Sensitivity Examination of the airEXODUS[1] Aircraft Evacuation Simulation Model

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Objective

The Building and Fire Research Laboratory at the National Institute of Standards and Technology (NIST) has been a leader in the development, application and evaluation of models for the simulation of fires and the associated hazards and risk to people. NIST's expertise is useful in the broader application of fire hazard analysis to transportation systems in general. Such a project related to passenger trains has been ongoing for several years, sponsored by the Federal Railroad Administration through the Volpe National Transportation Systems Center[1]. For aircraft, a fire hazard analysis could determine not only the time required for evacuation, but also the time available, based on the fire performance of the total system[2]. Such an application requires both predictive models of the fire environment and of passenger evacuation during fires.

The Federal Aviation Administration (FAA) is interested in the use of computer simulation models for examining the compliance of commercial aircraft with FAA regulations for the evacuation of passengers and crew. This interest derives from both a desire to reduce the expense of testing every aircraft configuration and to reduce dependence on evacuation tests involving people and the attendant risk of injury in such tests. The FAA's plan is to allow the use of modeling to qualify derivative aircraft, those that exhibit variations in interior configuration or stretch versions, for which demonstration tests were performed on the basic version. There is also interest in using models to assess evacuation for advanced designs that may vary in significant ways from current passenger aircraft. An appropriately validated model could be used both to test compliance of derivative designs and to evaluate evacuation as part of the design of new aircraft prior to actual compliance testing. In the longer term, the coupling of an evacuation model with a fire model would allow designers to evaluate evacuation under more realistic fire conditions.

One candidate model specifically developed to simulate the evacuation of commercial aircraft is airEXODUS developed at the University of Greenwich in the United Kingdom[3]. The developers have been conducting extensive verification of the predictive accuracy of the model using data from the historical records of certification tests as a step in developing the capability of the model to simulate evacuation during a fire. The FAA asked the National Institute of Standards and Technology to examine the sensitivity of the airEXODUS model to reasonable variation in user inputs to determine if the model results might be unduly impacted without being obvious to those reviewing the results. A copy of the latest pre-release version (v 1.01) of the model was supplied to NIST by the developers for this purpose. NIST has studied the evacuation times for a

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1 Certain commercial products are named in this report for completeness only and this does not represent any endorsement of these products by NIST or the federal government.

simple geometry (a passenger rail coach car with exits at both ends) and found the times predicted by airEXODUS and two other emergency evacuation models were nearly identical[4]. The following describes the results of an examination of airEXODUS as applied to two aircraft designs along with pertinent observations. However, any decision of the suitability of the model for regulatory purposes can only be judged by the FAA.

The Boeing 757-200

The FAA requested that this evaluation utilize the Boeing 757 as the test case. This selection was based on the fact that this is the only aircraft certified in two exit configurations. Thus, the ability of the model to assess derivatives of the same aircraft could be investigated.

The Boeing 757 is described by its maker[5] as a twin-engine medium to long range jetliner that is popular among both US flag and foreign carriers -- there are 874 aircraft in service worldwide as of March 1997. The aircraft has a wingspan of 38 m (124 ft 10 in), an overall length of 47.3 m (155 ft 3 in), a cabin width of 3.5 m (11 ft 7 in) and a range of about 5000 km (3130 mi).

Figure 1 B757-4 configuration

From the viewpoint of emergency evacuation, the B757 is unique in that it is available in two exit configurations – one (which we will refer to as B757-4) has four pairs of exit doors (type I) and the other (which we will call B757-3) has three pairs of exit doors (type I) and two pairs of overwing window exits (type III). Both configurations have been tested and certified by the FAA as having demonstrated an emergency evacuation time less than 90 s under FAR25.803.

The specific interior configuration of any aircraft varies by airline and even among aircraft operated by a single airline, with the most variation found in seat width and pitch (the distance from one row of seats to the next). Typical dimensions were selected for use in this study.

Both aircraft configurations used in the study assume first class compartments with 24 seats arranged in 6 rows of 4 seats, two on either side of an aisle 1m (40 in) wide. The first class seats are 0.75 m (30 in) wide (including armrests) with a pitch of 1.5m (60 in). In the main cabin, 156 seats are arranged in 26 rows of 6 (B757-3) or 158 seats arranged in 26 rows of 6 and two seats in row 7 (B757-4). Coach seats are 0.43 m (17 in) wide with a pitch of 0.95 m (37 in). The main cabin aisle is the same width as in first class. These layouts along with the locations and spacings of galleys and lavatories were taken from actual seating diagrams of US commercial airlines.

The airEXODUS Model

The airEXODUS model is a "node and arc" model of the type most commonly used in evacuation modeling, and from which derived the developer's evacuation model for buildings, EXODUS[6]. The airEXODUS model incorporates many details on passengers and the physical characteristics of the aircraft. It provides tools to configure aircraft geometries, add passengers of specific sex and age or groups of passengers with a specified distribution of age and sex, seat the passengers in specific locations or distribute them randomly, station flight attendants at exits to assist evacuation, and designate exit(s) as being unuseable for any specific simulation.

In addition to being able to populate an aircraft with passengers that are distributed in age and sex, the model can randomly assign these passengers to seats and randomly reassign seating of the same population to determine a distribution of evacuation times. Each of seven types of exits has associated with it a range of *exit delay*[2] times (passengers pause briefly at the exit before proceeding through). These time ranges were determined by detailed review of video tapes of evacuation tests conducted on all types of commercial aircraft. The model assigns a random delay time within the range for each passenger. This delay time is further affected by the presence of a flight attendant and whether that attendant is designated as "assertive," "in-between," or "unassertive." The final result of the model calculation is the time needed for all passengers to exit the aircraft and the time of egress and exit used for each individual.

Configuring an Aircraft in airEXODUS

There are four modes used in setting up an evacuation simulation -- geometry mode, population mode, simulation mode and scenario mode. The aircraft configuration is specified in the model's *geometry mode* by specifying nodes and connecting them with arcs. Nodes are locations in the aircraft (seats, aisles, obstructions, or exits) and arcs are distances connecting nodes. People can move along aisle nodes (as long as they are connected by an arc) and if blocked, can move over seats with an increased degree of difficulty. With the seat back in its vertical position the "obstacle" value is high and is higher if the direction of movement is toward the rear of the aircraft. However, if the back of an airplane seat is pushed with enough force it will fold forward (called "break") against its own seat. Thus, if the direction of movement is toward the front (in the direction of break) the obstacle value is lower. Instances of passengers going over seat backs has been reported in actual emergency evacuations but has not been observed in evacuation drills. Some seats near overwing window exits do not break and such seats can also be simulated.

Specifying a configuration geometry begins with creating aisle and seat nodes and connecting them by arcs of specified length. Groups of nodes and arcs can be repeated to facilitate this process. Finally, doors are added in the required locations and connected to the ends of the aisles leading to them. Arcs connecting doors to the last aisle node automatically have zero length. Aisle nodes can be assigned an "obstacle" value in the same manner as for seats. For aisle nodes obstacle values of 1 or 2 are recommended to simulate aisle locations in which carry on objects have been placed to impede egress as is done in 90 second certification tests. The software also

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2 Terms that appear in the software as variable names or labels have been italicized in this report to familiarize those who may subsequently use that software.

supports multiple decks connected by stairs, such as in the B747. These geometries are constructed in a similar manner to a single deck aircraft.

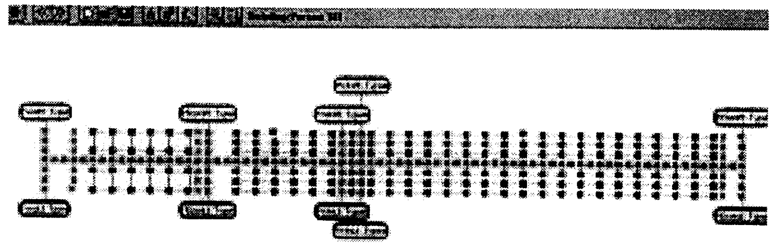

Figure 2 B757-3 basic geometry

There are a number of visualization tools within airEXODUS available to the user. Seats are drawn as a red square with a black offset square that identifies the direction in which it faces. Arcs are shown in different colors to differentiate direction and can be turned off if they become confusing. Aisle and obstacle nodes are shown in green and blue, respectively. There is a *boundary mode* display that draws lines around connected nodes to assist in visualization. Exits are shown as ellipses containing the door type as a label. Double clicking on any node, arc, or exit symbol brings up a dialog box containing all current settings and allowing the user to change any of these settings. Some settings can only be set in particular modes. If a setting cannot be altered in the current mode it is greyed out.

Populating the Aircraft

Passengers are selected in *population mode.* By selecting "populate," the user is asked for the number of passengers and these are generated with a distribution of sex and age that conforms to the distribution of the traveling public as specified in FAA FAR 25.803. Groups of passengers that meet specific group criteria are referred to as a "panel." Passengers can also be selected individually or the characteristics of passengers modified through the passenger dialog box. Sex, age, and weight are set in the main dialog box, detailed characteristics such as movement speeds, response delays, agility and drive coefficients are modified in the "attributes" box and physiological characteristics and response when exposed to fire gasses are set in the "gasses" box.

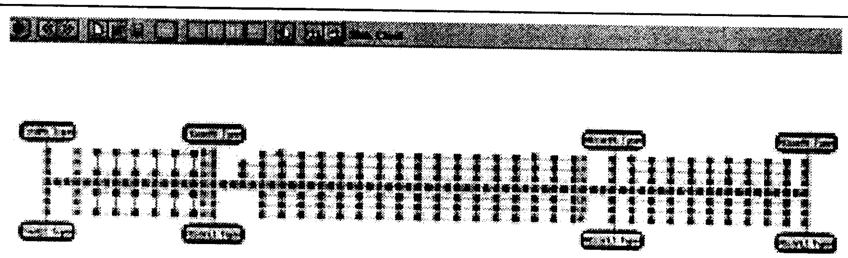

Figure 3 B757-4 with passengers

Passengers can be assigned to seats randomly by the model or individually by the user. Seats can be reassigned randomly to the same population with a single button so that an envelope of evacuation performance can be developed for several, random seating locations of a single population. Even when evacuations are repeated for the same population, somewhat different results will be obtained because of randomized variables assigned during the run. Finally, passenger sets generated from the same profile (such as the "90 second panel") will result in some random variation in assigned passenger characteristics. Thus, varying each of these parameters is recommended by the developers for determining the evacuation performance of an aircraft configuration.

Submodels

The process of evacuation is governed by a series of submodels within airEXODUS. The *movement submodel* governs the movement of people from node to node along arcs toward an exit. The main function of the movement submodel is to determine the travel speed for the person under the current conditions. If the adjacent node to which the person is moving is occupied they must wait. If waiting in a queue and their patience runs out they might climb over seats to go around, if they have sufficient agility and seat jumping is activated as an option.

The *behavioral submodel* is closely linked to the movement submodel in determining evacuation behavior. The behavioral submodel determines a global goal of an overall escape strategy (e.g., which exit to use) and then local response to the current situation. The rules incorporated in the behavioral submodel come from aircraft evacuation in actual accidents, behaviors observed in certification drills, and full-scale experiments.

Globally, passengers move toward the closest serviceable exit unless directed to another by crew. Local conditions that arise during evacuation have a significant effect on any passenger's progress toward their global goal, and are strongly affected by the passenger's attributes. Normally passengers caught in a stationary queue will wait until their *patience* expires when they might choose another (more distant) exit if such exists or may go around or over seats if this is the only option. However, if *extreme behavior* is enabled passengers whose patience has expired will move into seat rows to find an alternate path if they have sufficient *agility* to jump over seats or in two aisle aircraft they may pass through a seat row to get to the other aisle.

Since a node can be occupied by only one person at a time conflicts that arise are resolved by the *drive* attribute for the passengers in conflict. A passenger can overtake a slower moving passenger only where there is sufficient room to pass and there is an alternate node and arc path. Because of the narrowness of aisles in most aircraft, overtaking is rare in actual aircraft evacuations.

Passengers traveling in aisles move at their *maximum fast walk rate*, and in seat rows at their *maximum walk rate*. If traveling over seats the *maximum leap rate* is used but again, only if the conditions for seat jumping have been met. Passengers on stairs travel at *stairs-up* or *stairs-down* speeds as appropriate.

Crews have an effect on the use of exits and efficiency of egress. An exit with an *assertive* attendant is more attractive than one with a *non-assertive* attendant or one that is *unattended*. The time at which a given exit is opened or closed can be set as an exit attribute (*opening time*). Exits also can be *active* or *inactive*. Passengers will queue at active exits even if closed but will not use inactive exits even if open.

There are two other submodels in airEXODUS – the *Hazard submodel* and the *Toxicity submodel.* The Hazard submodel determines the interaction of passengers with heat and smoke conditions that might be present due to a fire within or external to the aircraft. The toxicity submodel determines the effects of exposure of passengers to fire gases using either Purser's relationships from the general fire literature[7] or Speitel's formulas for aviation applications[8]. As airEXODUS does not contain a fire model, both of these submodels require that smoke, temperature, and fire gas data be entered by the user. This user input is entered through the model's *Scenario Mode* as data points or mathematical functions, based on estimates or calculations external to airEXODUS.

Since the current work considers the use of airEXODUS under the conditions specified for FAA evacuation certification and that does not include exposure to fire conditions, these submodels are not applicable to this study and were not evaluated. However, in future this is an area where coupling of airEXODUS to NIST's fire models would improve the utility and expand the use of the simulation by including fire exposure.

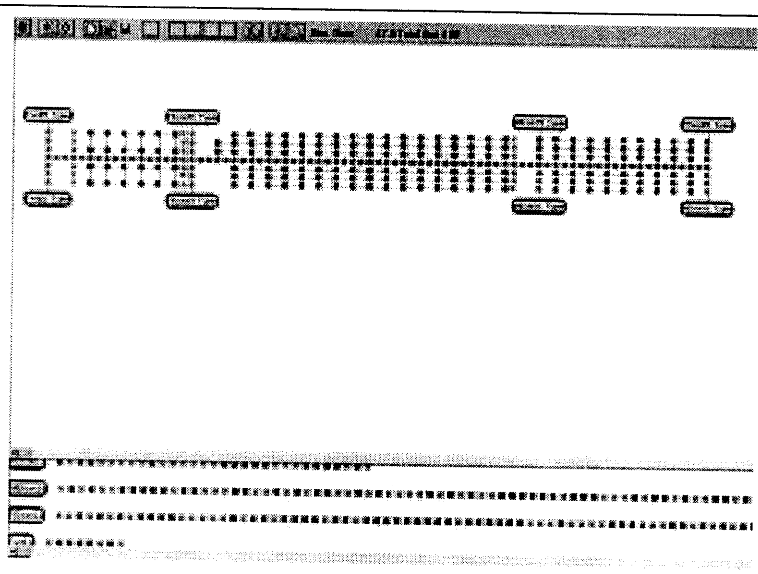

Figure 4 Display shows exit used by each passenger

Simulating an Evacuation

Once the aircraft has been configured and populated, evacuations can be conducted in *simulation mode.* When the play button is pressed the simulation clock begins to run and passengers move from node to node toward the exits. As passengers pass out a door a lower window opens to display the passenger icons in a row after the exit from which they left and the total number out is displayed next to the simulation clock. A number of graphs and tables of output are produced and displayed at the bottom of the screen. These include the number of passengers using each exit and the total out of the aircraft.

Simulation results can be saved for subsequent study. Subsequent simulation runs are plotted on the same graphs so that they can be compared. Even if no overt changes are made, the results of subsequent simulations will be different because of the random assignment of such parameters as delay times. The developers recommend that the following procedure be followed for aircraft certification to obtain a range of results representing the envelope of performance for that aircraft configuration and passenger mix regardless of seating.

(a) Generate several target populations (typically 3-5).
(b) For each population run 10 to 100 repeat simulations for a given seating arrangement.
(c) Randomize the seating arrangement for a each population about 3 times.
(d) For each randomized seating arrangement for each population repeat (b).

This process could result in up to 1500 runs for each analysis. Each distribution can then be described in terms of the mean evacuation time, the maximum and minimum evacuation time and the 95 percentile evacuation times.

Use of airEXODUS for Aircraft Certification

The airEXODUS model is a highly specialized software tool for studying the complex interactions of the aircraft configuration and passenger behavior in emergency evacuation. Evaluating its accuracy in predicting the performance of specific aircraft configurations in FAA certification drills is beyond the scope of this study, but is being pursued by the developers and aircraft manufacturers using the detailed data and videos from numerous certification exercises. NIST was asked by the FAA to review and comment on the sensitivity of the model's results to variables under user control in the context of use to simulate certification testing.

Table 1. Important Variables in airEXODUS

Representative model variable(s)	Actual Characteristic
Geometry and Configuration Variables	
Number, type, & arrangement of nodes; locations and length of arcs; obstacle values for nodes	Physical dimensions of aircraft and its configuration, number and size of seats, seat pitch, location of bulkheads
Opening times, door delays, off times, exit status	Number, type, location of exits and their availability
Door delays, exit potentials	Crew stationed at exits
Passenger Population Variables	
Number, sex, age, weight; response delay, agility, drive; walk, fast walk, leap rates, up and down stairs rate	Number, sex, age, physiological & psychological characteristics
Seating assignments	Passenger location

The airEXODUS model includes literally hundreds of input variables under user control. When used as a research tool, the large number of variables under user control makes sense, but for simulation of certification testing can be more limited. Table 1 shows the variables included in airEXODUS judged to be important in the context of certification testing. These variables were included in the sensitivity analysis in this report. All other variables were left at default values recommended by the model developers.

Limits for many of these variables are obvious from the regulations covering the certification testing. Geometric variables (e.g., aisle width, seat pitch and width, location of bulkheads) can be set to match the actual aircraft configuration. In the context of certification testing, the aircraft is full and passenger characteristics are required to reflect a specified distribution of age and sex consistent with the traveling public. Travel speeds, patience levels, mobility, drive, and agility values can be based on a single set assigned for FAA use. Thus, for certification simulations these variables can be fixed at values appropriate for the aircraft of interest. Randomized variables such as seating locations and door delay times that vary over a range established from observations also make sense in conjunction with using multiple model simulations to obtain a range of expected results.

This leaves the selection of available exits, the variables which effect egress through these exits, and passenger population as important variables for the sensitivity analysis in this report. These variables include door opening times, door delays, exit potential, and off times as the important user variables. Since off time is not currently included in the airEXODUS model, it was not considered further in this paper.

Setting Exit Characteristics

The *status* parameter of exits can be specified as *open* or *closed* and the *active* parameter is set to *yes* or *no*. The difference is that an active exit that is closed will result in a queue of passengers who are delayed in egress until they realize that the exit is blocked. This can also be used to simulate delays due to difficulty in opening exits.

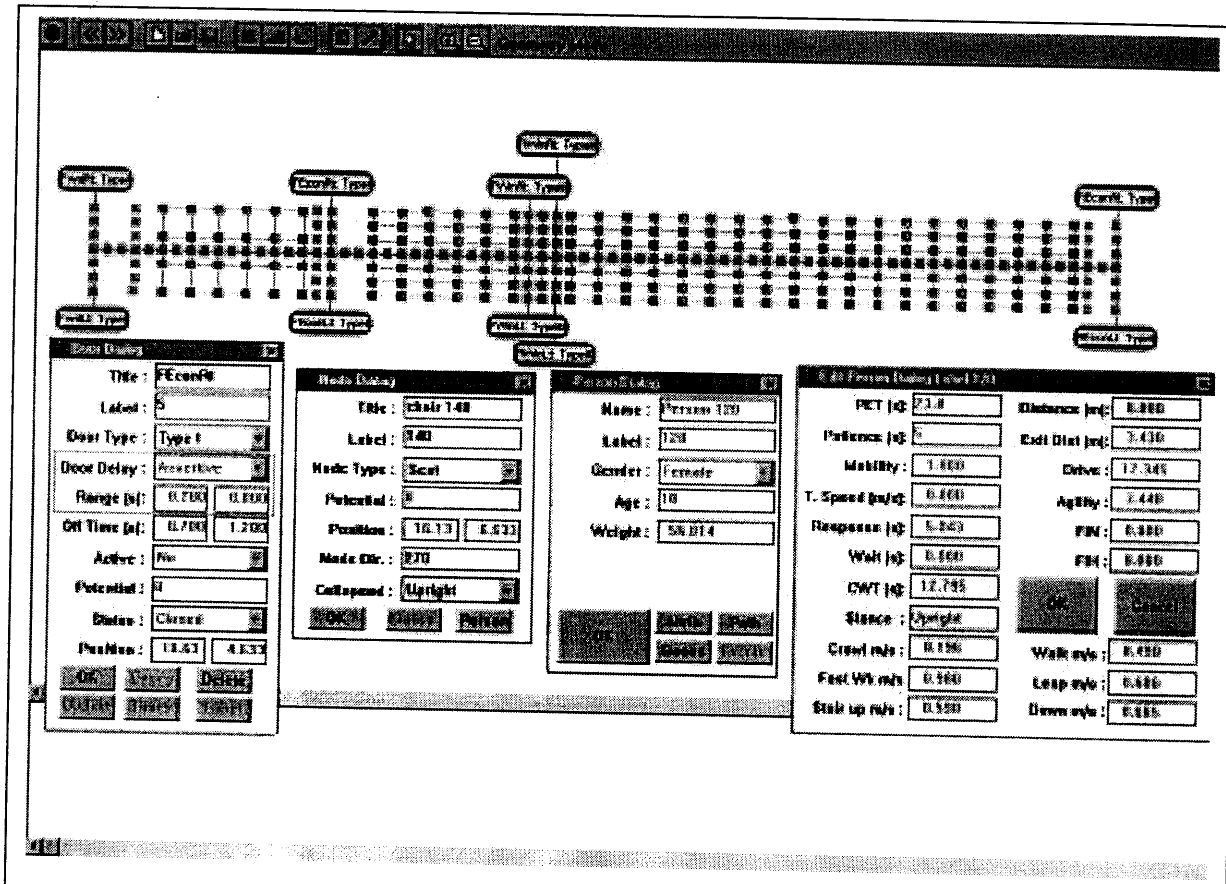

Figure 5 Data entry via dialog boxes

Each exit can have a crew member who is either assertive, in-between, unassertive, or the exit can be unattended. The choice determines the range of delay times associated with that exit. Further, an unattended exit will not attract passengers in queues at other exits with longer lines. FAA evacuation certification tests include crew members at each exit who are trained to be assertive. Although aircraft do not always have sufficient crew to staff every exit they have enough to staff half of them and certification testing is done using only half the exits.

The difference among exit types and the presence or absence of crew leads to the range of *door delays* assigned to an exit. These door delays represent the hesitation time when the passenger reaches the door and prepares to exit and the time needed to move through the exit onto the slide or wing. Door delays are determined from the certification testing by analyzing video tapes and tabulating delays by exit type, crew presence, sex, age, and gender. In the pre-release version of airEXODUS that is being used for this study, door delays for Type I and Type III exits with assertive crew are the only values available (the Type I delay range is 0.2 s to 0.8 s, randomly assigned within the range for each passenger). These times are based on limited analysis of data from certification tests. As this analysis continues these numbers are subject to change. Other exit types and crew conditions currently default to zero.

The FAA evacuation certification test procedure requires that only half of the available exits are used for evacuation, but does not specify which exits are to be open. The choice of which exits to disable for the certification test is within the purview of the FAA testing officer. Since an aircraft only has to demonstrate the ability to evacuate the plane in a single choice of openings, typical FAA certification testing has been done with one of each pair of exits in the aircraft closed. This means that the shortest cumulative travel distance condition is that which is typically tested. Other choices such as using the front and rear exits or closing middle door exits would result in longer waiting times. Closing all exits on one side would increase waiting times, but would have no effect on travel distances. With the airEXODUS software it would be practical to examine several combinations of exits disabled.

Setting Population Characteristics

As discussed previously, the population with the distribution of age and gender specified in FAA FAR 25.803 can be obtained in population mode by using the populate button. Specifically the certification procedure specifies:

a) At least 40 percent of the passenger load must be female
b) At least 35 percent of the passenger load must be over 50 years of age
c) At least 15 percent of the passenger load must be female and over 50 years of age

This leaves some room for variations and these will have a significant effect on the outcome. For reproducibility it would be better if one or more population distributions were uniquely specified. For example, the analysis might use the population above along with one that contained a higher percentage of older passengers and one that includes more families traveling with children.

Seating assignments may also have a significant impact on results, but this is an uncontrolled variable in real aircraft. Thus, the developers of airEXODUS recommend that the evacuation simulation be repeated several times with the same population randomly reseated (done with the *randomize* button in population mode). This procedure provides an envelope of evacuation performance for a range of seating assignments.

Some passenger characteristics, such as patience, walking and crawling speeds, are set as a function of age and gender. Walking and crawling speeds are based on published data. Further, the validation of the model against certification test data uses these values. For the analysis in this paper, these default values were used for all model simulations.

There are additional passenger behavioral features such as jumping over seat backs that are included in the model but do not occur unless an *extreme behavior* feature is activated. Seat jumping can be specifically suppressed in several ways. These behaviors are reported in actual evacuations but have never been seen in certification drills. For the analysis in this paper, the *extreme behavior* feature was not activated for any of the model simulations.

Other Parameters

The model includes a variable referred to as the *exit potential.* This is a numerical value that represents the attraction of an exit to a particular passenger. The influence of exit potential diminishes with distance, so this is a way of attracting passengers to the nearest exit. But door exits may be more attractive to passengers than window exits, or exits forward may be slightly more attractive than ones to the rear, so these effects can be included by setting exit potentials. Evacuation times are optimum if the last passenger out each exit leaves at the same time. This optimum distribution of passenger movement can be achieved by adjusting exit potentials and may be used to bracket the range of evacuation times for a specific configuration. For the analysis in this paper, default values were used for all model simulations.

Another parameter not implemented in the pre-release version of the model used for this study is *off time*. This is the time required to reach the ground once the passenger has passed through an exit and it varies with the type of exit and slide arrangement. The developers intend to include default values for this parameter in the release version, for specific aircraft where such times can be established from test data. For the analysis in this paper, *off time* was not considered.

Assessing Sensitivity to Inputs

A pre-release version of airEXODUS was supplied by the developers so that NIST could determine the sensitivity of results to typical variations in input parameters that might be used in a regulatory analysis. This assessment began with establishing a baseline case and then varying specific inputs to determine the impact on the predicted evacuation time, leaving all other variables fixed as discussed above.

Baseline Analysis

The baseline case used the two B757 configurations discussed previously. The aircraft was populated with a full passenger load as specified in the FAA regulation and the right exit of each exit pair was inactivated for the evacuation. The active exit of each pair was assigned a 10 second opening time and an aggressive flight attendant such that the default door delays were utilized for both exit types. The evacuation simulation for each configuration was run five times with the same population randomly reseated for each trial. This produced a set of five evacuation times for each condition. This is sufficient to demonstrate the sensitivity of the model to input changes for this study and is a compromise between total simulation time for the model and greater statistical accuracy for the range of passenger egress times. Thus, the sensitivity of the model will be assessed based on the average values for the five trials for each configuration. The time (in seconds) for the first and last passenger to exit the aircraft for each trial as well as the average evacuation time (last passenger out) for the group of five trials are reported in the tables below:

Table 2 - Baseline Evacuation Simulation: B757-3 with Three Type I and Two Type III Exit Pairs

Run File Name	First Passenger Out	Last Passenger Out	Avg Evacuation Time
B757AA	10.59	92.62	86
B757AB	10.16	77.68	
B757AC	10.29	85.65	
B757AD	10.17	86.22	
B757AE	10.40	86.64	

Table 3 - Baseline Evacuation Simulation: B757-4 with Four Type I Exit Pairs

Run File Name	First Passenger Out	Last Passenger Out	Avg Evacuation Time
B757AF	10.62	65.73	65
B757AG	10.48	65.06	
B757AH	10.18	60.88	
B757AI	10.65	66.90	
B757AJ	10.41	67.69	

The average predicted evacuation time for both aircraft is within the 90 s limit for evacuation as required by the FAA, with a range approximately Å10 %. The different exit types on the two aircraft have a significant effect on the predicted evacuation time, with the evacuation time predicted for the B757-4 approximately 30 % faster than that predicted for the B757-3.

Effect of Door Opening Times

The effect of varying several input variables was then determined for one of the aircraft configurations. The first was changing the door opening times for all active exits from 10 s to zero. In Table 4 it can be seen that it takes from 3.57 to 5.75 s (avg 4.79 s) for the first passenger to reach an exit, so the exiting delay resulting from a 10 second opening time is about 5 s. The average evacuation time decreased by 4.79 s, which is consistent.

Table 4 - Effect of Setting Door Opening Times to Zero on B757-4 Configuration with Four Type I Exit Pairs

Run File Name	First Passenger Out	Last Passenger Out	Avg Evacuation Time
B757AK	4.38	61.64	61 (-6 %)
B757AL	5.62	57.42	
B757AM	4.61	56.27	
B757AN	3.57	65.02	
B757AO	5.75	66.64	

Effect of Exit Door Choice

The FAA evacuation certification test procedure requires that only half of the available exits are used but does not specify which. The typical practice is for one of each pair of exits to be used. In the next set of runs the effect of using a different group of exits was examined. From examination of the baseline runs it was observed that the most passengers exit through the aft exits and the fewest through the forward exits. Thus the "worst case" would be to close the aft two pairs. The results of these runs for the configuration with four type I exit pairs is shown in Table 5. This shows a dramatic increase of 132 % in the evacuation time needed when only the forward two pairs of exits are used.

Table 5 - Effect of Evacuation Through the Forward Two Type I Pairs (Aft Two Type I Pairs Disabled) on B757-4, Four Type I Exit Pair Configuration

Run File Name	First Passenger Out	Last Passenger Out	Avg Evacuation Time
B757AP	10.36	153.50	152 (132 %)
B757AQ	10.75	156.65	
B757AR	10.85	149.68	
B757AS	10.64	146.05	
B757AT	10.45	151.77	

Effect of Exit Door Egress Delay

The next variable examined was door delays. In the baseline cases exit delays for the Type III overwing window exits are in the range of 0.3 to 2.3 s, randomly assigned to each passenger using that exit. In this case the door delay was fixed at 2.3 s for every passenger using that exit. Door delays for the Type I exits on this aircraft were not changed. As shown in Table 6 this resulted in a 57 % increase in the evacuation time.

Table 6 - Effect of Fixing Window Exit Door Delays at 2.3 s for the 757-3, Three Type I and Two Type III Exit Pair Configuration

Run File Name	First Passenger Out	Last Passenger Out	Avg Evacuation Time
B757AU	10.81	138.55	135 (57 %)
B757AV	10.34	117.72	
B757AW	10.39	147.55	
B757AX	10.22	131.22	
B757AY	10.27	138.22	

Effect of Age Distribution

The final variable examined was the age distribution of the passengers. Here, the percentage of male and female passengers in the age group 50-60 was increased to 30 % each, and the percentage of male and female passengers 18-50 was set to 20 % each. This has the effect of increasing travel time since the walking speed of older passengers is slower. This resulted in a 12 % increase in total evacuation time.

Table 8 - Effect of Older Passenger Distribution for the 757-4, Four Type I Exit Pair Configuration

Run File Name	First Passenger Out	Last Passenger Out	Avg Evacuation Time
B757BE	10.30	74.23	73 (12 %)
B757BF	10.49	69.10	
B757BG	10.33	77.32	
B757BH	10.28	75.34	
B757BI	10.56	69.01	

Discussion of Results

Changes in many of the inputs included in airEXODUS would be obvious for a specific aircraft design. For example dimensions of the aircraft, configurations and size of seats, exit types, and passenger characteristics are based on observable parameters and were fixed based on data for the actual situation being simulated. Significant changes outside the range of observable values would be obvious attempts to influence results.

Other input parameters such as door opening times, egress delays, or exit potentials, are more likely to be estimates for which appropriate values should be agreed, but should be based on well defined criteria. For example, exit potentials will depend on the nature of the scenario and the geometry of the aircraft. Where regulatory purposes are best served by restricting variables to a single value, that value can be "hard coded" into a regulatory version of the model. Where allowance for variation is needed, appropriate values or ranges of values can be agreed. This would limit opportunity for inappropriate influences on the results.

Part of the purpose of this study was to identify those variables which can have the greatest impact on the predicted egress times and thus those variables which should be carefully controlled to insure reliable estimates of egress times. The variables studied and a summary of their potential impacts on reducing predicted evacuation times when applied to the FAA certification analysis are summarized in Table 9. The first entry in the table, seating assignments, provides an indication of the uncertainty in the calculation, with several random seating assignments of the same passenger population providing about a 10 % variation in predicted evacuation times. Other variables studied had a greater impact on evacuation time, ranging from 12 to 132 %.

Table 9. Effect of Model Inputs on Predicted Evacuation Times

Representative model variable(s)	Actual Characteristic	Impact on reducing predicted evacuation times
Passenger Population Variables		
Seating assignments	Passenger location	Randomizing several different seating assignments provides a range of passenger egress times approximately ±10 % of evacuation time.
Number, sex, age, weight; response delay, agility, drive; walk, fast walk, leap rates, up & down stairs rate	Number, sex, age, physiological & psychological characteristics	Faster movement rates have the most impact; reducing response delay or increasing drive is much less. Impact was approximately +12 % in simulations.
Geometry and Configuration Variables		
Opening times, door delays, off times, exit availability	Number, type, location of exits and their availability	Shorter door delays have the greatest impact because they are cumulative. Impact was as large as +57 % in simulations.
Door delays, exit potentials	Crew stationed at exits	Inappropriate exit potentials would increase evacuation times or result in an unused exit. Impact was as large as +132 % in simulations.

The science and data cited in the development of airEXODUS are consistent with other emergency egress models, including model design as a node and arc model, movement speeds, behavior and reaction to cues. Other aspects of the software such as the conflict resolution rules are unique.

References

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