, FL (Fort Lauderdale / Hollywood International Airport [FLL])	DC10/30	Part 121: Air Carrier FEDERAL EXPRESS CORP	unknown	unknown
88	08/24/99	Tulsa, OK (Tulsa International Airport [TUL])	B727-100	Part 121: Air Carrier FEDERAL EXPRESS CORP	unknown	unknown
89	08/26/99	Las Vegas, NV (Mc Carran International) (LAS)	Boeing 757-200	Air Carrier	0	N/A
90	08/03/99	New York, NY (John F Kennedy International) (JFK)	Boeing 757-200	Air Carrier Delta Airlines	No injuries	
91	06/26/99	Wilmington, NC (Wilmington International) (ILM)	Fokker F28	Air Carrier US Airways	4 minor	During evacuation (some due to slides)

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
92	06/17/99	LOUIS ARMSTRONG NEW ORLEANS INTL (MSY)	Boeing 727-200F	Federal Express Corporation	No injuries	N/A
93	06/04/99	Charleston Int'l Airport, CHS	Boeing 737-200	Delta Airlines	No injuries	
94	4/28/1999	Ontario International Airport (ONT)	Mc Donnell Douglas Boeing DC8-71 C	Air Carrier United Parcel Service	No injuries	N/A
95	04/08/99	Oklahoma City, OK (Will Rogers World) (OKC)	Boeing 737-500	Air Carrier United Airlines	1minor	during evacuation
96	12/26/98	DFW AIRPORT, TX	McDonnell Douglas MD-88	SCHD Part 121: Air Carrier (D.B.A. DELTA AIRLINES)	1 serious	While using Slide
97	11/01/98	ATLANTA, GA (ATL)	Boeing 737-200	SCHD Part 121: Air Carrier AIRTRAN AIRWAYS INC	16 - 2 passengers received serious injuries, and 14 passengers received minor injuries	
98	07/09/98	SAN JUAN Luis Munoz Marin International Airport, San Juan, Puerto Rico (SJU)	Airbus Industrie A-300B4-605R	SCHD Part 121: Air Carrier AMERICAN AIRLINES, INC.	28 Minor	During evacuation
99	05/26/98	Indianapolis Intl Airport (IND)	DC-9	Northwest Airlines	1 Minor	On ground, while helping people to evacuate
100	05/11/98	Tokyo Int'l Airport (TYO)	Boeing 747	SCHD Part 121: Air Carrier UNITED AIRLINES (D.B.A. UNITED AIRLINES, INC.)	4 Serious, 20 Minor	During evacuation
101	04/25/98	Detroit, MI (Detroit Metropolitan Wayne County) (DTW)	Mc Donnell - Douglas DC-9-31CF	Air Carrier Trans World Airlines	0	
102	03/08/98	MANCHESTER (MAN) United Kingdom	McDonnell Douglas DC-10-30	SCHD Part 121: Air Carrier CONTINENTAL AIRLINES	0	N/A

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
103	02/09/98	Honolulu, HI (Honolulu International) (HNL)	Mc Donnell-Douglas-Boeing DC-9-51	Air Carrier Hawaiian Airlines Inc	0	
104	02/09/98	O'HARE INTL AIRPORT, CHICAGO, ILLINOIS, U.S.A. (ORD)	B727-223	AMERICAN AIRLINES	22 Minor	
105	01/03/98	Detroit, MI (Detroit Metropolitan Wayne County) (DTW)	Mc Donnell - Douglas DC-9-51	Air Carrier Northwest Airlines	0	N/A
106	12/25/97	Eugene Airport, OR	Boeing 737-522	SCHD Part 121: Air Carrier UNITED AIRLINES	No injuries	N/A
107	12/19/97	San Francisco Int'l Airport	McDonnell Douglas MD-80	SCHD Part 121: Air Carrier ALASKA AIRLINES	No injuries	N/A
108	09/24/97	Salt Lake City, UT (Salt Lake City International) (SLC)	Boeing 727	Air Carrier Frontier Airlines	0	N/A
109	08/07/97	HONOLULU, HI (Honolulu, Hawaii, International Airport) (HNL)	Lockheed L-1011-385-1-15	SCHD Part 121: Air Carrier DELTA AIR LINES INC	1 Serious, 58 Minor	During evacuation
110	08/02/97	Dallas, TX (Dallas Forth Worth International) (DFW)	MD 88/90	Delta Airlines	2 minor	During Evacuation
111	07/06/97	ALBUQUERQUE, NM (Albuquerque International Airport) (ABQ)	Boeing 727-247	SCHD Part 121: Air Carrier (D.B.A. DELTA AIR LINES, INC.)	3 Minor	During evacuation
112	06/18/97	Las Vegas, NV (Mc Carran International) (LAS)	Boeing 727	Delta Airlines	No injuries reported	
113	06/14/97	Orlando International Airport	Boeing 727-200	Air Carrier Sun Pacific International	0	N/A
114	04/28/97	CHICAGO, IL (O'Hare International Airport) (ORD)	Boeing 737-200	SCHD Part 121: Air Carrier UNITED AIRLINES	2 Minor	During evacuation
115	04/28/97	Tuscon, AZ (Tuscon International) (TUS)	Mc Donnell-Douglas-Boeing MD-80-82	Air Carrier American Airlines	no injuries	N/A
116	03/17/97	Miami, FL (Miami International) (MIA)	Mc Donnell-Douglas-Boeing MD-80-82	Air Carrier American Airlines	0 but 1 F.A with burning eyes and treated on spot, then fine	unknown

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
117	03/07/97	Newark, NJ (Newark Liberty International) (EWR)	Mc Donnell-Douglas-Boeing MD-80-81	Air Carrier Continental Airlines	no injuries	N/A
118	02/19/97	Denver Int'l Airport (DEN)	Boeing 737-200	United Airlines	No Injuries	N/A
119	02/02/97	Grand Forks, ND (Grand Forks International) (GFK)	Mc Donnell - Douglas DC-9-31CF	Air Carrier Northwest Airlines	0	
120	1/21/1997	Will Rogers World Airport (OKC)	Boeing 727-200	Air Carrier Federal Express Corp	0	N/A
121	01/18/97	ARUBA, Aruba (AUA)	Boeing 737-400	NSCH Part 121: Air Carrier RYAN INTERNATIONAL AIRLINES	1 Serious	During evacuation
122	01/08/97	Unknown	Boeing 737-400	Air Carrier Ryan International Airlines	1 passenger broke ankle	During evacuation
123	11/26/96	Washington, DC (Washington Dulles International) (IAD)	Boeing 757-200	Air Carrier American Airlines	0	
124	11/23/96	DFW AIRPORT, TX	McDonnell Douglas MD-82	SCHD Part 121: Air Carrier AMERICAN AIRLINES	3 minors	During evacuation
125	11/18/96	GRAND RAPIDS, MI (Kent County International Airport) (GRR)	Boeing 737-222	SCHD Part 121: Air Carrier (D.B.A. UNITED AIR LINES)	1 Serious, 2 Minor	Unknown
126	10/28/96	Jamaica, NY (JFK International Airport)	McDonnell Douglas MD-80-82	SCHD Part 121: Air Carrier AMERICAN AIRLINES, INC	1 Serious, 2 Minor	Most probably during evacuation
127	10/13/96	Dayton, OH (James M Cox Dayton International) (DAY)	Boeing 757-200	Air Carrier US Airways	9 minor	During emergency evacuation
128	9/12/1996	Great Falls International Airport (GTF)	Boeing 727-200F	Air Carrier Federal Express Corp	No injuries	
129	08/21/96	Atlanta, GA (Hartsfield-Jackson Atlanta International) (ATL)	Fokker F-28	Air Carrier US Airways	5 treated for scrapes or bruises	
130	08/08/96	HONOLULU, HI (Honolulu, Hawaii, International Airport) (HNL)	Douglas DC-9-51	SCHD Part 121: Air Carrier HAWAIIAN AIRLINES, INC	No injuries	N/A

No	Date	Location	Model	Type of Air Carrier Operation	No. of Injuries	Location Where Injuries Happened
131	07/08/96	NASHVILLE, TN (Nashville Metropolitan Airport) (BNA)	Boeing 737-200	SCHD Part 121: Air Carrier SOUTHWEST AIRLINES	1 Serious, 4 Minor	During evacuation
132	07/06/96	PENSACOLA REGIONAL AIRPORT, FLORIDA, U.S.A. (PNS)	MD88	DELTA AIR LINES	2 Fatal, 2 Serious, 3 Minor **But only three minor happened during slide evacuation**	
133	04/30/96	Ontario, CA (Ontario International Airport)	Boeing 737-300	Air Carrier Southwest Airlines	0	N/A
134	03/20/96	Atlanta, GA (ATL)	Boeing 737-200	Air Carrier Delta Airlines	7 minor	
135	02/22/96	Miami International Airport (MIA)	Boeing 707 - 320C	Air Carrier Million Air	Unknown	Unknown
136	02/20/96	JAMAICA, NY (JFK)	Airbus Industrie A-300B4-605R	SCHD Part 121: Air Carrier AMERICAN AIRLINES	2 Serious, 32 Minor	During evacuation
137	2/20/1996	PORTLAND, OR	Boeing 767-332	SCHD Part 121: Air Carrier DELTA AIR LINES	1 serious, 3 minor	During Evacuation
138	02/19/96	HOUSTON INTL AIRPORT, TEXAS, U.S.A. (IAH)	DC9-32	CONTINENTAL AIRLINES		
139	02/18/96	Detroit, MI (Detroit Metropolitan Wayne County) (DTW)	Boeing 757-200	Air Carrier Northwest Airlines	1 minor	(ankle injury)
140	02/03/96	Kahului, HI (Kahului) (OGG)	Mc Donnell-Douglas-Boeing DC-9-51	Air Carrier Hawaiian Airlines Inc	3 minor	
141	02/02/96	Las Vegas, NV (Mc Carran International) (LAS)	Mc Donnell-Douglas-Boeing DC-9	Air Carrier Continental Airlines	Unknown	
142	2/1/1996	Nashville, TN (Nashville International) (BNA)	Mc Donnell Douglas Boeing DC9-32	Air Carrier ValuJet	No injuries	

APPENDIX E

Documented Injuries During 142 Emergency Slide Evacuation Events in the Period of January 1, 1996, to June 30, 2006

Date of Event	Airport	Type of Injury	Location where Injury happened	Note
05/30/06	Dulles, VA (IAD)	1 serious – Broken ankle	During evacuation	It has not been specified exactly how injuries occurred
05/14/06	DFW Int'l	2 minor - one sprained left forearm and one minor abrasions and lacerations	During evacuation at the bottom of slide	A 34 year old male passenger had a sprained left forearm caused by another passenger grabbing his arm (because he was assisting other passengers with exiting the slide at the bottom) ----- a 54 year old female passenger got minor abrasions & lacerations to left foot and right elbow. Also sprained left ankle upon landing on the pavement (cause was impact on the pavement at the bottom of the slide)
04/09/06	Dulles, VA (IAD)	3 – minor	Unknown	It has not been specified what type of injuries occurred and where
02/07/06	Philadelphia, PHL	3 minor	Unknown	
12/12/05	Houston, IAH	0 due to slide	N/A	The injuries that occurred on this flight were not due to use of slides
11/8/05	Stewart Int'l (SWF)	Unknown	Unknown	N/A
08/19/05	Agana, GU (GUM)	2 minor	During evacuation	Injury mechanism is unknown
06/10/05	Oklahoma City, OKC	2 minor	Unknown	
05/10/05	Minneapolis Int'l Airport	1 minor	Due to use of slide	
03/14/05	Buenos Aires, Argentina	5 minor	Unknown	
03/11/05	Buenos Aires	8 minor	Unknown	
12/29/04	Austin, TX	1 Serious	During evacuation	One passenger had a fractured heel/foot during emergency evacuation
03/05/04	Atlanta, ATL	1 minor	During evacuation	1 scraped knee while sliding down the slide
12/18/03	Memphis, MEM	2 minor	During evacuation	Injury mechanisms are unknown

Date of Event	Airport	Type of Injury	Location where Injury happened	Note
10/05/03	Kahului, OGG	1 minor	During evacuation	1 flight attendant suffered from slide abrasions
09/25/03	Dallas, DFW	8 minor	During evacuation	1. aggravated an old back injury upon landing at the bottom of the slide 2. sliding down the slide 3. sliding down the slide 4. friction from sliding down the slide 5. landing on the pavement at the bottom of slide 6. passenger stated he fell forward onto the pavement after reaching the bottom of the slide 7. impact with the pavement at the bottom of the slide, she was the first passenger off and nobody to catch her 8. anxiety from evacuation
06/23/03	Tampa, TPA	26 minor and 3 serious	During evacuation	
04/22/03	Denver, DEN	1 minor	During evacuation	Injury mechanism is unknown
04/16/03	DFW	1 serious, 1 minor	During evacuation	Minor- Cut on right index finger due to sliding down from slide Serious, Fractured right ankle due to impact on the pavement
03/26/03	LGA	1 serious, 22 minor		1. Abrasions on elbows and knees from "tumbling" off forward right slide 2. Abrasions to arm- struck by another passenger while using forward right slide 3. swollen knee, treated by family physician

Date of Event	Airport	Type of Injury	Location where Injury happened	Note
				4. bruise on left leg 5. abrasion on hand from forward right slide 6. injured tailbone, landing on door sill before going down forward left slide 7. Head, neck and back pain 8. contusion on right arm 9. strained hamstring in right thigh from jumping off of wing 10. Fractured left ankle 11. abrasion on knee 12. injured tailbone and back 13. twisted knee, lacerated knee 14. abrasion and contusion on knee 15. cuts and bruises 16. cuts and bruises on right leg 17. pelvic pain 18. neck, back and shoulder pain 19. bruise on right arm 20. neck and back pain 21. abrasion on left hand
11/09/02	Flushing, LGA	1 serious, 6 minor	During evacuation	Injury mechanisms are not available
08/28/02	Phoenix,	1 serious, 9 minors	During evacuation	Injury mechanisms are not available
08/23/02	Atlanta, ATL	1 minor	During evacuation	A female passenger toppled and landed head first – minor facial abrasions
08/03/02	Sarasota, SRQ	1 minor	During evacuation	Injury mechanism is not available
06/20/02	Memphis, MEM	1 minor	During evacuation	A female passenger suffered from leg burns/abrasions from nylon/slide contact

Date of Event	Airport	Type of Injury	Location where Injury happened	Note
06/12/02	Atlantic City, ACY	6 minor	During evacuation	Bruises, cut, sprain and 1 heart problem
05/31/02	New Orleans, MSY	1 minor	During evacuation	Injury mechanism is not available
03/31/02	Charlotte, CLT	5 serious, 11 minor	During evacuation	Injury mechanisms are unknown
01/24/02	Indianapolis, IND	1 serious	During evacuation	A passenger suffered a broken wrist when he fell off the side of the slide
12/16/01	Dallas, DFW	3 minor	During evacuation	Injury mechanisms are not known
10/29/01	Dulles, IAD	1 serious	During evacuation	one passenger broke her ankle, while exiting the bottom of the emergency slide
07/22/01	Dulles, IAD	4 minor	During evacuation	Injury mechanisms are not available
06/19/01	Flushing, LGA	3 minor	During evacuation	Twisted ankle, twisted knee and scraped elbow
06/15/01	Kansas city, MCI	1 minor	During evacuation	Abrasion due to sliding down
05/26/01	Nashville, BNA	3 minor	During evacuation	Injury mechanisms are not available
03/17/01	Detroit	3 minor	During evacuation	Injury mechanisms are not available
12/01/00	Atlanta, ATL	2 minor	During Evacuation	Injury mechanisms are not available
11/29/00	Atlanta, ATL	13 minor	During Evacuation	Injury mechanism are not available
11/20/00	Miami Int'l	19 minor, 3 serious	During Evacuation	Serious include: 1. Leg Fracture 2. Sprained Knee 3. Back pain Minors include: Abrasions and Contusions
08/30/00	Pittsburgh Int'l, PIT	3 minor	During evacuation	Injury mechanism are not available
08/08/00	Greensboro Piedmont Triad Int'l, GSO	6 minor	During evacuation	5 passengers and 1 ground crewmember received minor injuries
07/17/00	Dallas, DFW	4 minor	During Evacuation	1. Friction burns on forearms from friction from slide surface

Date of Event	Airport	Type of Injury	Location where Injury happened	Note
				2. Bruises and abrasions 3. Friction burns on calves of both legs from friction from slide surface 4. Sprain/strain of lower left leg from impact with the ground at the bottom of the slide
03/19/00	New York, LGA	4 minors	During evacuation	Injury mechanisms are not available
03/15/00	Tampa, TPA	4 minor	During evacuation	Sustained minor injuries evacuating down the aft slides with the engines operating
03/11/00	Seattle, SEA	2 minor	During evacuation	Injury mechanisms are not available
03/08/00	Mc Allen, MFE	3 minors	During Evacuation	Injury mechanisms are not available
03/05/00	Burbank, BUR	3 minor	During Evacuation	1. injured tailbone (at the top of the slide), abrasions 2. head, neck, knees and back strain (incurred at bottom of slide) back pain and numbness in thighs from going off the end of the slide
09/09/99	Nashville, BNA	3 minor	Unknown	
09/08/99	Houston, IAH	5 minor	During evacuation	5 passengers sustained twisted ankles
06/26/99	Wilmington, ILM	4 minor	During evacuation	
04/08/99	Oklahoma City, OKC	1 minor	During evacuation	Injury mechanism is not available
12/26/98	Dallas, DFW	1 serious	During evacuation	Injury mechanism is not available
11/01/98	Atlanta, ATL	14 minor, 2 serious	During evacuation	Injury mechanism is not available
07/09/98	San Juan, SJU	28 minor	During evacuation	28 passengers sustained Sprains, strains, bruises and friction abrasion but injury mechanisms are not available
05/26/98	Indianapolis, IND	1 minor	During Evacuation	1 passenger sustained minor injury on the ground while helping people to evacuate

Date of Event	Airport	Type of Injury	Location where Injury happened	Note
05/11/98	Tokyo Int'l, TYO	4 Serious, 20 minor	During Evacuation	
02/09/98	Chicago, ORD	22 minor		
08/07/97	Honolulu, HNL	1 serious, 58 minor	During Evacuation	1 passenger sustained fractured ankle, 56 passengers and 2 flight attendances sustained minor injuries including contusions, sprains, strains and friction abrasions….injury mechanisms are not clearly available
08/02/97	Dallas, DFW	2 minor	During evacuation	Injury mechanisms are not available
07/06/97	Albuquerque, ABQ	3 minor	During evacuation	3 abrasions from evacuation, clear injury mechanism is not available
04/28/97	Chicago, ORD	2 minor	During evacuation	Injury mechanisms are not available
01/18/97	Aruba, AUA	1 serious	During evacuation	Injury mechanism is not available
01/08/97	Unknown	1 serious	During evacuation	Broken ankle during evacuation but clear injury mechanism is not available
11/23/96	Dallas, DFW	3 minor	During evacuation	Injury mechanisms are not available
11/18/96	Grand Rapids, GRR	1 serious, 2 minor	During evacuation	1 passenger broke her ankle because the passenger did not jump out the exit as directed, but rather sat down, and slid out 2 passenger received minor injury one of which was a twisted knee
10/28/96	Jamaica, JFK	1 Serious, 2 minor	During evacuation	Injury mechanisms are not available
10/13/96	Dayton, DAY	9 minor	During evacuation	7 female passengers and 2 male passengers sustained minor injuries, clear injury mechanisms are not available

Date of Event	Airport	Type of Injury	Location where Injury happened	Note
08/21/96	Atlanta, ATL	5 minor	During evacuation	Scrapes and bruises
07/08/96	Nashville, TN	1 serious, 4 minor	During evacuation	Injury mechanisms are not available
07/06/96	Pensacola, PNS	3 minor	During evacuation	Injury mechanisms are not available
03/20/96	Atlanta, GA	7 minor	During evacuation	Injury mechanisms are not available
02/22/96	Miami Int'l, MIA	Unknown	N/A	
02/20/96	NY, JFK	2 serious, 32 minor	During evacuation	Injury mechanisms are not available
02/20/96	Portland, OR	1 serious, 3 minor	During evacuation	Serious – an ankle fracture during the evacuation process Minor injury mechanisms are not available
02/19/96	Houston Intl, IAH	Unknown	N/A	
02/18/96	Detroit, DTW	1 minor	During evacuation	1 minor ankle injury
02/03/96	Kahului, OGG	3 minor	During evacuation	Injury mechanisms are not available
02/02/96	Las Vegas, LAS	Unknown	N/A	

APPENDIX F

Study on Emergency Evacuation Challenges on Large Transport Aircraft

Executive Summary

The purpose of this study was to investigate emergency evacuations challenges from large transport aircraft. The world's largest commercial aircraft, the Airbus A380, is considered as a very large transport aircraft (VLTA). It will be the first full double-decker aircraft, with two independent decks connected by stairs. There have been several arguments concerning whether this aircraft will be able to evacuate passengers in a safe and efficient manner. The height of the upper deck was a main concern regarding this issue. The massive increase in passenger capacity and aircraft size are concerns to the difficulties which would be encountered in an evacuation. In order to conduct this research, a dynamic mathematical model was developed to obtain the velocity of an individual sliding down from the upper deck as a function of position on the slide. Parameters, such as the initial velocity and coefficient of friction were changed to see the effect they had on the results. A comparison was made between sliding from the upper deck slide of the A380 versus one of a B747. In addition to this, research was done to obtain information about slide emergency evacuation events from large transport aircraft currently in service, such as the Boeing B747. Part 121 and Part 129 slide emergency evacuations over a certain period of time were captured. The A380 passed the certification test in March 2006 which met a list of unique requirements for this type of aircraft and evacuation results were obtained from Airbus. Conclusions and recommendations for safer evacuations from larger transport aircraft will be made based on the results of the study.

Introduction

Passenger safety has always been a major concern to the traveling public and the improvement of safety procedures and equipment has been a major goal of the aviation industry and regulators alike. One major element to ensuring the safety of passengers is providing for the safe and orderly evacuation of passengers in emergency situations. To this end, several studies have been done concerning the evacuation of commercial passenger aircraft (Hynes 1999 & 2000; NTSB, 2000). As dictated by Part 25 of the Code of Federal Regulations, aircraft that have exits located more than 6 feet above the ground are required to have inflatable slides.

The recent launch of very large transport aircraft has raised many questions regarding emergency evacuations. The major differences for larger aircraft, such as the Airbus A380, are associated with the configuration of the airplane such as the height of the emergency exits on the upper deck and thus the characteristics of the slides. There have been many discussions on whether this new aircraft would meet the certification requirements. The reasoning behind this would be that more injuries may occur during the evacuation test due to its special features. This paper will investigate this issue.

Background

1. Large Aircraft

The Boeing 747, which has been in use since 1970, features a partial upper deck, but does not contain as many passengers as the A380 will on the upper deck. Today, the Boeing 747 is widely used throughout the world and is the largest passenger aircraft. The A380 will be the first fully double-deck airliner holding 555 passengers in a three-class configuration. It will be the world's largest airliner, farther beyond Boeing's 747. Figure 1 shows the dimensions of the Boeing 747 versus the Airbus A380.

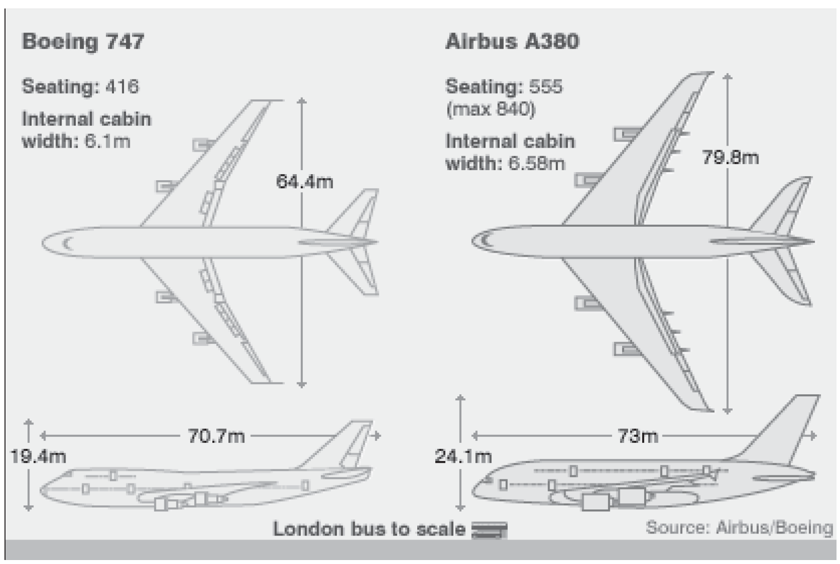

Figure 1: Boeing 747 versus Airbus A380 (Source: www.samtsai.com)

2. *Emergency Evacuation Inflatable Slides*

As dictated by Code of Federal Regulations (14CFR & 25.810), the assisting means (which must be capable of carrying simultaneously two parallel lines of evacuees) for emergency evacuation must meet the following requirements:

- must be automatically deployed
- must be of such length after full deployment that the lower end is self-supporting on the ground and provides safe evacuation of occupants to the ground after collapse of one or more legs of the landing gear
- must have the capability, in 25 knot winds directed from the most critical angle, to deploy and, with the assistance of only one person, to remain usable after full deployment to evacuate occupants safely to the ground

Inflatable slides are located on commercial aircraft doors for evacuating passengers and crew in the event of an emergency. The slides are stored deflated within the aircraft. Once the door opens, the slides inflate through the application of air pressure.

According to Part 4.12 of the Technical Standard Order (TSO-C69c), there are inflation time requirements according to the type of exits or devices. Type I floor-level exit slides [1]devices must be automatically erected in 6 seconds after actuation of the inflation has begun. Other devices must not exceed 10 seconds.

There is a sequence for the slide deployment process: it starts from the opening door and ends when the slide is inflated. To start the inflation, pressured gas (3290 psi of mixed nitrogen and CO2) passes from the cylinder through the aspirators to the inflatable part of the slide. The aspirator's flapper valve opens which draws in external air. The mix of gas under pressure and external air starts the inflation of the slide. The inflation process is completed when the slide has reached the pressure controlled by a pressure relief valve (Asse, 2003).

Several tests are required for the materials to be used. Coated fabrics must have strength, adhesion, permeability, hydrolysis requirements.

The inflatable fabric must be air holding, lightweight, high strength and have radiant heat requirements. It has for base a nylon cloth and is coated on both sides with polyether based polyurethane or neoprene. The sliding surface fabric does not have to be air holding. These are the sliding surface requirements:

- high mechanical strength both in traction and tear resistance (nylon cloth woven)
- high bonding and cementing properties on the inflatable structure
- coating electrical conductivity to eliminate static electricity build up
- low friction
- light weight and flexibility

It is coated on one side with a low friction, conductive polyurethane compound on which evacuees can slide. The other slide has a silver-gray reflective compound (Escoffier, 2001).

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[1] Type I: Inflatable Slide

a. Airbus A380 Slide Characteristics

Figure 2 shows the evacuation slides of the Airbus A380. The aircraft provides two independent passenger decks. There are a total of eight exits on each side of the aircraft: 5 Type A exits on the main deck and 3 Type A exits on the upper deck. The sill height[2] is 5.1 meters for the main deck versus 7.9 meters for the upper deck. The longest slide is 14.7 meters. More information about A380 slides angles and lengths can be found in Appendix A.

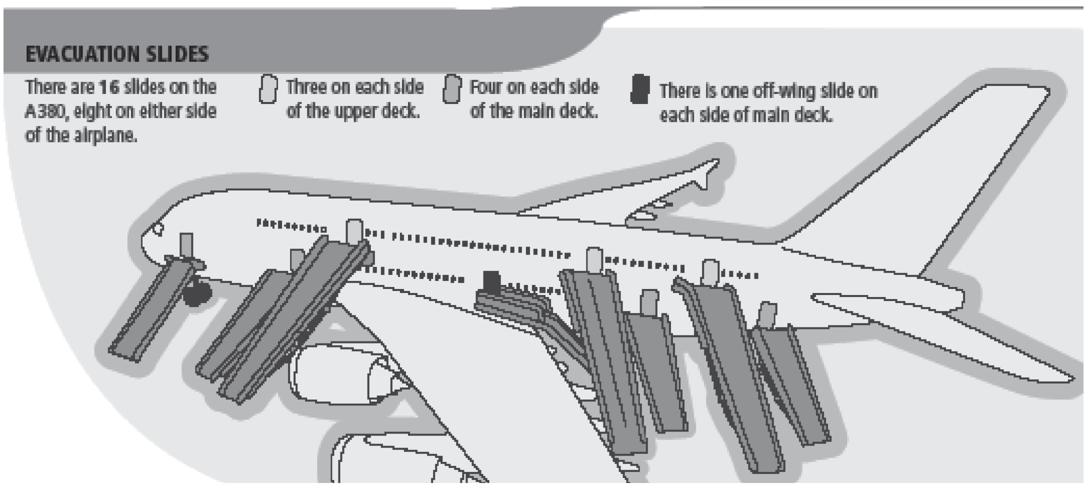


Figure 2: Airbus A380 Emergency Evacuation Slides
(Source:http://www.aviationnews.com.au)

Literature Review

There have been several studies and papers done on emergency evacuations of commercial aircraft. Some research has been focused on larger transport aircraft evacuation, especially with the future new largest commercial aircraft, the Airbus A380 (Verres, 2003; Jungermann, 2000 & 2001).

A one year study done for the European Commission, called the Very Large Transport Aircraft (VLTA) Emergency Requirements Research Evacuation Study (Verres, 2003), was carried out to investigate evacuation challenges of future aircraft. Some people have categorized the Airbus A380 as a VLTA. This project also includes potential future designs such as blended-wing body aircraft. A computer model or software for the simulation of an evacuation as well as a double-deck large cabin simulator was used to analyze these issues. This report includes results of the first evacuation research trials of large double-deck aircraft and recommendations.

Also, Helmet Jungermann discusses the issues of emergency evacuation from a double-deck aircraft in several papers (Jungermann, 2000 & 2001), of one which was

[2] normal sill height: the height of the exit sill above the ground with all aircraft landing gear extended (TSO-C69c Glossary of Terms)

presented at the International Aircraft Fire and Cabin Safety Research Conference in Atlantic City in 2001. He developed a model to analyze how factors such as slide design, visibility and passenger safety instruction would influence an individual's performance and observed the reactions to different situations. He also studied the psychological effects of the upper deck height on human performance. He found out that additional research had to be done but found a difference in the hesitation time between individuals from the upper versus main deck.

Problem Definition

The topic of emergency evacuations from larger transport aircraft has been a major concern, especially with the future world's largest commercial aircraft, the Airbus A380. U.S Federal Aviation Administration (FAA) certification criteria and tests are essential in evaluating the evacuation capabilities of a new aircraft. One of the final measures for an aircraft's readiness to operate is the full-scale evacuation demonstration. In order to pass the FAA certification, an aircraft has to be evacuated under specific conditions within 90 seconds as required by Part 25 and Appendix J to Part 25 of the European Aviation Safety Agency (EASA) Joint Aviation Requirements and the U.S. Federal Aviation Regulations (FARs).

The main question surrounding this aircraft was whether the evacuation would take longer and the number of injuries would be higher compared to conventional main deck evacuations. An additional concern for the A380 was the height from which the upper deck passengers would need to slide in case of an emergency.

Study Objectives

This study will examine the effect of the upper deck height and will look at slide emergency evacuations from larger transport aircraft. The objectives of this study are:

1) to develop a dynamic model to determine the velocity of a person during the slide

2) to analyze large transport slide emergency evacuation events
   - B747 events and certification test done for the Airbus A380 will be evaluated in detail. Mechanisms of injuries will be determined.

3) to identify issues regarding large aircraft slides (particularly upper deck slides) and provide recommendations, if any, to improve slide emergency evacuations for these type of aircraft

Description of Model and Analysis

A dynamic model has been developed based on an assumed curvilinear path with friction to calculate the velocity of a person at any given location (x,y) on the inflatable slide. Several assumptions are needed to compute the velocity including: initial velocity, constant coefficient of friction, constant curvature of the slide and no deflection due to weight of individuals on the slide. The parameters required are: the total length of the slide, the initial velocity of an individual and the coefficient of friction. These parameters are changed to see the effect they have on the velocity. For this model, conservation of energy is used neglecting the air drag on the person, but accounting for friction.

In order to find the optimal shape of the aircraft evacuation slide, the Brachistochrone method is used. This approach is done in a Classical Mechanics course[3]. The curve should be designed such that it takes the least possible time to slide from an exit at a height h down the ground at some distance x away from the aircraft

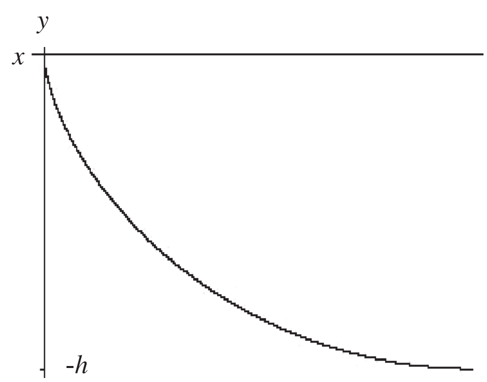


Figure 3: Shape of Evacuation Slide from y=0 to y=-h at a distance x away from the aircraft

The method used is to find the fastest curve between the starting point (0,0) and ending point (a,b) with friction. At each point on the curve (x,y), there is a unit normal and tangent vector. This is illustrated in the figure below.

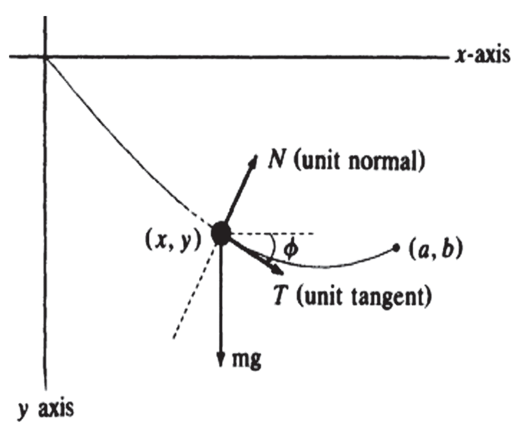


Figure 4: Unit normal and unit tangent vectors at point (x,y)
(Source: Haws and Kiser, 1995)

[3] Classical Mechanics homework – B: Evacuation Slide (p.3-5) www.st-andrews.ac.uk/~ulf/cmhome.pdf

These unit directional vectors can be written as:

$$\vec{T} = \frac{dx}{ds}\hat{i} + \frac{dy}{ds}\hat{j} \qquad \text{(unit tangent)}$$

$$\vec{N} = -\frac{dy}{ds}\hat{i} + \frac{dx}{ds}\hat{j} \qquad \text{(unit normal)}$$

where s represents the arc length.

The force of gravity acting in the y direction is:

$$\vec{F}_g = mg\hat{j}$$

Similarly, the friction force can be expressed as:

$$\begin{aligned} \vec{F}_f &= -\mu(\vec{F}_g \cdot \vec{N})\vec{T} \\ &= -\mu \; mg\frac{dx}{ds}\vec{T} \end{aligned}$$

The components for the force of gravity and friction force in the tangent direction along the curve are:

$$\vec{F}_g \cdot \vec{T} = mg\frac{dy}{ds}$$

$$\vec{F}_f \cdot \vec{T} = -\mu \; mg\frac{dx}{ds}$$

Using Newton's first law $(\sum F = ma)$, and substituting $a = \frac{dv}{dt}$, we get

$$m\frac{dv}{dt}\vec{T} = mg\frac{dy}{ds}\vec{T} - \mu \; mg\frac{dx}{ds}\vec{T}$$

which simplifies to

$$\frac{dv}{dt} = g\frac{dy}{ds} - \mu \; g\frac{dx}{ds}$$

Then, using the relation: $v = \frac{ds}{dt}$ or $dt = \frac{ds}{v}$, we obtain that:

$$\frac{dv}{dt} = \frac{dv}{(ds/v)} = v\frac{dv}{ds} = \frac{1}{2}\frac{d(v^2)}{ds}$$

Substituting $\frac{dv}{dt}$ in Newton's second law, we obtain:

$$\frac{1}{2}\frac{d(v^2)}{ds} = g\frac{dy}{ds} - \mu\, g\frac{dx}{ds}$$

Integrating the above equation with respect to s, we obtain:

$$\frac{1}{2}v^2 = gy - \mu\ \ gx + C \qquad \text{or} \qquad \frac{1}{2}v^2 = g(y - \mu\ x) + C$$

It is necessary to find the constant of integration, C . Using the initial condition, at the initial point, the velocity equals the initial velocity (at point (0,0), $v = v_0$), therefore:

$$\frac{1}{2}{v_0}^2 = 0 + C$$

which gives $C = \frac{1}{2}{v_0}^2$

Plugging the constant of integration back in the equation gives:

$$\frac{1}{2}v^{\ 2} = g(y - \mu\ x) + \frac{1}{2}{v_0}^2$$

Simplifying the above equation yields

$$v^2 = 2g(y - \mu\ x) + {v_0}^2$$

$$v = \sqrt{2g(y - \mu x) + {v_0}^2} \qquad (1.1)$$

Equation (1.1) is used in the program to calculate the velocity at any given point (x,y) on the curve.

Then, by applying Euler-Lagrange equation: $\frac{d}{dx}(Fy') - Fy = 0$, we obtain a second order differential equation.

The equations obtained (Haws and Kiser, 1995) for the fastest curve with friction are:

$$x(\theta) = x_c(\theta) + \mu\ \rho\,(1 - \cos\theta) \tag{1.2}$$

and

$$y(\theta) = y_c(\theta) + \mu\ \rho\,(\theta + \sin\theta) \tag{1.3}$$

where: $x_c(\theta) = \rho(\theta - \sin\theta)$ and $y_c(\theta) = \rho(1 - \cos\theta)$

ρ and θ_f are determined with the ending point (a,b).

The Matlab program can be found in Appendix B.

1. Discussion of Model Implementation and Assumptions

These are the following known parameters:

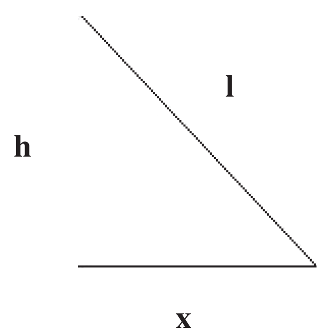
- The length and height of the slide are known values.
- According to Part 5.5.4.3.1 of TSO-C69c, the test subjects' clothing which contacts the device surface shall be a material with a coefficient of friction of at least 0.4 per ASTM Standard D1894-90 (typical of cotton or polyester/cotton blend).
- It should also be noted that according to Part 4.17 of TSO-C69c the means provides protection for an evacuee who crosses the emergency exit threshold at a horizontal velocity of 6 feet per second.

Equations (1.2) and (1.3) are used to plot the shape of the curve. The coordinates for the ending point (a,b) are needed:

- the y-component is the height (h) from the ground to the top of the evacuation slide
- the x-component is unknown. When no person slides down, the evacuation slide does not bend down. According to Pythagorean

theorem, the x component has then a maximum value of $(h^2 + l^2)^{0.5}$. Figure 5 illustrates the problem. When a person slides down, the slide bends and the x component is therefore smaller than the maximum value. An approximation of this value will be inputted in the program and then tested and checked until the exact length of the slide is obtained.

h = height to top of the slide (known)
l = length of the slide (known)
x = distance away from the aircraft (unknown)



Pythagorean Theorem:

$$x^2 + h^2 = l^2$$
$$x^2 = l^2 - h^2$$
$$\rightarrow x = (l^2 - h^2)^{\frac{1}{2}}$$

Figure 5: Assuming a right triangle formed when no person slides down

By fixing θ_f as π, ρ can be calculated.

The output of the program gives the velocity of an individual and time as a function of position. The arc length is also calculated to check the initial guess of the x component and make sure the arc length obtained corresponds to the length of the slide.

2. Discussion of Results

From the equation obtained using Newton's second law, mass is eliminated as it is on both sides of the equation. Therefore this parameter does not have a direct effect on the results. It is important to note that even if counting for the person size, the mass effect on deflection will not have a big effect and the shape of the slide would not change by much. When mass changes, the weight changes too which has an effect on the coefficient of friction and thus the normal force. The two main parameters that affect the results are the coefficient of friction and initial velocity of an individual at the top of an evacuation slide.

Figure 6 shows an optimal shape of the A380 upper and lower deck slides as well as of a B747 upper decks slide. The A380 lower deck has a sill height of 5.1 meters and the slide length is 10.2 meters. The A380 upper deck has a sill height of 7.9 meters and the length of the longest slide is 14.7 meters. Similarly, the B747 upper deck has a sill height of about 7.5 meters and slide length of about 13.95 meters.

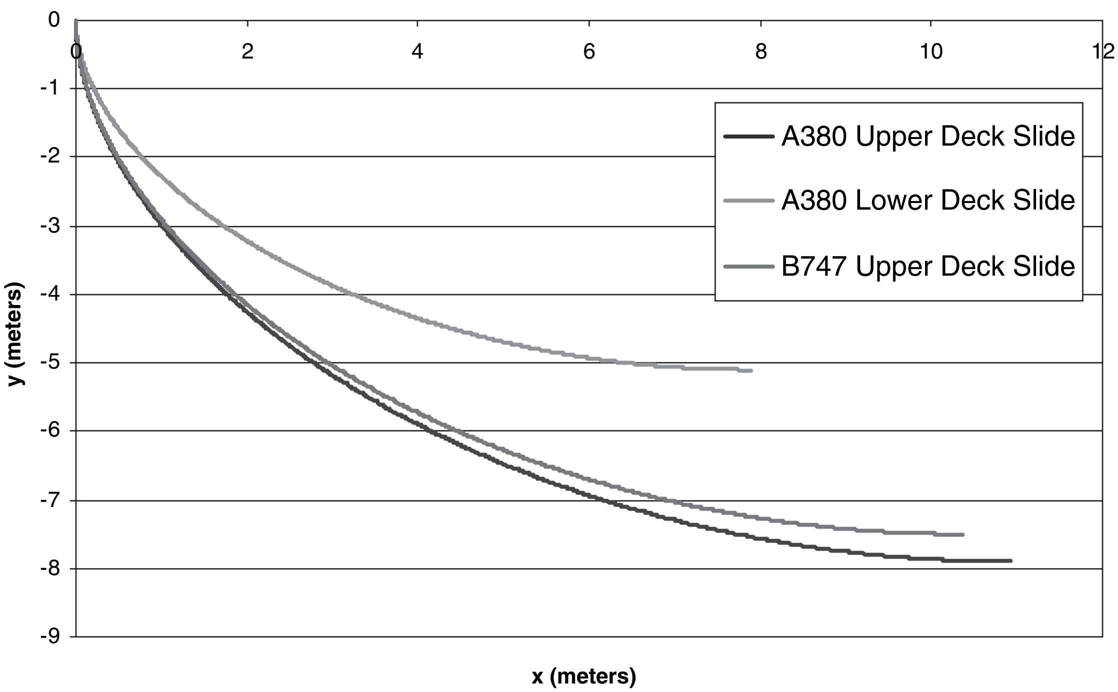


Figure 6: Optimal Shape of Upper and Lower Deck Slides with coefficient of friction of 0.4 and initial velocity of an individual of 6 ft/sec (or 1.83 m/sec)

Figure 7 shows the relationship between the velocity of an individual sliding down the A380 upper deck slide and the time. It can be seen that when the coefficient of friction increases, the time it takes for an individual to slide down increases. Also, at higher coefficient of frictions, the maximum velocity and velocity at the bottom of the slide are lower. With an initial velocity of 6 ft/sec (1.83 m/sec), the velocity of an individual at the bottom of the slide is 5.49 m/s for a coefficient of friction of 0.6 whereas it is 8.52 m/s when the coefficient of friction is 0.4. The time required to slide down to the bottom is 1.94 seconds when the coefficient of friction is 0.4 versus 2.17 seconds when the coefficient of friction is 0.6.

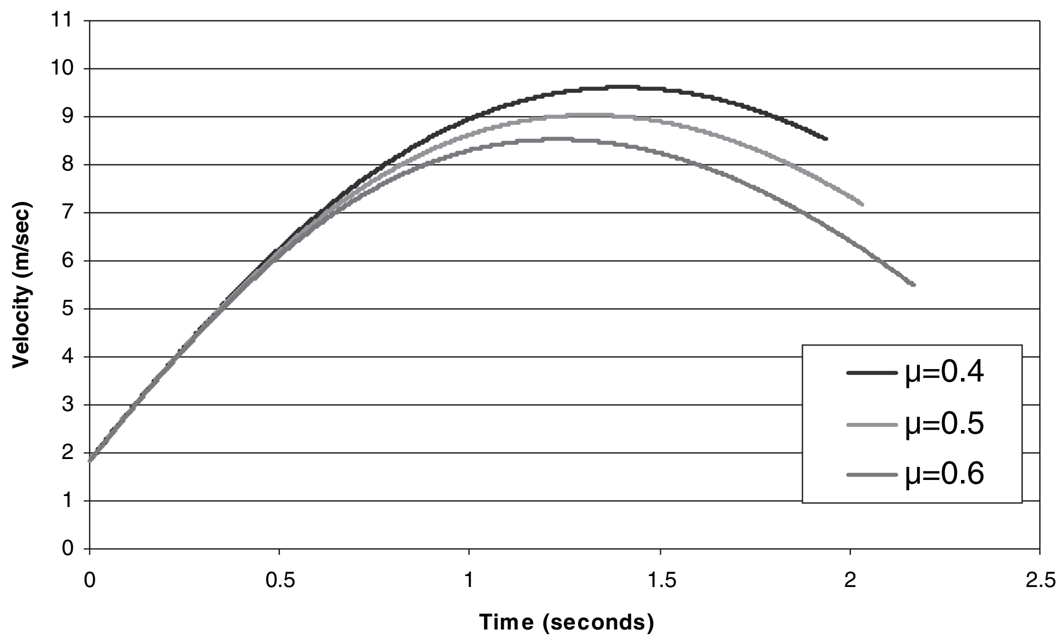


Figure 7: Velocity versus Time of an individual sliding on the A380 Upper Deck Evacuation Slide with an initial velocity of 6ft/sec (or 1.83 m/sec) with different coefficient of friction

Figure 8 shows the evacuee speed on the slide as the function of time with varying initial velocity. The results show that the effect of initial velocity is minimal.

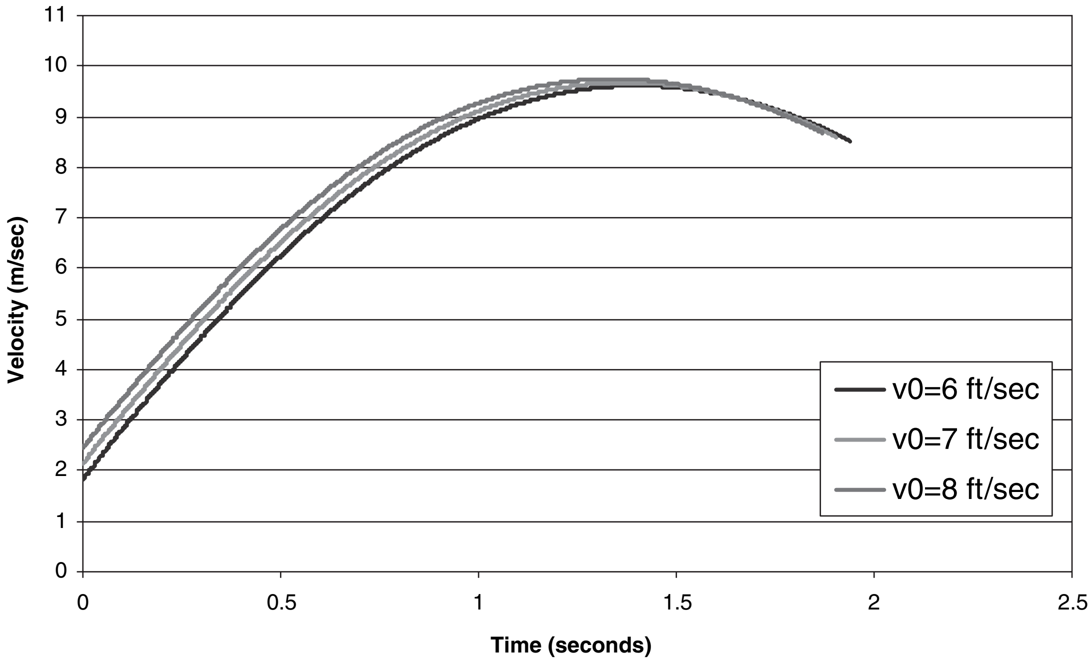


Figure 8: Velocity versus Time of an individual sliding on the A380 Upper Deck Evacuation Slide with coefficient of friction of 0.4 and different initial velocities

Figure 9 shows the comparison in results obtained between the A380 and B747 upper deck slides assuming the same initial velocity of an individual. Regardless of the specific accuracy of the model, the results illustrate that there is a small difference in the maximum velocity and velocity at the bottom of the slide between the upper deck of the A380 and upper deck of the B747. The time it takes to reach down the slide is about the same due to the slight difference in the length of the slides and heights to the top of the slides from the ground. From the results obtained, at an initial velocity of 6 ft/sec and coefficient of friction of 0.4, it takes about 1.94 seconds to slide down from the upper deck of the A380 versus 1.88 seconds to slide down from a B747 upper deck slide.

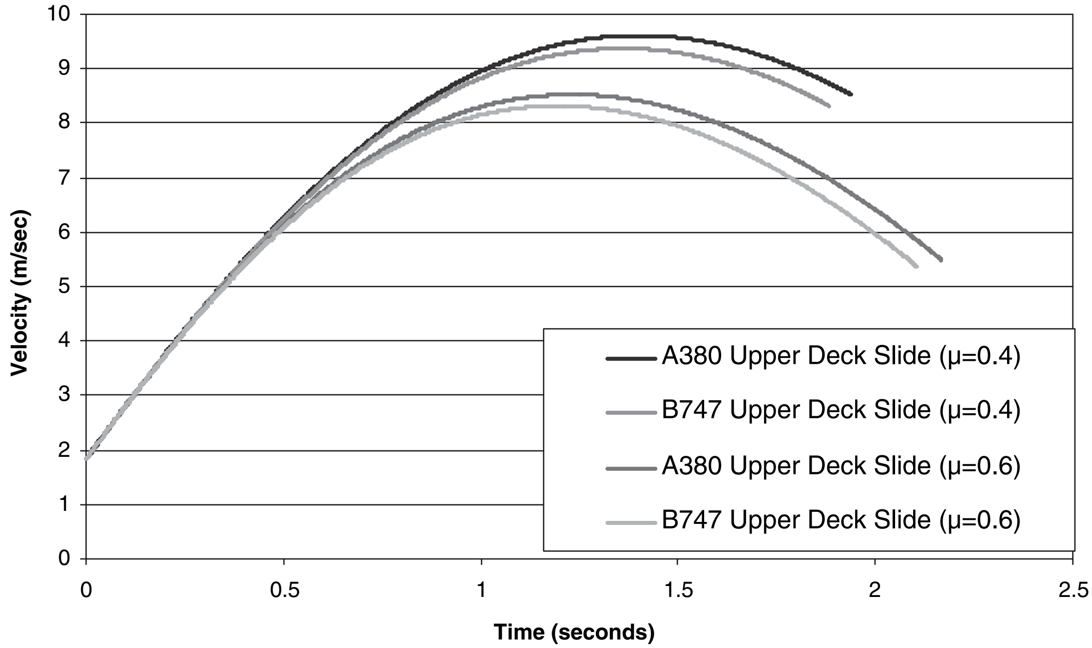


Figure 9: Velocity versus Time of an individual sliding on the A380 and B747 Upper Deck Evacuation Slide with an initial velocity of 6ft/sec (1.83 m/sec)

B747 Emergency Evacuation Events and Airbus A380 Certification

1. B747 Slide Emergency Evacuation Events

Major searches from different databases were done as a study for the National Academies of the Transportation Research Board to find slide emergency evacuation events. The events collected included both accidents and incidents over a ten year period from January 1, 1996 to June 30, 1996. The searches done concerned US air transport operations under Part 121, both scheduled and unscheduled. Several databases were used:

- FAA incident database, Aviation Safety Information Analysis and Sharing (ASIAS)
- NTSB's accident database
- CASE Database by Airclaims
- RGW Cherry & Associates Limited database

An additional search was done to capture Boeing 747 Part 129 slide emergency evacuation events.

From the 142 slide emergency evacuation events identified for the study for the Transportation Research Board, only 2 of those events involved B747 aircraft.

One event occurred on August 19, 2005 in Agana, Guam. A Boeing 747-200 landed with its nose gear retracted and an emergency evacuation was initiated. Two minor injuries occurred during the evacuation.

The second event occurred on May 1998 involving a B 747-400 in Tokyo. A very detailed report was found for this event produced by the Ministry of Transport of Japan; "Aircraft Accident Investigation Report" (Aihara, 2000).

This report states that of the 385 persons aboard, 365 passengers and 20 crew members, there were 4 serious injuries and 20 minor injuries. The report states that the four serious injuries were females aged between 38 and 73 and consisted of different types of fractures. Minor injuries suffered mostly from bruises, sprains, contusions, exocerations, abrasions, etc. The flight attendant that got injured stated that she picked up an elderly woman who was trembling at the top of the slide and took her down the slide. She got an injury on her right foot but no fracture. One female, aged 65, was seriously injured, from sliding down. She said that passengers were throwing away their belongings while she was on the slide. Her right index finger was fractured from a heavy briefcase that hit her hand. In addition to this, she hit her lower back against the ground at the bottom of the slide as there was no ground assistance. Another female, aged 73, sustained a serious injury at the bottom of the slide. She stated that "Sliding down was so fast that I was worried about being injured by the speed". She jumped at the bottom of the slide and while she was covering her face and head, she fractured her right arm. A passenger from the upper deck reported that he did not receive any guidance on evacuating. He mentioned that he deplaned via the ramp, connected to the airplane, and did not evacuate using slides. According to the report's analysis, they estimate that all the injuries occurred sliding down or at the bottom of the slide (Aihara, 2000).

Additional search of the data beyond the scope of the TRB study was conducted to identify additional events involving VLTA. Only one event was found on NTSB's database for Part 129 slide emergency evacuation event involving a Boeing 747 aircraft, which was operated by Iberia Airlines. The accident occurred in Jamaica, New York on August 11, 2002. Two passengers were seriously injured and one flight attendant and 34 passengers sustained minor injuries. Ten passengers were transported to medical facilities for treatment. A female passenger fractured her ankle. It was noted that the slide/rafts doors 4R and 5R did not work properly and all the 369 passengers and 17 crew members evacuated using 1R, 2R and 3R doors (NTSB Aviation Accident Report).

In addition to these events, an article was published by the Cabin Crew of Flight Safety Australia in July – August 2005 about emergency evacuations. It describes a B747-438 slide emergency evacuation event that occurred at Sydney airport on July 2, 2003. A very detailed investigation report was found, which was done by the Australian Transport Safety Bureau (ATSB, 2003).

Due to fire on the right landing gear, the captain ordered the passengers to evacuate and deployed the aircraft's slides. There were four serious injuries resulting from the evacuation. The injured included one crew member and three passengers (out of the 350 passengers and 14 cabin crew). Four passengers and one cabin crew member suffered from minor injuries. Figure 10 shows the Sydney incident.

Figure 10: Slide emergency evacuation of a Boeing 747-438 (Sydney, Australia, July 2, 2003) (Photo source: Australian Transport Safety Bureau)

The most serious injury occurred to one woman while she was on an over wing slide at the time it deflated. She got a fractured vertebra that required surgery as she landed heavily on the tarmac. One passenger sustained a fracture to her arm and another to her foot as a result of using the evacuation slides.

As far as the upper deck left side, the L2 and R4 escape slides did not deploy. The upper deck right slide was deployed but the crew declared it was blocked by a vehicle. The ground crew freed the slide and turned it to the right position on the ground. Upper deck passengers descended to the main deck and therefore did not use the upper deck slide to evacuate, but the copilot did. He descended on the upper deck right side while he was holding a 3kg fire extinguisher. The copilot stated that he was unable to control his speed and stability. He released the fire extinguisher while sliding down but due to momentum, he landed heavily on his shoulder and fractured his collar bone.

Some injuries were cuts, abrasions, sprains and bruises. One female passenger got injured at the bottom of the slide as she fell and cut her right elbow. Her husband evacuated holding his infant on his right hip with his right arm. He stated that he believes he tried to slow down using his left arm. Due to his fast descent, he also fell at the end of the slide, tearing his clothes and cutting his left knee and hand.

The cabin crew noted difficulties during the evacuation process. Some flight attendants let people take their belongings with them while others forced people not to take them when evacuating. Thus, some passengers evacuated down the slides with their cabin baggage. Passengers taking luggage or wearing high-heeled shoes risk damage the slide as they slide down. It was also observed that passengers collided with each other at the bottom of the slides as they did not do know what to do next. The ground crew decided to assist the passengers and directing them away from the aircraft (Australian Transport Safety Bureau, 2003).

2. Airbus A380 Certification

As mentioned, any new aircraft to enter service must pass the certification test. Certification is needed for all new aircraft models introduced in service. It is to ensure that the aircraft model and crew training provide safety. The main rule is known as the "90 second rule" which concerns the maximum exit time allowed for evacuation. The list of the critical requirements needed to attain FAA certification can be found in Appendix C. Results obtained from the certification test are considered as private, or are considered Airbus proprietary or Goodrich (slide manufacturer) which can not be disclosed to third parties. Many attempts were done to gather any type of information available to public.

Data, such as the A380 slides and doors characteristics as well as certification cabin evacuation test results, were obtained from Jean-Michel Govaere, A380 Chief Airworthiness Engineer. For the evacuation test, Airbus recruited volunteers to meet the population requirements. The test was held in March 26, 2006. Figure 11 shows the certification test. The A380 then received joint European Aviation Safety Agency (EASA) and Federal Aviation Administration (FAA) Certification in December 2006.

The population of the aircraft was 873 which included 315 passengers on the upper deck, 538 passengers on the main deck, 18 cabin crew members and 2 cockpit crew members.

The A380 certification test passed both Part 25 and Part 121 requirements, FAR 25.803 (c) including Appendix J and FAR 121.91:

- FAR 25.803 sates that "for airplanes having a capacity of more than 44 passengers, it must be shown that maximum seating capacity, including the number of crewmembers required by the operating rules for which certification is requested, can be evacuated from the airplane to the ground under simulated emergency conditions within 90 seconds".
- Appendix J to Part 25 lists the certification requirements which can be found in Appendix C.
- FAR 121.91 states that "this subpart prescribes rules for obtaining approval of routes by certificate holders conducting domestic or flag operations".

From the test results, there were no serious injuries and only very minor injuries. Minor injuries were not more serious than bruises. It was stated that the injuries were significantly less than the "official" 5% acceptable FAA percent injury rate.

The evacuation was performed in 78 seconds which meets the 90 second maximum time. As stated from the results obtained, there was no difference found in the behavior of passengers between those of the main deck and those of the upper deck, with the nominal capacity exceeding in most times 110 passengers per Type A door. No hesitation time was noticed from the passengers jumping from the upper deck.

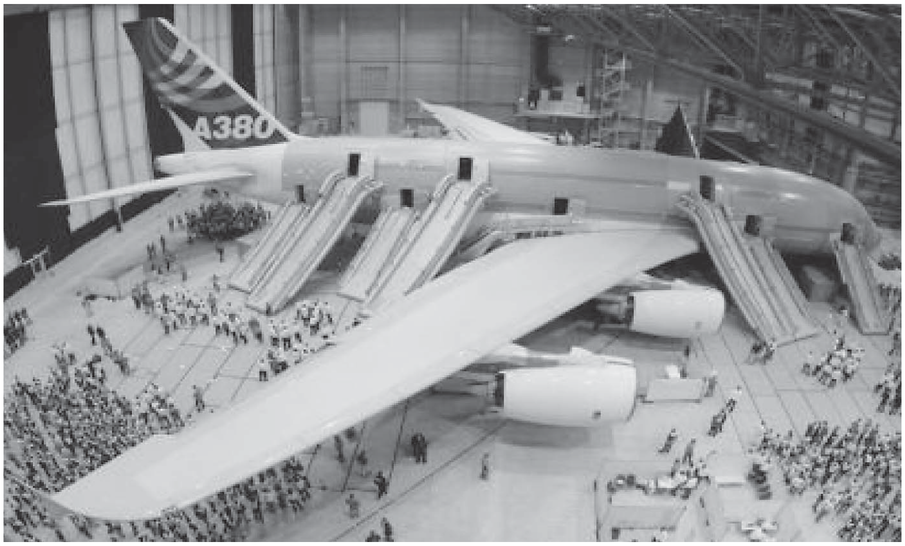


Figure 11: Airbus A380 Certification Test
(Source: http://www.airporttech.tc.faa.gov/safety/patterson1.asp)

Importance, Relevance, and Potential Impact of the Study

Safety standards have been maintained throughout the years in order to provide safe and efficient passenger evacuations. This study reviews emergency evacuation challenges of very large transport aircraft. There have been many concerns about emergency evacuations of the future world's largest transport aircraft, the Airbus A380 due to its massive passenger capacity and aircraft size. This study underlines and analyzes the evacuation "results" from larger transport aircraft.

Conclusions and Recommendations

This study focused on slide emergency evacuations from upper decks of very large transport aircraft. Several initial parameters were changed to see the effect they had on the velocity of an individual as a function of position on the slide. The graphs show and compare the results between sliding down from the upper deck of the Airbus A380 versus B747.

Certification requirements are based from only one single evacuation trial which can be skeptical on the capability of the evacuation. Unlike certification evacuations, passengers may be subject to other type of behavior in real emergency evacuations. There are concerns about this double deck aircraft and how real life emergency situations would differ from the drill conditions. One major point to note is that as the evacuation drill takes places in a dark environment, it is hard to come up with the conclusions Airbus made about the upper deck slides passengers' behavior. However, as the test was conducted in complete darkness, it is not surprising that passengers did suffer from minor injuries.

A number of factors affect the safe evacuation of passengers. As mentioned, passenger's reactions and decisions will have an effect on the overall process. The uncontrolled manner of passengers in an evacuation can result in injuries. Passengers' unexpected reactions is hard to predict as they are not always those one would expect.

The height of the upper deck slide could disturb passengers, refusing them to jump. This would create more panic for the rest of the passengers. Another major concern is the possible migration of passengers from the upper deck to the main deck using the stairs that connect the two decks. This could lead to a potential problem for the main deck doors due to the extra flow of passengers which would disrupt the evacuation process. It is the role of cabin crew to communicate, coordinate and redirect passengers. The huge crowd in this large aircraft may increase panic in case of an incident.

Emergency evacuation models can help to simulate different scenarios. There are, however, countless interactions that could occur during a real emergency evacuation that can not be tested. However, these are recommendations that should be taken into consideration for safer evacuations of large transport aircraft:

- Increased number of ground assistance and personnel needed. Due to the massive passenger capacity, it is crucial personnel at the bottom of the slides are there to make sure they direct passengers such as getting them out of the way as quickly as possible, calming them down and securing safe paths to protect them. It is also very necessary to have ground operation personnel to hold down the slides and assist them at the bottom due to the higher speed from the upper deck slides.

- Increased training on communication and coordination between cabin crew. They must be able to manage a safe evacuation of a massive number of passengers. Crowd management training is crucial. Also, new systems may be required to increase effective communication.

  - Cabin crew is one of the most important aspects against large transport aircraft evacuation problems. In large transport aircraft, the number of passengers is much greater which could cause confusion for the rest of the people.

- Provide passenger guidance in the aircraft. If the crew does not direct the passengers the right way, the passenger flow rates at different exits could create a major problem. It is their role to direct passengers in an orderly manner and to avoid upper deck passengers to go down to the lower deck.

- New passenger briefings and new evacuation procedures. It should be made clear to the passengers not to use the stairs during an emergency evacuation. Evacuations of the two cabins should take place in a separate way while at the same time.

It is certain that future research will continue on very large transport aircraft and new designs such as blended wing body (BWB) aircraft. A blended wing plane has no tail and has a flat and wide fuselage rather than a circular one. There have been studies that showed performance improvements over conventional transport aircraft such as increased lift and therefore improved fuel economy. Passenger's flights on blended wing aircraft will be able to carry 800 passengers in a double-deck cabin. Its configuration, involving two decks with multiple aisles per deck, poses emergency evacuation challenges. Concerns on how to handle emergency evacuation of large passenger cabins will be raised such as the location and number of emergency exits that will be sufficient for a safe evacuation, whether the 90 second evacuation requirement will be relevant to this type of aircraft.

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Appendix A- Airbus A380 Slides Lengths and Angles

Door	Slide Length	Slide Angles		
		Normal Sill	Maximum Sill	Minimum Sill
M	10.3 m (406.0") – Normal 13.7 m (540.7") - Extended	30°	47.5°	12°
M2	11.2 m (439.0")	30°	47°	16°
M3	5.7 m (225.0") – Ramp 7.2 m (283.5") - Slide	N/A	N/A	N/A
M	10.2 m (400.0")	33.5°	39°	12.3°
M5	10.2 m (400.0")	33.5°	43.8°	5.8°
U1	14.7 m (580.7")	35°	43°	25.6°
U2	13.9 m (546.7")	38°	40°	25.7°
U3	13.9 m (546.7")	38°	44°	19.4°

Source: A380 Cabin Evacuation System (Jean-Michel GOVAERE, A380 Chief Airworthiness Engineer, AIRBUS SAS)

Appendix B - Matlab Code

```
% Maryline Rassi, 07/31/2007

clear all; close all; clc;

% 1. INPUT
x = 10.9109;            %[m] x distance to the bottom of the slide
h = 7.9;                %[m] height
v_0 = 6*12*0.0254;      %[m/s] Conversion: 1 ft/s = 12 in/s = 12*0.0254 m/s
mu = 0.42;              % Friction coefficient
g = 9.81;               %[m/s^2]
n = 1000;               % Counter
```

```
% 2. PROCESSING
% 2.1. Calculate the parameters of the curves
for j = 1:n
   t(j) = (j-1)/(n-1) * 2* pi;
   result(j) = (1-cos(t(j)) + mu * (t(j) + sin(t(j)))) / (t(j) - sin(t(j)) + mu * (1-cos(t(j)))) -
h/x;
end
theta_f = pi

rho_x = x / (theta_f - sin(theta_f) + mu * (1 - cos(theta_f)) );
rho_y = h / (1 - cos(theta_f) + mu * (theta_f + sin(theta_f)) );


% 2.2. Calculation of x and y
for j = 1:n
   theta(j) = (j-1)/(n-1) * theta_f;
   x(j) = rho_x * (theta(j) - sin(theta(j))) + mu * rho_x * (1 - cos(theta(j)));
   y(j) =  rho_y * (1 - cos(theta(j))) + mu * rho_y * (theta(j) + sin(theta(j)));
% 2.3. Velocity
   v(j) = sqrt(2*g*(y(j) - mu*x(j)) + v_0^2);
end

% 2.4. Time
time(1) = 0;    % Time initialization
s = 0;
for j = 2:n
   dx(j) = x(j) - x(j-1);
   dy(j) = y(j) - y(j-1);
   ds(j) = sqrt(dx(j)^2 + dy(j)^2);
   dt(j) = ds(j) / v(j);
   s = s + ds(j);
   time(j) = time(j-1) + dt(j);
end

% 3. OUTPUT
s
time(n)
figure;
plot(x,-y)
xlabel('x [m]'); ylabel('y [m]');
axis equal
figure;
plot(time,v)
xlabel('Time [s]'); ylabel('Velocity [m/s]');
figure;
```

```
plot(y,v)
xlabel('y [m]'); ylabel('Velocity [m/s]');
```

Appendix C – Critical Requirements to attain FAA Certification

- Evacuation must take place either during the dark of the night or during daylight with the dark of the night simulated, so the plane's emergency lighting system provides the only illumination in the cabin.
- Passenger load (in normal health) must be representative with at least 40 percent female, at least 35 percent over 50 years of age, and at least 15 percent must be female and over 50 years of age.
- No practice runs are allowed before the drill.
- Passengers can not know the location of the emergency exits to be used.
- Crew members must be seated in their normally assigned seats.
- No passengers may be assigned specific seats.
- Before the start of the demonstration, about one-half of the total average amount carry-on baggage, blankets, pillows and other similar articles must be distributed at several locations in aisles and emergency exit access ways to create minor obstructions.
- Only half the emergency slides and doors can be used.
- Evacuation test is over when the last person on the plane (including crew members) is on the ground.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation