THE EVALUATION OF THE 90 SECOND CERTIFICATION TEST AND THE ANALYSIS OF HUMAN BEHAVIOUR WITHIN AIRCRAFT EVACUATION MODELLING

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DECLARATION

I certify that this work has not been accepted in substance for any degree, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy (PhD) being studied at the University of Greenwich. I also declare that this work is the result of my own investigations except where otherwise identified by references and that I have not plagiarised the work of others.

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ABSTRACT

The majority of fatalities during an aircraft accident occur after impact with approximately 95% due to burns and smoke inhalation due to sub optimal evacuations. If post-crash survivors can be evacuated quickly enough then the survival rate could be improved. This thesis will examine the influence of exit availability on the evacuation of narrow bodied aircraft during 90 second certification trials; carried out by aircraft manufacturers. These trials are carried out using one exit from each exit pair usually along one side of the aircraft. Analysis in the thesis will look at the effects of still using 50% of the exits but while using a different combination of available exits which may be closer to real accident scenarios. The analysis will make use of the airExodus evacuation model and will use the geometry of a narrow bodied aircraft cabin of a Boeing 737-300 containing two Type C exits, two Type B exits, and two Type III exits with a maximum loading of 149 passengers. A decreasing order of likelihood of exit availability found during real emergency evacuations according to the Aircraft Accident Statistics and Knowledge Database (AASK) V4.0 holds information from 105 survivable aircraft accidents with over 2000 survivors was used as a basis for choosing the exit zones used during this analysis. Similar analysis was also carried out on a wide bodied aircraft using the geometry of a Boeing 777-200 series aircraft with a loading of 440 passengers and 8 Type A exits.

This thesis also presents results from a questionnaire study of participant exit awareness and suggested exit selection during the event of an emergency aircraft evacuation involving a narrow bodied aircraft. The questionnaire study involved 459 participants with a number of levels of flight experience. The results of the study has supported the hypothesis that passengers have a poor understanding of where exits are located together with their relative size and flow rate and may be the contributing factor to poor exit decisions made by passengers during emergency aircraft evacuations. These results, have implications for the airlines while providing a better insight for evacuation model developers with regards to the decision making process carried out by agents in their exit selection.

Finally this thesis concludes by demonstrating the validation of data gathered and analysed from participants involved in the questionnaires and implemented into the airExodus evacuation model and by evaluating the current certification process in proving the safety of the aircraft which undergo this test.

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1 INTRODUCTION

1.1 RESEARCH MOTIVATION

According to the Boeing Current Market Outlook from 2013 to 2032, pax (passenger) aircraft traffic in 2012 rose by 5.3 % from 2011 levels. This is expected to continue over the next 20 years with pax traffic increasing around the world by 5% on a yearly basis despite uncertainties [108]. Boeing also predict that approximately 70% of the new planes delivered will be single-aisle aircraft, reflecting growth in emerging markets and the expansion budget carriers around the world. As key market forces such as fuel costs or the attractiveness of other means of transport impact the airline industry, Boeing reports that capacity strategy is now being used to maximise profits. Pax loads are at an all-time high in 2012 with 79.1 % while back in 2002 the capacity stood at just over 71% [108]. Passengers will be referred to throughout this thesis as either a pax (passenger) or paxs (passengers).

The National Transportation Safety Board (NTSB) found that the majority (78%) of fatalities during an aircraft accident occurred after the impact [107]. Approximately 95% were due to burns and smoke inhalation because of sub optimal evacuations. This report also claimed that if post-crash survivors can be evacuated quickly enough then the survival rate could be improved by approximately 98%.

The ICAO (International Civil Aviation Organisation) stipulates that an aircraft must be facilitated with enough exits to allow the cabin to be evacuated within 90s [109] known as the 90 second rule. As well as this, each new aircraft type must be evacuated using certain certification criteria as set out by the FAA (Federal Aviation Authority) [106] before being put into domestic use. The criteria included a full scale evacuation of the aircraft including paxs and crew under emergency conditions, demonstrating that the last person will be on the ground within 90s. This test requires 50% of the exits on board to be made available to the evacuees and these are often on one side of the aircraft [106]. For valid certification testing for each new aircraft type, a good cross section of the population will be used between the ages of 18-60 years of age [109]. These tests are extremely expensive to carry out and there is also a potential and serious risk to the safety of the paxs involved [15]. A number of safety standards enforced by aircraft have evolved over time. In Europe there is

JAR (Joint Aviation Regulations) [112,113] while in the United States of America, their rules are known as FAR (Federal Aviation Regulations) [1, 106].

Another rule that exists in terms of aircraft design and construction within FAR [115] is the “60 foot rule”. This rule states that no emergency exit can be further away from another emergency exit by more than 60 feet. This rule only applies to exits on the same side of the aircraft fuselage and measured parallel to the aircraft’s longitudinal axis. Work carried out by Blake et al. in 2002 [14, 54], examined the influence of exit separation size and found that the distance between the exits could be increased dramatically while recreating certification conditions in an aircraft with a maximum load of 220 paxs.

Due to the problems that exist in carrying out these live and dangerous evacuation trials on aircraft, it has led the way to the development of computer models which can be used to provide a prior insight into how the paxs and crew might behave during a live evacuation trial. These models are not only restricted to simulating certification trials but can also be used in accident reconstruction [87]. The aircraft model airExodus was used to reconstruct the British Airtours flight on a B-737 at Manchester Airport in 1985 where the flight was aborted and the plane was engulfed with fire causing 57 fatalities [103]. One of the first models to be developed was that of GPSS (General Purpose Simulation System) and funded by CAMI (Civil Aero-Medical Institute) in the 1970’s [30, 31]. A number of new aircraft evacuation models have been developed over the last 40 years with some standing the test of time and will be discussed in Chapter 2.

Many attempts have been made to simulate evacuation, irrespective of whether it involves transport or buildings and usually falls into 2 separate categories; those which only consider human movement and those models which combine human movement with human behaviour [110]. The airExodus evacuation model is one of the most widely used models to date and is additionally able to consider the impact of a post-crash fire within its simulations [100, 101]. New rule based and behavioural features have been introduced into some new aircraft models where paxs also make their own decisions during the evacuation and has been referred to as the agent-based approach [111].

1.2 THE MAIN SET OF RESEARCH QUESTIONS, HYPOTHESIS AND CRITERIA FOR SUCCESS

This thesis will examine the use of evacuation modelling as a technology that is suitable for carrying out valid simulations of 90s certification tests and what it is that is still missing from the airExodus evacuation model. It will firstly examine the robustness and the reliability of the 90s certification test on both narrow bodied and wide bodied aircraft. The first question that this research asks is:

(1) Is the current 90 s certification test a suitable and challenging benchmark for the safety of passengers travelling on aircraft?

The hypothesis is that the current 90s certification test is not a suitable benchmark for the safety of paxs as the current configuration of using half of the available exits usually down one side of the aircraft is not statistically relevant or robust enough as only one data point is being gathered [104]. The 90s certification test may not be fit for purpose and it is suggested that a combination of more realistic and challenging exit combinations be included as part of the overall test to ensure improved pax safety. These additional tests could be carried out by using computer simulations. The criteria for success in proving this hypothesis is by demonstrating that while still using 50% of exits on board of the aircraft as used during a certification process, a more relevant combination of available exits location will be tested and simulated, based on analysis carried out on past aircraft accidents. It is assumed that the on ground times may increase and the aircraft may not pass the 90s certification test.

This first question will be composed of a number of sub–questions which should assist in giving an overall answer. The sub-questions for question one, are as follows:

*(**1a**) What range of on ground times can simulations of a narrow bodied aircraft give when using a certification type scenario and making 50% of exits available **FR** (Forward Right)**, ROW** (Right Over Wing)**, AR** (Aft Right) to passengers on one side of the aircraft?*

*(**1b**) Will the following available exit combination on a narrow bodied aircraft (**A single forward exit, both over-wing exits and no exits in the aft section**) give better or worse results than simulation results of (**1a**)?*

*(**1c**) If **both forward exits, a single over-wing exit and no exits in the aft section** are used, will it give better or worse results than simulation results of (**1a**)?*

*(**1d**) If **both forward exits, no exits over-wing and a single exit in the aft section** are used, will it give better or worse results than simulation results of (**1a**)?*

(**1e**) If **a *single forward exit, no over-wing exits and both aft exits*** *are used, will it give better or worse results than simulation results of (**1a**)?*

(**1f**) *If **no forward exit, a single over-wing exit and both aft exits available** are used, will it give better or worse results than simulation results of (**1a**)?*

*(**1g**) Will the simulation results of (**1a**) produce the most efficient results than the more relevant combination of available exit locations described in (**1b – 1f**) based on analysis carried out on past aircraft accidents?*

*(**1h**) Where will the simulation results of (**1a**) rank in terms of evacuation efficiency when compared to the results of the more relevant combination of available exit locations described in (**1b – 1f**)?*

*(**1i**) Will any of the simulation results of the more relevant combination of available exit locations described in (**1b – 1f**) satisfy the 90 s certification criteria?*

The same form of testing as for narrow bodied aircraft will also be carried out on a wide bodied aircraft with the results presented and answered in a similar way during Chapter 5.

Analysis of the AASK database [2] has shown that 85% of paxs used their nearest exit while evacuating during aircraft emergencies with the rest of those questioned giving valid reasons as to why they did not (i.e. exit was blocked). Our second research question then arises which is:

(2) ***How do passengers evaluate the best path or route for evacuation on board a narrow bodied single aisle aircraft used for domestic flights***?

The hypothesis is that most paxs are unaware of the size, location and flow rates of exits on board an aircraft. This in turn can greatly reduce the effectiveness of the overall evacuation of the aircraft and cause unnecessary injury, incapacitation or even fatality to paxs.

The thesis will analyse data which has been gathered by way of questionnaire to answer this second research question before implementing the findings of the data analysis into the airExodus evacuation model by way of a path evaluation algorithm. If the hypothesis is correct, this new pax data gathered should demonstrate that the majority of paxs have a very poor understanding of the location and sizes of the exits on board. This new data will need to be validated against measured certification trial data [105] and simulations of base cases such as the 100% and 85% nearest exit scenarios as well as the Optimal Scenario which is most similar to the 90 s certification test scenario. In studies carried out using the AASK database [2, 3], the analysis showed that 85% of paxs questioned made use of their nearest exit with the others giving valid reasons as to why not. The criteria for success in proving that this hypothesis is true is by attaining similar mean evacuation results from the new path evaluation models where paxs are making their own individual decisions compared to evacuation simulations where 85% of the paxs use their nearest exit.

This second question will be composed of a number of sub-questions which should assist in giving an overall answer. The sub-questions for question two are as follows:

(2a) *What percentage of passengers can correctly identify 3 pairs of exits on a narrow bodied domestic aircraft? How does this compare for the subgroups of "****paxs who have flown in the past 12 months"*** *and "****those who have not"****? How does this compare for* ***"frequent fliers"*** *subgroup (passengers who have* flown five or more return trips in the past three years*) and the* ***"infrequent fliers"*** *subgroup?*

*(**2b**) What percentage of passengers know that the exits on a narrow bodied domestic aircraft are not all the same size? How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**2c**) What percentage of passengers can identify the number, the location and relative size of the exits on a narrow bodied domestic aircraft? How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**2d**) What percentage of passengers can correctly identify the difference in flow rates between the larger exit and the smaller emergency over wing exit? How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**2e**) If during an emergency situation the passenger was alone on the aircraft and situated in the aisle at an equal distance between the large FR (Forward Right) exit and the smaller ROW (Right Over Wing) exit which of these two exits would the passenger choose? How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**2f**) If during an emergency situation the passenger was not alone on the aircraft and situated in the aisle at an equal distance between the large FR exit and the smaller ROW exit which of these two exits would the passenger choose? This time there is a queue of passengers waiting at both exits. How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**2g**) If during an emergency situation the passenger was alone on the aircraft and situated in the aisle at an equal distance between the large AR exit and the smaller ROW exit which of these two exits would the passenger choose? How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**2h**) If during an emergency situation the passenger was not alone on the aircraft and situated in the aisle at an equal distance between the large AR exit and the smaller ROW exit which of these two exits would the passenger choose? This time there is a queue of passengers waiting at both exits. How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**2i**) How can the results of the findings be evaluated?*

Sub-question ***(2i)*** will require a path evaluation algorithm to be developed which uses the data gathered from the research questions indicated above. This path evaluation algorithm will assist the individual pax involved in the unfolding aircraft evacuation to estimate the best available exit to choose in order to minimise the amount of time required for them to exit the aircraft.

*(**2j**) Do the results of the model developed with the use of the data gathered match up to what is happening during emergency evacuations reported in the AASK database that 85% of passengers use their nearest exit.*

Sub-question ***(2j)*** can only be answered by running simulations for each model developed and comparing against a scenario where 85% of paxs make use of their nearest exit as stored in the AASK database.

The third research question evolves from the work carried out to answer the second research question and asks:

> **(3)** ***If passengers on board a narrow, bodied, single, aisle aircraft were provided with detailed and full information about the location, size and flow rates of the exits on board, would this improve the evacuation time of the aircraft and hence save lives?***

The hypothesis is that if paxs are better informed about the location, sizes and flow rates of the exits, then this should decrease the overall evacuation time of the aircraft and hence save lives. To test this hypothesis, an assumed hypothetical model was constructed where paxs were given full knowledge of the exit location, size and flow rate. The criteria for success in proving this hypothesis will be achieving on ground time results which are lower if the paxs are provided with full knowledge of the location, size and flow rate of the exit compared with a model constructed to direct or attract 85% of the paxs to use their nearest exit. Analysis of the AASK database [2] indicates that 85% of paxs questioned, use their nearest exit during aircraft accidents. If this hypothesis is correct then we may be able to assume that providing paxs with full knowledge regarding the exits will improve aircraft safety. To answer the third question, the following sub questions will need to be considered:

*(**3a**) If the passenger is alone on the aircraft and situated in the aisle at an equal distance between the FR exit and the ROW exit which of these two exits exit would the passenger choose if provided with differences in **EXIT SIZES**? How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**3b**) If the passenger is not alone on the aircraft and situated in the aisle at an equal distance between the FR exit and the ROW exit which of these two exits exit would the passenger choose if provided with the differences in **EXIT SIZES**? This time there is a queue of passengers waiting at both exits. How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**3c**) If passengers are provided with the information about the differences in **EXIT SIZES**, what is it that will now influence their decision on exit choice?*

*(**3d**) If the passenger is alone on the aircraft and situated in the aisle at an equal distance between the FR exit and the ROW exit which of these two exits would the passenger choose if provided with differences in **FLOW RATES**? How does this compare for the sub-groups previously mentioned in (**2a**)??*

*(**3e**) If the passenger is not alone on the aircraft and situated in the aisle at an equal distance between the FR exit and the ROW exit which of these two exits would the passenger choose if provided with the differences in **FLOW RATES**? This time there is a queue of passengers waiting at both exits. How does this compare for the sub-groups previously mentioned in (**2a**)?*

*(**3f**) If passengers are provided with the information about the approximate exit **FLOW RATES**, what is it that now influences their decision on exit choice?*

*(**3g**) How can we evaluate the results of our findings?*

Question ***(3g)*** will require a path evaluation algorithm to be developed which uses the data gathered from the research questions indicated above.

*(**3h**) Do the results of the model developed demonstrate that by providing passengers with better information regarding **EXITS SIZES** and **FLOW RATES** that the efficiency of the aircraft evacuation will be improved.*

*(**3i**) Will this improve the safety of passengers travelling on narrow bodied aircraft and hence save lives?*

Question ***(3h*** and ***3i)*** can only be answered by running simulations for each model developed and improving the knowledge of the passengers on board to ascertain if it has a positive effect on the evacuation results.

1.3 A BRIEF OVERVIEW OF CHAPTERS

Chapter 2 will discuss the human behaviour of paxs during aircraft evacuation and the differences in the human behaviour displayed between real accidents and certification trials. Conditions during an aircraft evacuation appear to determine the behaviour of the evacuees. As a situation changes, the behaviour of paxs and crew may alter in reaction to the developing situation. Chapter 2 will also give a review of the AASK database and a discussion of analysis carried out using the database. This analysis has provided a valuable insight into pax behaviour during real accidents challenging some of the '**myths**' which exist in the aviation safety industry such as, pax exit selection during evacuation, the nature and frequency of seat jumping, the speed of pax response and group dynamics to name but a few.

Chapter 3 will give an overview of aircraft evacuation models that have been developed to date. It will look at how the models represent human behaviour during aircraft evacuation and whether these models can accurately and adequately simulate both 90 s certification trials and real aircraft accidents. The chapter will also go on to discuss the current deficiencies and missing data which exists in aircraft evacuation models to date and why aircraft manufacturers should not rely solely on computer simulation for their 90 s certification tests.

Chapter 4 will assess the capability of the airExodus model to simulate 90 s certification tests and real accidents scenarios. It will discuss the current limitations of the model and the arbitrariness of the current pax decision making model which allows paxs to make individual decisions as the evacuation simulation unfolds. This chapter will finally discuss the improvements that need to be made within the airExodus model.

Chapter 5 examines the influence of exit availability on the evacuation time for both a narrow bodied and wide bodied aircraft under certification trial conditions using computer simulation. The aircraft certification trial (see FAR 25.803 [1]) is the aviation industry benchmark of evacuation performance and is considered by the travelling public and safety professionals as the ultimate mark of aircraft evacuation safety. This benchmark however should serve as an indicator of safety and should be as representative of reality and as challenging as possible. It is during this chapter that the first hypothesis that the current 90 s certification test is not a suitable or challenging enough benchmark for the safety of paxs on aircraft will be investigated.

Both a narrow and wide body aircraft which have previously passed certification trials are used as the test configurations within this thesis. Whilst maintaining the certification requirements of 50% of the available exits, a total of twelve different exit configurations are examined (six for each aircraft configuration). Each aircraft configuration will include the standard certification configuration (one exit from each exit pair) and five other exit configurations based on commonly occurring exit combinations found in accidents. These configurations are based on data which has been derived from the AASK database.

Chapter 6 will investigate the problem of pax exit selection and how this is done within the airExodus model. The chapter will also discuss the model weakness in relation to how exits are currently selected by paxs and a solution will be given on how the problem will be addressed.

During aircraft accidents stored in the AASK database, involving narrow body pax aircraft, a large number of paxs tend to select the centre over wing exit for evacuation even when other viable exits area available. This is quite a phenomenon considering the middle exit is in fact the smallest pax exit (otherwise known as a Type–III window or emergency exit) on board the aircraft and requires a larger amount of time to traverse through than the forward or rear exits otherwise known as Type I/C exits. The Type-III exit requires the pax to essentially climb through while the Type I/C exit allows the pax to simply walk through. Surprisingly during controlled evacuations such as the certification trial, paxs' use of the over wing exit is considerably smaller than found in real accidents and its use is almost optimal. This close to optimal certification evacuation is thought to be achieved due to the intervention of cabin crew redirecting paxs to larger and more efficient forward and rear exits.

Chapter 7 will firstly discuss how the proposed questionnaire was developed to investigate the second hypothesis which stated that the many paxs are unaware of the size, location and hence flow rates of exits on board an aircraft (narrow bodied with single aisle). This chapter will discuss why and how the questions were designed and their relevance to the way in which passengers select exits during an evacuation. It will also look at the participant groups questioned followed by the inclusion of the complete copy of questionnaire together with description of any necessary ethic's requirements.

The questionnaire developed in this chapter is aimed at attempting to understand the type of behaviour where paxs overuse the over wing exit when other larger and faster exits are available. In addition, in aircraft evacuation models, a number of key assumptions are made concerning the thought processes of paxs as they select an exit to use during an emergency. This research will provide some insight into the knowledge paxs have of exit capabilities and better inform the development of realistic computer egress models.

Chapter 8 presents the results from a questionnaire study of participant awareness and exit selection in the event of emergency evacuations involving narrow body aircraft. The study involved 459 participants with a variety of flying experience. Results of this study support the hypothesis that paxs have poor understanding of aircraft exit location and configuration may be a contributory factor in the resulting poor exit selection decisions made by paxs in emergency situations. These results have important safety implications for airlines and also provide insight to evacuation model developers regarding the decision making process in agent's selection. A comparison will also be made of behaviours and parameters from the questionnaire results with those already being used in the airExodus model.

Chapter 9 will discuss the development and validation of the airExodus path evaluation model and its variations which will use the geometry of a narrow bodied aircraft. Paxs in this model will make individual decisions rather than being told where to go by members of the crew or by using the airExodus potential map functionality. During the development process and discussion, a set of base cases will be reconstructed first and used for comparison, namely the 100% and 85% nearest exit scenarios. A further base case also used for comparison was the Optimal Exit Scenario. During development work required to validate the participant data gathered from the questionnaires, and to implement a form of pax decision making into the airExodus model, a total of 22 separate models (11 in Phase 1 and 11 in Phase 2) were developed. Phase 2 of the path evaluation model included some of the paxs still located ahead in the seat rows into the algorithm while the Phase 1 model did not. There was a higher level of complexity in the pax behaviour in models during Phase 2 development than in Phase 1.

In Chapter 10, the aim is to validate the models which have been implemented using the data gathered and analysed from questionnaire results discussed in Chapter 8. Two separate phases (Phase 1 and 2) of the airExodus Model were developed. This chapter will analyse the results of each model developed and its simulation outputs to see if there are similarities which may exist between these models and the base cases being tested against. These newly developed models need to be properly validated before achieving any confidence and hence the greater use of computer simulation in aircraft accident reconstruction.

Chapter 11 will discuss the conclusions of the main questions and sub-questions together with the hypotheses and compared against the criteria for success. This chapter will also discuss any shortcomings of the research and further work that will lead on from this research.

1.4 CONCLUDING REMARKS

The work carried out during this research aims to improve pax safety by improving the knowledge of how paxs will behave when faced with an aircraft emergency. It aims to gather data previously unknown about a pax's aircraft configuration knowledge and to use this data within the airExodus evacuation model. This research aims to improve the model in such a way as to bring the model closer to the agent based approach where paxs are making individual behavioural decisions taking real dynamic data into account. This should bring the model closer to being able to replicate pax behaviour within a real emergency where paxs may need to make their own decisions if the crew were to become incapacitated.

This research also aims to prove that paxs need to be provided with more information about the aircraft configuration around them to improve their overall safety in the event of an emergency evacuation.

2 A STUDY OF HUMAN BEHAVIOUR DURING AIRCRAFT EVACUATION

2.1 INTRODUCTION

This chapter will look at human behaviour during aircraft evacuation. It is important to note the differences in human behaviour displayed during real accidents and measured certification trials. Conditions during an aircraft evacuation appear to determine the behaviour of the evacuees. As a situation changes, the behaviour of passengers and crew alters in reaction to the developing situation. Is it possible to completely replicate the behaviour of an evacuee during an evacuation or is this far too complex? At present, aircraft models are still somewhat simplistic and mechanistic mostly considering the mechanisms related with movement. All proper and valid decision making has mostly been ignored. One model (airExodus) has on the other hand been developed which considers passenger exit choice and crew initiated bypass [14]. This model was also developed further to include the introduction of passenger route optimisation which was mostly concerned with aisle swapping and seat climbing [14]. Other new aircraft models [111, 116] are starting to follow suit. One of these models AAMAS [111,116, 117, and 118] considers passengers emotions as part of the evacuation simulation. With the development of artificial intelligence, passengers are designed in a way to behave more realistically taking their surrounding environment into conservation while also being able to represent decisions making as part of the process of aircraft evacuation [119-122].

During this chapter, there will be a review of the AASK V4.0 [4, 5 and 7] database followed by a discussion about the data differences between certification trials and real accidents. An evaluation will also be given as to data that is currently used in evacuation models and a discussion about data from 90 seconds trial and accident reports.

2.2 A REVIEW OF AASK V4.0 DATABASE

The Aircraft Accident Statistics and Knowledge (AASK) database started development in 1997 until the present with support from the UK Engineering and Physical Sciences Research Council (EPSRC) and the UK Civil Aviation Authority (CAA).

It is a unique deposit of data relating to the survivor accounts from aviation accidents conducted by investigative organisations such as the National Transportation Safety Board

(NTSB) and the Air accident and Investigation Branch (AAIB). Its main purpose is for the storage of observational and anecdotal data from actual occupant interviews. The most recent version of the database is AASK V4.0 which contains accounts from more than 2000 survivors of aviation accidents. The database consists of four main areas; the nature of the accident (105 accidents), accounts from surviving passengers (1917 passengers), accounts from surviving cabin crew (155 cabin crew) and finally information relating to fatalities (338 fatalities). Therefore the database itself holds information relating to 105 accidents, 1917 passengers, 155 crew members and 338 fatalities. The accidents stored in the AASK V4.0 cover the period between 04/04/1977 and 23/09/1999.

With the development of computer based models comes the need for a comprehensive data collection or generation relating to human performance under evacuation conditions. Any form of factual data regarding the evacuation process will become highly valuable and essential to aid the development of computer egress models. A reliable model will require or have a high reliance upon factual data in order to carry out extensive validation.

The AASK database is also being used to challenge some of the 'MYTHS' which exist in the aviation safety industry such as, passenger exit selection during evacuation, the nature and frequency of seat jumping, the speed of passenger response and group dynamics to name but a few. Much analysis and data extraction has been possible since the construction of this database [2-5], assisting in numerous publications.

There are several other aircraft accident databases available for browsing, for example Cherry [10] and Ranter [11]. These databases exclusively store information regarding the time, date and whereabouts of the aircraft accident. While such database types are valuable in themselves for obtaining the general accident trends, they are not concerned with important issues relating to occupant behaviour during evacuation. AASK has been specifically developed to address the needs and has the possibility of overcoming many of the unknown questions with the analysis of human factors data relating to aviation accidents [2].

Before the AASK database was implemented, a feasibility study was carried out which involved a highly detailed study of a small number of accidents which were detailed in terms of the human factors data available. It was important to determine whether a common set of behaviours existed in the passenger and crew accounts. If sets of data could be found, data could be saved in relational database form, increasing any potential of a proper in-depth analysis. Such a system could even go so far as assisting during the interview process of aviation accident survivors.

The initial analysis of the reports concerned with the feasibility study, indicated that some form of trends did exist. This suggested that the AASK database concept would be a feasible one. Looking for common trends was a time consuming process, but ensured that a range of observations and behaviours were indeed encapsulated. At the AASK development outset, an iterative cycle was followed. Every new observation or behavioural type not found in a previous account was added to the database. The initial design soon became extremely complex and it became necessary to split it into four main components namely; the **Accident**, **Flight Attendant**, **Fatality** and finally **Passenger** [3].

The Accident component stores information which relates to physical details about the accident such as the flight details, the accident details and the report details. The Flight Attendant component stores data relating to observations, actions and performances of the flight attendant such as person, performance and egress details. The Fatalities component, the smallest component in the database stores information relating to any fatalities such as physical attributes of the victim, egress details and toxicological data. Finally the Passenger component the largest component in the database, stores passenger account details such as physical details of the passenger followed by starting conditions, reaction to the alarm, egress details, egress conditions and exiting details [3].

The AASK database can be used for a wide variety of purposes; in fact its uses are far greater than originally envisaged by its developers. Many important aircraft analyses [2-7] have been performed using AASK which have led to further work which can be seen in the latter Section 5, which is a study of exit availability during aircraft accidents and its application using a B737-300 aircraft evacuation model.

2.2.1 Analysis Carried Out on the AASK Database

A large amount of analysis was carried out on the version V3.0 of the AASK database and the results were presented to the CAA [83]. Further results of analysis including some behaviour of both passengers and crew were later published [82, 84]. Some of the analysis carried out on the data included family and other group analysis, travelling companions [5], the gender of passenger and its relation to seat belt difficulty, the comparison of the survivors and fatality cabin positions, the levels and efficiency of cabin crew, their staffing levels, direction and distance travelled, exit availability and the problems encountered with malfunctioning slides and exits. Further analysis was undertaken with the enlarged data set and the new functionality of AASK V4.0 with 42 accidents involving intact aircraft, not in water and which had either 3 or 4 exit zones [5, 86]. The results suggested that 33.3% had less than half of the exits available to evacuating passengers and only 7% of accidents had exits available on one side of the aircraft only which is the exit scenario often used during certification trials for the 90s benchmark test.

It was found that number of passengers travelling in a group was found to represent a significant number [5]. Just under half of the passengers were found to be travelling alone. The nature and composition of the groups was investigated during the analysis. These groups gave rise to further investigation into the assistance that may have been administered by passengers to each other (parents helping children and spouses helping each other) within the groups. Of those travelling with a companion or in a group, Galea reports that 16% reported having to provide some form of assistance [5]. Of those that report having to give assistance, it was found that 62% were male presenting them in the role of the protector or carer. The analysis also found that while females were dominant in giving assistance to the infants, children and other family members, males are more likely to assist spouse.

During the Beverley Hills Supper Club fire, Johnson et al found that collective behaviour existed with families staying together as a unit and evacuating together [123]. Galea's AASK analysis [5] suggests that the family or companion bonds during aircraft evacuation may not be continued indefinitely due to some statements given by survivors. Galea also suggests that crew procedures developed from the analysis of certification trials where no social bonds exist may become irrelevant during a real emergency where social bonds do become relevant. During further analysis of AASK V4.0 Galea found that out of 16 families (made up of 2 parents and 2 children) that existed within the AASK data, 10 families evacuated together as a unit while 6 split into smaller sub groups and used different exits. Family groups are currently not included by regulators as part of the certification of an aircraft and yet they seem to play a significant role in aircraft evacuation behaviour.

The data from four aircraft was also used for the analysis and comparison of distance travelled for survivors and fatalities. There was sufficient data to proceed and the analysis found that on average, fatalities sit further away from available exits. An earlier study by Snow [85] showed similar findings.

The relationship between the number of cabin crew and evacuation efficiency was also analysed using the data from 87 accidents. There were 9 cases which lost some of its crew members. Crew were considered effective if they made a form of contribution to the overall passenger evacuation. The efficiency of the evacuation was related to distance travelled by passengers to an available exit. Many different relationships were analysed involving reduced cabin crew levels and its effect on the distance travelled by passengers [82, 83, and 84]. Galea [4-5] found that there was a strong correlation between the number of available cabin crew and the overall efficiency of the evacuation.

2.3 A DISCUSSION OF DATA DIFFERENCES BETWEEN CERTIFICATION TRIALS AND REAL ACCIDENTS

2.3.1 Certification Trial Data

From analysis of 90-second certification trial videos, it is possible to ascertain several different behavioural traits which are common to the certification trial. Passengers for instance would normally spend very small amounts of time unbuckling seat belts, there is very little occurrence of aisle swapping, seat jumping is extremely rare, passengers nearly always obey crew instructions, passengers hesitate at the exits before jumping onto the slide, etc. These behaviours may be very relevant to certification trials but totally irrelevant during a real aircraft accident. It is also possible to quantify many of the passenger attributes that are displayed during the 90- second trial such as the passenger exit hesitation times, the flow rates of passengers at the exits and in the aisles, passenger off times (time for a passenger to traverse a slide) and the time to open various types of exits [105]. The gathering of this type of data is extremely important and necessary if models are to reproduce the exact type of behaviour seen during the certification trial. It must also be noted that the certification trial is set up by regulators without consideration of companions or family bonds and participants will evacuate as singletons with little thought for others. During the certification trial, there will be no use of smoke or fire during the test for the obvious reasons while in a real accident, these factors may become all too prevalent as seen in the Manchester accident which involved a B737-236 aircraft where over fifty passengers perished [103].

Certification trial data is very difficult to obtain and is considered valuable, propriety and confidential information to an aircraft manufacturer that could in fact give an advantage to competitors. FSEG of the University of Greenwich on the other hand, with its sponsorship from the UK Civil Aviation Authority and through strict confidentiality agreements with all major manufacturers involved (i.e. Airbus Industries, British aerospace, Boeing Commercial Aeroplane and Douglas Aircraft Company Inc (McDonnell-Douglas (MDC) Corporation)), has access to most of the 90 second data footage which currently exists. FSEG has carried out analysis of this valuable information and the data extracted, forms a crucial and integral part of the airExodus model [12, 13]. This data while available to the regulatory authorities is not usually available to the developers of other aircraft models.

Some 30 evacuation trials of 24 aircraft have been analysed, covering a period between 1969 and 1996 which include commuter, single aisle, dual aisle and double deck aircraft. This represents the total evacuation of 68 Flight crew, 194 Cabin crew and 8865 passengers [14].

Data has been extracted concerning the behaviour of passengers and crew on different aircraft types whilst using various types of exits. From the data gathered, the following type of information was ascertained: Cabin Crew Response Times, Exit Opening times, Slide Inflation Times, Exit Ready Times, Passenger Off Times (amount of time required by passenger between the exit and the ground), Flow Rates, Optimal Performance Statistic (Efficiency Measures). This data has been presented in a tabular form for each individual aircraft certification trial investigated [12, 13] and provides a means to further validate aircraft models which have been designed to simulate 90 second certification trials.

The 90-second certification trial videos provide much of the data required for development and validation of aircraft models which are intended for the simulation of 90-second certification trials. However it must be noted that this data is by no means perfect and model developers have needed to contend with much missing data due to visibility problems on the trial videos. These videos were not necessarily recorded with the intention of aircraft model development and therefore were not carried out in the controlled experimental manner which would have been more useful and desirable to developers.

2.3.2 Real Accident Data

Real accident or emergency data is very different to the data of certification trials. During a real accident or emergency, passengers and crew are subjected to real psychological, physiological and physical threats that may engender competitive behaviour [25] and consequently endanger life. The modelling of real behaviour during an emergency situation is far more complex than modelling the behaviour during a certification trial. Collecting data which describes and quantifies human behaviour from a real accident is very difficult unlike a certification trial where cameras are positioned accordingly to record unfolding events. Muir [25] tried to motivate pax during a controlled evacuation experiment where a £5 pound reward was offered to the first 50% passengers to evacuate the aircraft. Muir reported similarities during this experiment with the competitive behaviour reported during real accidents. Wilson [124, 125] reports difficulties with Type III hatch placement during controlled experiments using smaller transport aircraft carried out in Cranfield University. Type III exit hatch placement is not something considered during the certification trial and yet a factor in the evacuation efficiency during a real accident as it may impede the exit of the passengers climbing through the Type III exit.

The 90-second trial is not a proper measure of evacuation performance during a real emergency [15] it is therefore necessary to identify potential sources of data which describe and quantify behaviour from real aircraft evacuations. A good source of information which concerns human behaviour during evacuation is provided though accident reports from organisations such as the NTSB from the USA and AAIB from the UK. These reports provide a large amount information relating to interviews with aircraft evacuation survivors; both passengers and crew. This important data is normally collected and documented on behalf of these organisations which aids in the investigation of the accident. However, these accident investigation reports do not provide a finite means by which to model reliable actual human behaviour during a range of evacuation emergency situations.

Whilst developing an evacuation model capable of simulating a real emergency, it is important to be aware of and establish the behaviour that requires modelling. An early study was carried out by Snow et al in 1970 which analysed four specific aircraft accidents. The study was used to highlight any common factors which influenced or corresponded with survival [16]. This paper concluded that aircraft configuration, procedures, environment and passenger behaviour were all necessary in the understanding of survival. This work was the first attempt made at building a measured understanding of the dynamics of real emergency evacuations on board an aircraft and it is an approach that is still widely used today.

A number of studies [2, 17] and databases [18] concerning aircraft have been developed or carried out but these have mostly concentrated on accident details rather than on the resulting passenger behaviour. There have been two detailed studies into human behaviour over a range of different accidents, one which is an on-going study by FSEG of the UK known as the AASK database [2-7] and the other by the NTSB of the USA which studies a range of recent accidents and precautionary evacuations [19].

2.4 AN EVALUATION OF HUMAN BEHAVIOUR DATA USED IN EVACUATION MODELS

Can the results of an evacuation model be trusted and verified? *Is the human behaviour that we are modelling accurate*? These are very important questions and to some extent answered during this chapter and subsequent chapters by examining the capabilities of airExodus to simulate both 90-second certification trials and real accidents. To satisfy these questions fully, it is therefore necessary for the model to be subjected to a succession of qualitative and quantitative tests. Confidence in results produced by any evacuation model can only be gained if there is an assurance that comprehensive evaluation has formally taken place.

A validation study was carried out by FSEG [20] of the 90 second certification trials of four previously certified wide-bodied and two previously certified narrow-bodied aircraft. This was the most comprehensive set of aircraft evacuation model validations to date. This evaluation assessed the performance of the airExodus model in two ways, firstly its accuracy at reproducing the results of 90-second trials which were being assessed. This could only be achieved by using the data which was derived from the actual trial. The accuracy of the model could be assessed by using the ‘best” information available. Following on from this, was the assessment of the capability of airExodus to predict the results of a 90-second trial by configuring the model with ‘generalised data’ (i.e. average data) which is based on performance levels from many aircraft evacuations.

Extensive validation of human behaviour in 90-second certification trials have been made through the study carried out [20]; however validation of human behaviour during a real accident scenario is much more difficult.

Further changes have been made to the airExodus model, incorporated a greater amount of human behaviour, relevant to real accident scenarios such as seat jumping, aisle swapping and decision making for both passenger exit choice and crew initiated passenger bypass. Validation of human behaviour during the real accident is much more difficult as no videos are available from which to gather data only anecdotal reports. Human behaviour during real accidents is very much dependant on psychological, physiological and physical threats that may engender competitive behaviour and consequently endanger life (see section 2.3.2). A test of this nature would be too dangerous for those involved.

Aircraft evacuation models currently work on the assumption that passengers have complete knowledge of the aircraft layout and functionality. Work carried out in Chapter 0 shows that this is not usually the case.

In aircraft accidents, 85% of passengers attempt to use their nearest exit during evacuation [2]. Using the nearest exit however is not necessarily the most efficient evacuation strategy, especially if there is a difference in exit flow rate capacity or exit performance between the available exits.

2.5 DATA CURRENTLY USED FOR EVACUATION MODELS

This section will briefly discuss data from both 90 second certification trials and accident reports and how they are used for modelling and validation of the evacuation models such as airExodus. Galea [81] has generally discussed the validation of aircraft evacuation models with applications to airExodus. The FAA is also very interested in the use of computer simulation to drive down the cost of testing and dependence on certification tests [127] and requested sensitivity testing of airExodus with reasonable changes.

2.5.1 Discussion of data from 90 second Trials

A certification test which involves "**live"** participants will always give a good insight into what will happen if there was a real, emergency evacuation. The total evacuation time of an actual 90s certification trial for a particular type of aircraft is not the only possible result that could exist however. The certification trial will only use one set of participants or population but with a change of participants, the on ground time of the aircraft could be very different. Computer simulation could be used as a compliment with numerous random simulations being carried out with a variety of populations being used giving a better overall picture of the performance limits.

When considering the test data taken from the video footage of a 90 s certification trial for the B737-300 which took place in 1984 [105] we are provided with a wealth of information regarding the breakdown of passenger and crew genders and age, the roles of the crew, the exits used, cabin crew and exit opening passenger response times, exit data which includes first out of door and when the slide becomes usable, exit opening and ready times, participant off-times and flow rates. Finally the overall evacuation efficiency measures are provided which calculates whether the doors are being used efficiently in the most optimal and balanced manner.

Although the data from this test is rich there are also some pieces that are missing and some issues which may cause the results to be better than if the same situation was happening in reality. For example, the age band of the participants is quite narrow with nearly three quarters of the plane being between the ages of 18-50. The remaining participants are above 51 years old but the report doesn't specify the upper age limit. There were no participants included below the age of 18 for possible legal reasons of safety. This is not representative of real accident data on stored in the AASK V4.0 database where the minimum age is less than 2 and the maximum age was 86, with a mean age of 40 [5]. Unfortunately, only 69% of the ages of the paxs were known in the AASK V4.0 database. There are a number of pieces of data missing relating to the exits especially relating to the over wing passenger operated exit. In reality, a passenger should use an over wing porch and off wing slide but during this trial, the participants are able to evacuate using an off-wing ramp. This may improve the results dramatically for this type of exit as much easier to evacuate via a ramp. The report also states that the over wing ROW exit hatch is considered as open when the opener hands the hatch to another participant or assistant on the wing. Could the assistant be improving the results of this test? Wilson and Muir [124 - 126] discuss the difficulties of hatch placement by passengers and how it can seriously impede the evacuation of passengers.

Although there are pieces of data missing in the report for the B737-300 aircraft [105], the data available has proved extremely useful in the development of aircraft evacuation models and has made possible to develop a model such as airExodus which can emulate a certification trial very closely. A challenging piece of validation was carried out on airExodus [78,79] when it was sponsored by the UK CAA to predict evacuation results using past aircraft certification data of both narrow and wide bodied aircraft. Six cases were tested using airExodus with all trial results being successfully recreated [20].

2.5.2 Discussion of data from Accident Reports and Experiments

In aircraft accidents, passengers are faced with real psychological and physical threats unlike what is experienced by participants during a certification trial. The behaviour becomes more competitive with the introduction of behaviour not seen in trials such as aisle swapping, seat jumping and passenger redirection [14].

Snow et al. undertook one of the first major investigations into aircraft accidents by analysing 4 separate cases [16]. The work found that procedures, the aircraft environment and configuration as well as the behaviour of passengers played a major role in passenger survival.

Unlike certification trials, there is no video footage of the evacuation taking place of the emergency from which to gather data. Data from these accidents are based on reports written by accident investigators. Behavioural data from accidents can only really be determined from crew and passenger statements. These statements do provide an insight into the movement and behaviour of those involved and can assist model developers to ascertain whether certain behaviours may be relevant or not for development. As previously mentioned a large amount of statements relating to accidents is held within the AASK V4.0 database.

Due to the difficulties of gaining accurate quantification of data from real accidents, this has brought the need to carry out controlled evacuation experiments from sponsored test sites such as Cranfield University in the UK and CAMI (Civil Aero Medical Institute) in the USA which use a number of active cabin simulators [128,129]. A number of useful experiments have been carried out including the use of disabled passengers [130], the effects of seating configuration adjacent to the over wing exit [131-132]. Muir also found that the effects of seating configuration adjacent to the over wing exit brought additional results [132] which demonstrated that the width of the passageway leading to a Type III exit influenced the flow rates and hence trial results.

Muir who often lead the tests in Cranfield found that flow rates at the floor level exits (Type-I) were increased by using assertive cabin crew [128]. Difficulties in the handling of the hatch for the Type III passenger operated exit was analysed by Wilson and Muir [124, 126] and included as part of controlled experiments. Handing of this over wing Type III exit is something which needs to be seriously considered during a real accident as passengers will probably be opening the hatch for the first time if they are located adjacent to it.

In some aircraft experiments carried out by the FAA in the seventies and eighties where more toxic environments were tested using smoke filled cabins to test passenger visibility of self-illuminating signs [133]. This toxic cabin environment is not the subject of this thesis.

2.6 CONCLUDING REMARKS

The AASK database provides a very useful research tool for the analysis of human behaviour during aircraft evacuation and for the development of evacuation models such as airExodus. Although much data exists in relation to aircraft evacuation, some data is limited in its scope. The quality of data therefore outweighs the quantity of data in this aspect. Conclusions drawn from AASK must be treated cautiously and with full understanding of the implications derived from questions posed and the nature of the data which is used for provision of the responses. AASK continues to shed light on what really takes place during an evacuation as seen and experienced by trained flight attendants and by ordinary passengers. It is helping to alleviate some of the myths which still exist in aviation safety. AASK has and can be used in the analysis of past accident scenarios and the human behaviour involved. It can and has also been used in the extraction of a more representative set of certification scenarios as suggested in Section 5. This type of analysis is necessary if trends in passenger behaviour are to be understood for the ultimate reason of improving overall passenger and aviation safety.

3 OVERVIEW OF AIRCRAFT EVACUATION MODELS

3.1 INTRODUCTION

This chapter gives an overview of the aircraft evacuation models that have been developed to date. It will look at how the models represent human behaviour during aircraft evacuation and whether these models can accurately and adequately simulate both 90 second certification trials and real aircraft accidents (see Section **Error! Reference source not found.**). The chapter will also go on to discuss the current deficiencies which exist in aircraft evacuation models to date. "*What is still missing in these aircraft evacuation models?*" and "*Why do aircraft manufacturers not rely solely on computer simulation for their 90 second certification tests?*", (See Section 3.3).

Before continuing with this chapter, it would be useful to consider a typical aircraft evacuation. Each evacuation is different in itself however there are some common characteristics which can be identified such as available and functioning exits, the presence of fire and smoke, passenger load and the decisions of crew to name but a few. The typical sequence of events during an evacuation is described in the next couple of paragraphs.

During a typical aircraft evacuation, the passengers would be informed or alerted to evacuate the aircraft immediately; this could be sudden or could be after a time of preparation where an in-flight fire has already commenced. Ambiguity however may exist amongst passengers between the call and the actual need to evacuate [27].

In the need for immediate aircraft evacuation, the crew members should release their seat belt, stand up and head towards their assigned exit to check if it is useable. Usable exits are those exits which will open but will not pose a threat of injury, fire or smoke entering the cabin to both passengers and crew. If the crew member determines that their assigned exit is safe to use, they will proceed to open the exit and deploy the escape slide if at all present. Some smaller aircrafts models do not have escape slides and passengers would be required to jump from a small height to reach the ground. If the exit is deemed unusable, the crew member should in fact guard the exit and direct passengers to use other available exits. Paxs will proceed during this time to unbuckle seat belts, stand up from seats and attempt to move to their chosen exit to evacuate as quickly as possible. Paxs sitting by the over wing Type III exits will be required to open these hatch type exits without the assistance of the cabin crew and should have already started to do so. Passengers have been known to take more than 45s to operate over wing exit hatches which can seriously hinder the overall evacuation [124].

During accident scenarios, passengers normally elect to go to their nearest exit [28, 29] while in 90 second certification trials, the passengers are directed and redirected by the crew towards exits which will make the overall evacuation more optimal [78,79,104]. While heading from seats, towards the exits, passengers will normally experience some form of congestion when moving into and along the aircraft aisle [14].

The cabin crew play a very important part during the aircraft evacuation and are responsible for calling passengers towards the exits and onto the exit slides as quickly as possible. Crew should command passengers to “jump rather than sit” once reaching the exit and to “form two lines” for exits which allow dual lane flows such as the Type A and Type B exits. Non-assertive cabin crew only vocally instruct the passengers while assertive crew would effectively push the passengers’ backs to move them more speedily on their way. The crew member assigned to the exit must be careful not to hinder the flow rate of passengers by their possible obstruction so close to the exit.

Cabin crew with no dedicated role during the evacuation or those guarding unavailable exits may start to redirect passengers between exits to optimise the total evacuation time [14]. This type of action usually occurs closer to the middle or end of the evacuation [14]. Passengers evacuating from wide bodied aircraft may choose to switch aisles and some seat climbing has been reported during extreme aircraft evacuation [14]. Seat climbing has not been reported very often during 90 second certification trials. These types of actions demonstrate passengers trying to optimise their personal evacuation time and hence possible chances of survival. Once all passengers have evacuated from the aircraft the cabin must be checked by a member/members of cabin crew to assure that no passengers are remaining [1]. This check can be performed either visually or by the crew member/members walking very swiftly down a designated aisle and checking that all of the seat rows are empty before finally exiting themselves via the exit slide. The cabin sweep can start before all passengers have left the aircraft by a crew member whose area has already cleared. Crew members must not leave before passengers however.

3.2 AIRCRAFT EVACUATION MODEL OVERVIEWS

3.2.1 Discussion of the aircraft evacuation models

Originally, computer modelling and simulation of an evacuating aircraft was pursued by the Civil Aero-medical Institute (CAMI). One of the first computer based evacuation models to be used was GPSS [30, 31] developed by IBM back in the 1970's but required the use of large mainframe computers [87]. GPSS was an aircraft evacuation model with simulations intended for the study of certification tests and not particularly for the reconstruction of an aircraft accident. GPSS could not simulate toxic combustion gas products and nor was passenger evacuation behaviour considered during dangerous life threatening accidents. Unfortunately, this model did not convince engineers and authorities, possibly due to the computer limitations at that time and its modelling capability. This caused the area of aircraft evacuation modelling to effectively come to a halt for nearly 20 years [104].

By the mid-nineties the FAA had commissioned a review of the relevant computer evacuation models and their data needs. There were three different aircraft evacuation models in development and use, namely GA (Gourary Associates) Model [26] developed under FAA sponsorship, AIREVAC [91, 92], was developed under the sponsorship of Air Transport Association of America and finally airEXODUS [104] was developed by The Fire and Safety Engineering Group within the University of Greenwich in the UK.

The GA model could produce a display showing an overhead view of the simulated aircraft was able to model life threatening scenarios unlike GPSS and also includes a crude toxic environment simulation which represented the influence of products in combustion from a fire [87]. In 1987, the GA model had the benefits of being developed using a powerful personal computer based on an Intel 80286 processor, now a very outdated piece of technology. GA divided an aircraft into a series of cells, with each cell being the length of one row and the width of one seat and /or aisle. Every passenger had a number of parameters, such as endurance or agility and was assigned an exit to use. A cell could be occupied by the maximum of two passengers and with each tick on the simulation clock (3 ticks per simulation second), the passengers move closer to the exit that they have been assigned to. Each passenger could move from one cell to another using a set probability. This passenger probability is a function of their agility, surroundings and endurance. The passenger speed within the GA model is not a parameter defined by users unlike many other evacuation models but specified by the probability of moving from one cell to another. Therefore, a passenger with a higher probability was faster than a passenger with a lower probability value. The probability of passenger movement is influenced by the certain factor that reduces the pax's endurance with every simulation tick of the clock. A pax fatality could occur during a simulation if their endurance value was to drop below a certain threshold value. The GA model can also simulate a crew member manning an aircraft exit; however the GA model only enables one exit at a time to be manned by a crew member. Suggested methods and techniques were made by Gourary [88] to enable crew members to be stationed at many exits during the simulation (single clock tick).

Marcus's review of the models [87] found that the downfall of the GA model was its inability to model a wide body, dual aisle aircraft and is completely limited to the modelling of a single aisle aircraft. There also appears to be a problem with blocked pax flows especially when fatalities occur and other paxs are not able to pass through in order to get to an available exit. A later version of GA has corrected this problem to some degree according to Marcus. The GA model was validated by Gourary using 3 accident reconstructions [89]. Two of the accidents were chosen and simulated as very detailed, accident reports were available and a third case was chosen as being a good example of where the GA model could be properly applied [87, 90].

Another aircraft evacuation model called AIREVAC developed by Schroeder [91, 92] was under the sponsorship of ATA (Air Transport Association of America). This aircraft evacuation model was not developed for accident reconstruction but for the certification test of an aircraft. Schroeder has developed AIREVAC with the intention to study the impact on the aircraft emergency evacuation, with disabled passengers being involved [87]. It was his intention to develop a model with possible wider applications. His model was solely intended for the simulated evacuation test of a B 727-200 aircraft. To be able to simulate any other type of aircraft, the user would be required to reprogram the model using Simscript which is the computer language in which AIREVAC is written. Simulation of the aircraft evacuation runs much more slowly than real time and simulating a 90 s certification test of an aircraft could take a number of hours. The simulation clock for the AIREVAC model runs at 5 ticks per second.

AIREVAC uses many of the parameters associated and required by a model of evacuation, namely the number of passengers involved together with their location and movement speed. The model also included a detailed set of psychological and social parameters of a passenger involved in an evacuation such as his or her level of frustration, dominance or submission and knowledge of aircraft routes and exits. AIRVAC creates passengers by use of a randomiser with each passenger being given a unique and random set of parameters. Unfortunately AIREVAC was unable to simulate the influence of toxic smoke and its influence on passengers during an evacuation. AIRVAC also didn't take into family bonding or groups into consideration which may be important in an accident or emergency but not so in a certification test.

EXODUS [61] was and still is being developed by Edwin Galea at the University of Greenwich in the United Kingdom. This evacuation model was developed together and in conjunction with CFD (Computational Fire Dynamics). The CFD model attempts to simulate the spread of fire, while predicting the temperatures and by products from fire. Unlike the GPSS, GA and AIREVAC evacuation models, EXODUS was developed with the intention to simulate emergency situations. Galea has also used EXODUS to simulate evacuation within other modes such as building [96], rail [95] and ships [93, 94, and 97] where large numbers of people are involved in evacuation possibly in an accident scenario. Galea used EXODUS to simulate certification tests of both narrow body [66, 98] and wide bodied aircraft [66]. EXODUS has also been used for accident experiments [99,100, 101 and 102] and reconstruction [103] as it has the ability to accept environmental details about the cabin allowing simulation of the production and absorption of toxic fire elements such as carbon monoxide, hydrogen cyanide and heat. EXODUS can run on any modern based PC system and the evacuation simulations of a narrow bodied single aisle aircraft can take a matter of seconds to evacuate a full load of passengers. This makes it very easy for a large number of random simulations to be run and analysed in batches [98]. A batch of a thousand simulations of a full, narrow bodied, single aisle aircraft could be completed within 1 hour approximately. EXODUS has a good graphical user interface and the user can watch the evacuation simulation as it unfolds together with the results. Detailed information is output about each individual passenger which can include their response time, out of aircraft time, on the ground times and the time and position of death. The output from each passenger involved in a simulation can also include detailed information about environmental toxins that they can absorb during the evacuation.

EXODUS is made up of 5 components that interact with each other, namely the Behaviour model, the passenger model, the hazard model and the Toxicity model. The behaviour model determines how a passenger will respond to a current or evolving situation based on his or her personal attributes. The passenger model describes the passenger by use of attributes and variables; such as name, gender, age, movement speed, passenger drive etc. These attributes may be fixed or some may change depending on the developing evacuation simulation. The hazard model encompasses the atmosphere and the built up environment. It deals with hazards from fire such as the heat. The airExodus model uses a cabin space which is sub-divided by 0.5m by 0.5m square nodes which has been criticised by some [111] due to the fact that each node can only be occupied by one passenger at a time. It has been considered by some as an unrealistic representation of emergency processes with passengers getting very close to each other [111].

Two types of enclosure are usually used to represent the aircraft geometry and these are namely the FINE NETWORK and the COURSE NETWORK approach [104]. AIREVAC, airExodus, DEM and GA would be considered as fine network models where the aircraft enclosure is split into a series of tiles or nodes that may be occupied usually by one person. GPSS on the other hand is a course network model [104] where the space in divided in to compartments or regions. AIREVAC, GA and airExodus are also rule based models which can incorporate and simulate the behavioural attributes of individuals involved.

In 2001, an aircraft model was introduced by Strathclyde University called DEM (Discrete Element Method) [122]. This model was intended for both certification purposes and accident reconstruction using a fine network approach with each passenger having their own attributes such as size, movement speed and dominance [14]. Robbins and McKee [139] used DEM to simulate the evacuation of a commercial airliner involved in the 1985 Manchester air disaster. During this published literature [139] there was no indication that exit hesitation delays or passenger response times were being used. The exit flow rates were simply determined by the supply of pax to the exits and only one pax was allowed to occupy the slide at a time [14]. In addition, the designers applied a uniform 2 second delay to the pax's negotiation of the Type III exit. This delay was not something that appears to have been validated and published in literature and was one of the major failing of the model. The DEM model included some rules to allow for redirection by passengers themselves by using the pax dominance attribute to avoid congested aisles. This would be done by paxs assessing the length of the queue by an alternative exit and if it was shorter, the pax would decide to change direction [139]. In terms of accident reconstruction, this model should be considered very limited as literature found does not indicate any representation of fire hazards within the model. Very little has been found in published literature regarding the DEM model in recent years.

In 2008, the VacateAir model was introduced by the State University of New York. This model's intention was for certification purposes and for real evacuation situations [122]. This model is an optimisation model (Particle Swarm) [142], validated using data from Cranfield University trials. The model implements behaviour where occupants move in groups but unfortunately the results didn't match well with certification results [122, 140]. Xue and Blocbaum investigated the impact that the width of the fuselage, the aisle and the exit had on the efficiency of the aircraft evacuation for purposes of aircraft design [111, 140]. VacateAir [142] was able to simulate human behaviour for each evacuee based on inputs. The model can simulate three types of behaviour with first the first category being psychological which allows the evacuee to make a decision to evacuate as well as take the shortest route out of the aircraft and taking alternative exits [142]. The second category is about physiological behaviour which includes, visibility, velocity and mobility and the third category aims to capture social behaviours which includes how evacuees interact with others. This interaction can also include helping disabled people. VacateAir has attempted to include behaviours which have been identified within the AASK database [3, 4, 5]. Xue and Blocbaum [142] found from analysis and results demonstrated that significant delays were encountered when both attempting to help disabled evacuees and including group behaviours in the model. Xue and Blocbaum [142] reported the need to enhance the model further so that it can be used with wide bodied aircraft. As the model was only able to represent a section of the cabin, certain factors such as human decision making such as exit choice, redirecting and aisle switching was not possible to study [142].

More recently, paxs in aircraft simulation models and proposed approaches have been developed to include some form of human intelligence, with the aim of more accurately simulating a decision making process during the evacuation which is unfolding [111, 119, 120, 122, 141].

In 2013, Liu et al. [111] proposed a new aircraft evacuation model with a purpose of both certification and accident reconstruction. Liu et al. criticised the traditional network node models and proposed that nodes should not necessarily be equi-size. The cabin space within this newly proposed model was designed with multiple levels of fine nodes with different sizes. The model also allowed paxs to occupy part of neighbouring nodes which basically indicated that nodes may contain more than one pax. This strategy of Liu et al. which allowed paxs to stay very close to each other during an emergency doesn't appear to have been taken from work previously researched or published [111] but may have been observed in certification trial footage. In this model, the paxs are allowed to make decisions such as identifying and choosing the least crowded escape route. If more than one route has the same queue length, then the shortest route will be chosen to overcome the problem. Liu et al. used data from the AASK database [3, 4, and 5] which suggested that over 70% of pax tended to use their nearest exit. Liu et al. [111] stated that paxs would find difficulty in accurately assessing the distance between two separate routes and would more than likely choose a route based on paxs choosing the shortest route combined with the number of paxs standing in the queue. Although this seems like a sensibly argument to make there is no indication of Liu et al. taking this idea from published or gathered data. It was concluded that the model was tested against the certification trial of a Boeing 767-300 [12] with close results but that the lack of data from real egress trials may have hindered proper validation. It was also reported that there was a lack of data regarding certain types of exits and that further data was required to broaden the application of model by Liu et al.

In 2009, the Polytechnic University of Madrid developed an aircraft evacuation model called ETSIA [122, 143] for purposes of certification within a long term research project sponsored by the Spanish government. Verification of this model has taken place using certification data from A320-200 and B757-200 aircraft [122]. ETSIA is an agent based model and composed with 3 basic sub models which are namely geometry, occupants and time and these assemble together to form the kinetic sub model. This aircraft model can include both pax and crew and for any pax involved in the evacuation, the local speed is dependent on the evacuation path width. The individual speed is determined by a kinetic factor multiplied by the local speed. Hedo and Martinez [122] discuss simulations carried out and compared against 26 airplanes where both the average and 95% confidence values were below the 90s limit. Hedo and Martinez describe that ETSIA could eventually substitute the actual certification trial but doesn't appear to be ready with further validation required.

During the dormant period of aircraft evacuation models, the building industry saw the benefits of in the evacuation modelling and developed numerous models such as (EVACNET+ [32, 33], TAKAHASHI's MODEL [34], BGRAF [35], DONEGAN's ENTROPY MODEL [36], EXITT [37, 38], EGRESS [39, 40], E-SCAPE [41], EVACSIM [42, 43], EXIT89 [44, 45], SIMULEX [46-48,], MAGNETMODEL [49], PAXPORT [50,51], VEGAS [52, 53] EXODUS [54-68], CRISP [69, 70], WAYOUT [71]).

These models were developed partially for architects to construct new concepts in building design. At the same engineers and regulators were faced with the problem of proving that the new building designs were safe and that occupants would be able to evacuate in a time manner in the event of an emergency. Modelling human behaviour in buildings has been underway for nearly 40 years. This work has taken two strands; firstly researching the movement of people in buildings under non-emergency conditions and secondly the evacuation or movement of people in buildings under emergency conditions such as fire.

Predtechenski and Milinskii [72] as well as Fruin [73], were involved in very early research concerning the normal movement of people during non-emergency situations. The research considered people moving in areas that were crowded and on stairs. This research was very important and lead to the development of PAXPORT/ PEDROUTE [50, 51]. Research into modelling emergency egress during fires took place much later with papers being published during the early eighties [74]. A review of sources of occupant performance data by Kady and Gwynne [75] indicates as many as 62 different evacuation models to date. Kuligowski and Peacock [76] review as many as 30 in 2005. A more in depth discussion of methodologies for modelling is given by Gwynne at al. [77].

Way finding within buildings has been studied by psychologists, human behavioural researchers and urban planners alike [144]. Passini [145] believed that way finding was a continuous spatial process of uncertainty. Arthur and Passini [146] were able to provide a definition of way finding being a process of reaching a destination whether in a familiar unfamiliar territory which would involve three separate processes. These process were namely information processing, decision making and decision execution. It could be argued that these processes identified by Arthur and Passini could be applied to paxs evacuating from aircraft enclosure also.

Most evacuation models use the shortest path algorithms based on an assumption that evacuees will always choose the shortest path for means of escape [144]. According to Veeraswamy [144], these models would bring unrealistic results when there is more than one path available. From data held in the AASK database [3], approximately 15% of the pax in aircraft emergency evacuations do not report using the shortest path or nearest exits but have a valid reason for doing so. Arthur and Passini [146] describe two main decision models with the first being the optimising model and the second being the satisficing model. The optimising model basically means that the evacuee would choose the best solution to the problem while in the satisficing model, the evacuee would choose an acceptable option without considering the most optimal solution. Arthur and Passini believe that this is what happens in everyday life. This is also evident in aircraft accident data as not paxs report using the nearest exit which could be considered the most optimal solution. Veeraswamy [144], states that in buildings, exit selection is very important in the route that evacuees choose with people preferring to use more familiar exits over unfamiliar emergency exits. This is not the case in aircraft emergencies according to the AASK database [2] with a high volume pax flocking to the middle Type III exit on a narrow bodied aircraft.

Veeraswamy [144] carried out 2 separate questionnaires to understand way finding within building enclosures with participants being presented with a number of path selection tasks via images to understand the preference for selecting left or right handed paths, longest or shortest leg paths, clockwise or anti-clockwise paths. Veeraswamy found from the results of the first questionnaire that participants preferred to use right handed paths. Veeraswamy also found that handiness played a strong part in the choice of which route was chosen by the participant. Full results of the two questionnaires can be found in the PhD thesis of Veeraswamy [144]. Data substantiated from the questionnaire results were then implemented into the buildingEXODUS [54-68] before being validated using the station Night Club Scenario [147].

3.3 DISCUSSION OF THE CURRENT DEFICIENCIES OF AIRCRAFT EVACUATION MODELS

Before a computer model can be used in place of live certification trials by aircraft manufacturers, it must undergo strict validation testing. Although model testing may never prove total confidence, its predictions may be improved as it produces more reliable outcomes. Some aircraft models such as airExodus [8, 62, 63, 79, and 80] have proved successful in its prediction of previous 90-second trial outcomes.

Although the models may be useful in reconstructing what is currently happening during 90s certification trials, there is very little data which demonstrates the knowledge that paxs have regarding exits sizes and flow rates. Blake [14] suggests that aircraft evacuation modelling would greatly benefit from gathering data which related to what passengers understand about the differences in exit sizes and flow rates. In the development carried out on airExodus by Blake, it was made based on a premise that passengers were not able to distinguish between the flow rate characteristics of exits [104]. This has become even more important in the event of manufacturers such as Boeing and Airbus launching VLTA (Very Large Transport Aircraft) with some possibly carrying up to 1000 paxs [99, 112]. This brings an even bigger challenge for authorities when the aircraft may have many different types of exits over more than one deck.

A number of aircraft evacuation models previously discussed, included some form of decision making and some pretty sensible assumptions such as paxs choosing the shortest route to evacuate irrespective of everything else around. Unfortunately these assumptions were based on paxs having perfect knowledge of the aircraft, while always choosing the exit which was nearest to them in the event of an emergency. These models assumed that all paxs would use this form of decision making. Data from the AASK database [2] tells us that approximately 15% of paxs do not use their nearest exit during an emergency and may be optimising their evacuation strategy in some other way whether it be due to redirection or some other type of prior aircraft knowledge. **Do they initially choose the nearest exit and then redirect? Do they initially assess the situation and then opt to go to a larger, further away exit which might in turn optimise their own personal evacuation time?** Proper understanding of this is required before any model can be validated. This can only be achieved by gathering some data to understand what it is that these paxs are doing during the initial decision making process.

3.4 CONCLUDING REMARKS

Although some evacuation models do include some form of decision making for the paxs involved in the aircraft emergency evacuation these have not been fully validated and there appears to be a lack of data to validate these models with. An individual should be able to decide what is best for them and should be able to evaluate a route to evacuate based on the knowledge that they have. This deficiency which was discovered by Blake [14] due to the lack of data available regarding paxs understanding of exit sizes and flow rates will be researched further in this thesis during Chapters 6, 7 and 8.

4 ASSESSMENT OF AIREXODUS V4.1 TO SIMULATE 90 SECOND CERTIFICATION TRIALS AND ACCIDENTS

4.1 INTRODUCTION

During this chapter there will be a discussion of the effectiveness of the airExodus V4.1 to simulate 90 s certification trials and real accidents. The airExodus model as mentioned in Chapter 2 has already been used in numerous consultancy projects for the prior understanding of how a new aircraft model and its paxs might perform during a 90s certification trial. As previously mentioned, airExodus [78,79] was sponsored by the UK CAA to predict evacuation results using past aircraft certification data of both narrow and wide bodied aircraft with a number of trial results being successfully recreated [20].

In 2003, FSEG who develop airExodus was commissioned to take on the VERRES Project [78, 79, 104] by the European Commission to find a methodology and procedure for the introduction of aircraft evacuation simulation to the aircraft certification process. The airExodus tool was used during this project which placed emphasis on the simulation to certify VLTA (Very Large Transport Aircraft). The VERRES report [104] does however suggest that the methodology and procedures could be applied to narrow bodied domestic aircraft also. As well as the model's effectiveness to simulate certification trials and real accidents a brief overview of the model and its features will be given.

4.2 AN OVERVIEW OF THE airEXODUS V4.1 MODEL

There is a large amount of literature which describes or critically accesses the functionality of the airExodus model for the evacuation concept which began in 1989 [54, 61-65, 104]. The model was developed for purposes of assessing aircraft design, simulating 90 s certification requirements, the development of safety procedures for crew, for accident reconstruction and to assist with any operational procedures which may be required.

The software is composed of five main sub models which interact and these are namely: **Passenger, Behaviour, Movement, Toxicity** and **Hazard**. This research work will not concern itself with either the **Toxicity** or **Hazard** sub models. All of these sub models operate within a space which is created by the user and known as the **Geometry.** The **Geometry** is basically a region of space or enclosure from where the paxs will evacuate. A diagram for the interacting sub models can be found in literature [14,104] but can be described simply as people to people, people to fire, and people to structure interactions. This thesis will not concern its self as previously mentioned with people to fire which would require the use of the **Toxicity** and **Hazard** sub models.

4.2.1 The GEOMETRY

The geometry within airExodus can be created manually by the user or imported from a Computer Aided Design file [104]. The space of the geometry is covered by nodes which are interconnected by a series of arcs. The nodes are spaced at a distance of 0.5m away from each other with each node representing a space which can be potentially occupied by a single passenger. The airExodus model does not permit more than one passenger to occupy a node. Each node in the geometry also has its own set of defining attributes which define different spaces within the aircraft such as AISLE, SEAT, BOUNDARY and STAIR [14] which may significantly affect the movement of the passenger i.e. travelling over an AISLE node is considered easier for a pax than travelling over a SEAT node where the pax speed will more than likely be reduced. Each node is supplied with a numerical value known as a potential. If the potential value is lower, then it usually means that the node is closer to the exit making nodes with lower potential values more attractive to paxs involved in an aircraft evacuation. The arcs interconnecting the nodes in the geometry have numerical values applied which can affect the speed of travel for the paxs.

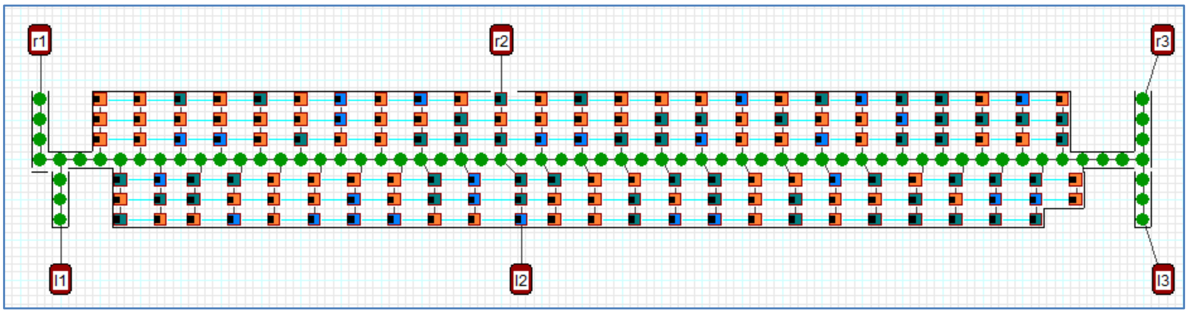


Figure 4-1: Geometry of an aircraft with nodes and connecting arcs

4.2.2 The PASSENGER sub model

This sub model allows each pax to be created with individual attributes such as gender, age fast walking speed and response time to name many. The speed of the pax is of great concern during evacuation of aircraft as it can determine the outcome of the evacuation with much of the data being provided by human performance data gathered from Fruin's study of building evacuations [73] with aisle speeds specified from unhindered stair speeds gathered within the same study and often affected by pax congestion. In addition to some of these attributes already mentioned, psychological attributes (Drive, Patience and Response Time) are also included and used to determine a pax's response to a variety of situations that may occur during the evacuation. The Drive attribute is a measure of a pax's competitiveness which is determined by age and gender [30]. Pax patience is measured by likeness to wait in a queue with higher values indicating a higher patience and less likely to embark upon extreme behaviour such as seat jumping. Response time is the time that pax takes in order to understand the need to evacuate and to stand up after unbuckling seat belts in order to commence with the evacuation.

Crew members who are also part of the passenger sub model have additional attributes such as visual access to certain parts of the cabin and physical and vocal assertiveness when dealing with paxs [104]. Within this sub model, each pax can be assigned an itinerary which can be used to perform additional tasks if necessary. These itineraries are often used by crew members who may need to perform a final cabin sweep to check that all paxs have left the aircraft.

4.2.3 The BEHAVIOUR sub model

This model which determines how a pax will respond to the evacuation based on their personal attributes works on two separate levels; either **global** or **local**. The **local** model represents what the pax will do as an individual and how they will respond to their own current situation. The **local** model can include extreme behaviour, determining how paxs will behave in queues and whether they are capable of seat jumping depending on their attributes and whether they have exceeded their own patience threshold. The **global** model on the other hand involves paxs simply using the potential map route to the exit and its strategy is to determine the evacuation of the aircraft as a whole.

It is possible for airExodus to simulate extreme pax behaviour similar to that reported during accidents [2, 3]. Extreme behaviour such as seat jumping usually only occurs during real evacuations.

Research carried out has suggested that exit flow rates can be improved when there is higher cabin crew assertiveness [12, 23]. Distributions for passenger Exit Delay Times have been substantiated and determine the different levels of cabin crew assertiveness. Many cabin crew procedures are carried out during certification trials [24, 105, 135] and real emergencies [136, 137] such as re-direction and exit-by pass strategies possibly due to information they have on surrounding conditions in order to maximise the use of the exits and to increase the overall efficiency of the evacuation.

During aircraft certifications, paxs are usually more inclined to obey crew commands while in real accidents, the paxs may be less likely to obey crew commands as the pax will be more interested in evacuating in their own self-interest or preservation.

4.2.4 The MOVEMENT sub model

This model is used to control the movement of paxs from where they are currently positioned to their next available location or node and is responsible for assessing the waiting period. This model includes the control of behaviour such as overtaking and other types of movement actions performed by paxs.

4.3 DISCUSSION OF MODEL CAPABILITY TO REPRESENT CERTIFICATION TRIALS AND REAL ACCIDENTS

4.3.1 Certification Data used with the airExodus Model

Data from the 90s certification trials archive [12] is used to specify particular model parameters [65] within airExodus. One of the most important parameters within the airExodus model is the Exit Delay Time which is used by passengers and constitutes two parts of the exiting process; namely the exit hesitation time and exit negotiation time. Practically all passengers will hesitate first at the exit prior to negotiating or dealing with the exit for reasons of evacuation. The hesitation time will start when the passenger stretches out a hand to touch the exit and the negotiation time involves the time taken to pass through the exit. More information can be found relating to exit hesitation time which is used in airExodus within [12, 138]. It must be noted that different types of exits will require the use of quite specific distributions to be used for the type of exit in question. For each exit type, it must be noted also that there is a different exit delay time distribution for the different level of cabin crew assertiveness (i.e. low, medium and high). For every exit type, pax Exit Delay Time distributions have been created using the 90s certification trials archive [12] and these are dependent on the performance category of the crew member responsible for each exit. Blake has indicated that distributions for Exit Delay Times for performance category of the crew member were not available for all exit types due to a lack of data for crew assertiveness types [14].

Many other parameters will also be referred to when describing the results of the model in Chapters 5 and 10. These parameters are known as PET (Person Elapsed Time), TET (Total Evacuation Time), CWT (Cumulative Wait Time), DIST (Distance), Response Time, Exit Ready Time, OPS, Flow Rates and Off Times (see [14, 62, 104] for more details).

4.3.2 Results and discussion of certification trial cases validation

The airExodus evacuation model has been the subject of much validation in the past [8, 80, 104, 138] concerning a variety of different types of aircraft. To properly validate a model requires a significant amount of work and effort in selecting the right cases and scenarios. A report was carried out by the CAA on the testing and evaluation of the airExodus model. The main point of this study [138] was to demonstrate that airExodus was capable of predicting small changes that may arise between the different aircraft which would belong to the same aircraft family. The most favourite aircraft according to literature are both the narrow and wide boded aircraft. During this study it was considered important to select and test aircraft which presented both a variety of exit types and cabin crew assertiveness. A total of four wide bodied aircraft cases were examined along with two narrow bodied aircraft cases. Each of aircraft tests included was defined using two separate scenarios; firstly using **actual data** from the certification trial and secondly with **generalised data** [12, 138].

In terms of actual data used, Case 1 generated results which were mostly higher than the trial results by 3.5% on average, Case 2 generated results which were 3% (2.2s) faster than the actual trial, Case 3 generated TETs which were 4.8% (3.5s) lower than the trial while Case 4 generated results that were slightly longer than the trial (3.4% or 2.5s). In Cases 1 to 4 it must be noted that in all four instances the trial results fell within the envelope of distribution results [138] generated by airExodus.

In terms of generalised data used, the results were better for Cases 1 and 2 but worse for Cases 3 and 4, but it should still be noted that the results of the total evacuation time (TET) for the trial still fell within the boundary for the distribution of results [138] for Cases 1 to 4 using generalised data. The report suggests that while general trends in the results between general data and actual data have been maintained, there were some differences in the nature of the frequency distribution which were produced.

Within the same study, the same form of tests were carried out on narrow bodied aircraft for Cases 5 and 6 using both **actual** trial data and **generalised** data. In Case 5 using actual data airExodus produced results which were 10% slower on average [138], while in Case 6, the results were 7% shorter on average. While using the actual data, the trial TETs were still within the bounds of distribution results although at the lower and higher end of the scale. It should also be noted that in Case 5 and 6 some differences with the OPS (Optimal Performance Statistic) [104] between the simulations and the actual data may have caused inconsistencies with these results.

Case 5 and 6 were then tested using generalised data [138]. The results of Case 5 appeared to be better when using generalised data than with the actual certification trial time falling in a more centralised location within the distribution of results produced by airExodus. Case 6 however has proved much worse with the results being 11.6% faster on average and the actual trial result falling out with the boundary of the distribution of results produced by airExodus. Although the results for Case 6 may be considered poor airExodus has managed to do what it intended during this study and that was to demonstrate differences between the results produced for the derivatives between the same aircraft family.

4.3.2.1 What are the limitations?

Unfortunately difficulties arise when validating the airExodus model against one data point generated by running only one actual 90s certification trial. In terms of how the model results could be improved to demonstrate more similarity between the certification trial and the airExodus model, it may be useful to simulate an explicit capability to simulate crew instigated passenger by-pass which would enable crew members to send paxs to underperforming exits rather than depending on a system of potential values. This functionality has already been researched and developed by Blake [14] but is not currently being used during any known pre-certification reports. During the validation of the six cases used in the CAA report [138], the OPS [104] value should more closely represent that of the actual data from the 90s certification trial while still producing the relevant value for the TET. It may be useful to try to recreate an evacuation simulation which produces an identical exit performance statistic (OPS) while still producing a relevant TET value.

4.3.2.2 Discussion of arbitrariness of decision making model with regards to passengers making exit choices

Blake [14] had developed a model for passenger reasoning within airExodus to answer the question "Does redirecting help?" It was developed to allow passengers to estimate the time required for their evacuation through each of the available exits [14]. This model however limited the dynamic information getting to the paxs by use of a visual scheme. Blake believed that paxs would not have full visual information and would affect any calculation in determining the best exit to use or redirect to. Blake suggested that paxs initially make their own exit choices but a crew member may intervene and redirect them to a more optimal exit. Blake [14] developed a model where paxs were able to consider redirection based on aisle swapping involving wide bodied dual aisle aircraft. Blake also developed a model [14] where paxs were able to use seat climbing when conditions were considered to be severe.

4.3.2.3 What are the limitations?

Although Blake had developed these features into the airExodus model based on an investigation carried out using the AASK database [14], these new features were never fully validated due to the difficulty in obtaining video footage of severe and real emergency incidents to compare with. Blake in his thesis suggested that with his models developed it was very difficult to gain a proper empirical understanding of the human behaviour in order to justify it with a number of approximations also being required [14].

Blake came to the premise that <u>**passengers were not able to distinguish between exits and hence their flow rates**</u> suggesting that this probably caused paxs to move to their nearest exits rather than to the exit which would optimise their overall evacuation time [14].

Blake suggests that a research study to gather data in this area would greatly benefit both aircraft evacuation modelling and safety.

Although Blake [14] was able to include a model for the redirection of paxs by crew members, the further work section of the thesis suggested a possibility for introducing small group redirection rather than just individual paxs redirection as being a more realistic scenario.

4.4 CONCLUDING REMARKS

4.4.1 Work that needs to be done on model

There are many areas requiring work on the airExodus model but from the premise made by Blake during the thesis [14], it appeared that more data needs to be gathered for a model to represent pax behaviour during a real accident to be justified or validated. This new data should take the form of trying to understand how paxs might perceive the exit sizes and flow rates when they are called to evacuate and aircraft in a real emergency. This passenger knowledge data is missing from the current airExodus model. At present there is no knowledge about how passengers distinguish between exits or flow rates.

Knowledge gained from the AASK database suggests that 85% of paxs use their nearest exits during an emergency situation [2]. Any development done to the model which may use any new data would require validation against what is already known from the AASK database [2, 3]. It is suggested that simulations should be constructed to send 85% of passengers to their nearest exits with simulation outputs analysed. Any new data implemented into the airExodus model relating to Blake’s premise of gathering data relating to pax’s understanding of exit sizes and flow rates, should then be validated against the results of the case constructed to simulate 85% pax nearest exit use.

5 A STUDY OF PASSENGER EXIT AVAILABILITY USING EXISTING AIRCRAFT EVACUATION MODEL TO DEMONSTRATE ITS IMPORTANCE

5.1 INTRODUCTION

The evacuation certification trial (see FAR 25.803 [1]) is the aviation industry benchmark of aircraft evacuation performance and is considered by the travelling public and safety professionals as the ultimate mark of aircraft evacuation safety. This benchmark however should serve as an indicator of safety and should be as representative of reality and as challenging as possible.

This chapter examines the influence of exit availability on the evacuation time for both a narrow bodied and wide bodied aircraft under certification trial conditions using computer simulation. Both a narrow and wide body aircraft which previously passed certification trials are used as the test configurations. Whilst maintaining the certification requirements of 50% of the available exits, a total of twelve different exit configurations are examined (six for each aircraft configuration). Each aircraft configuration will include the standard certification configuration (one exit from each exit pair) and five other exit configurations based on commonly occurring exit combinations found in accidents. These configurations are based on data which has been derived from the AASK database. All evacuation simulations are carried out using airExodus. The results show that the practice of using half of the available exits mostly down one side of the aircraft is neither challenging nor statistically relevant. For the narrow bodied aircraft cabin layout examined, the exit configuration used during the certification trial produces the shortest egress time. For the cabin layout examined for the wide bodied aircraft, the exit configuration used during the certification trial produces the second shortest egress time.

5.2 SELECTION OF EXIT AVAILABILITY CERTIFICATION TRIAL CASES

This section details the selection of exit availability during certification trial cases which will be utilised using the existing aircraft evacuation model to demonstrate its importance.

5.2.1 Exit availability analysis conducted using AASK

A full and proper description of the analysis of exit availability in aircraft accidents presented in this section can be found in [2]. A brief summary will be presented of this analysis and the main conclusions drawn and used during the study of narrow and wide body aircraft certification tests. During the analysis, an exit is considered 'available' when the exit and it evacuation assisted means (i.e. slide) are physically and safely operative, and passengers have been authorised to use the exit by crew. Exits which may not meet the specified criteria, but were used by at least one passenger are also considered to be 'available'. During this analysis, exit availability has been considered as a function of the total number of exits on board an aircraft, irrespective of exit positioning or whether exits are single or in a pair.

Incidents within the database, classed as precautionary evacuations or post-incident deplaning are not included in the analysis. The analysis does include planned and unplanned emergency evacuations and can include situations in which the aircraft was involved with fire, partially or fully immersed in water or suffered a cabin rupture. The results for aircraft with three exit zones and four exit zones are presented and may also be found in [2]. Within AASK V4.0, 42 accidents met the criteria with 31 accidents involving aircraft with three exit zones and 11 accidents involving aircraft with four exit zones.

In contrast to the evacuation certification requirements, the AASK V4.0 study suggests that a third (33%) of the emergency evacuations examined involve aircraft in which less than 50% of the exits are available (see

Table 5-1). The data also suggests that the available exit distribution for small (i.e. aircraft with three exit zones) and large aircraft (i.e. aircraft with four exit zones) is different with smaller aircraft having a greater tendency than larger aircraft to have less than 50% of their exits available during an emergency evacuation. In addition, the accident analysis suggests that over half (55%) of the accidents investigated involve a cabin section in which no exits were available [2].

Table 5-1: Availability of exits in planned and unplanned emergency evacuations [2]

Type of Accident	Less than 50% of exits available	Exactly 50% of exits available	Greater than 50% of exits available
Aircraft involving 3 exit zones.	**36%**	**19%**	**45%**
Aircraft involving 4 exit zones.	**27%**	**9%**	**64%**
All Aircraft	**33%**	**17%**	**50%**

However, according to the accidents investigated, the statistics suggest that approximately 67% involve an exit availability of 50% or more. Therefore, as the most frequently occurring exit availability involves more than 50% of the exits, it would not be unreasonable to expect 50% exit availability in certification evacuation scenarios. If frequency were the sole driver for selecting exit numbers in certification trials, using 50% of the available exits could be considered on the conservative side. This argument however ignores the fact that a significant minority (33%) of the accidents investigated had less than 50% exit availability, which would result in a significantly more challenging and possibly difficult evacuation scenario. Furthermore, based on the data from analysis, there would be an argument to expect a configuration in which at least one exit zone had no available exits.

In the previous analysis, exit availability was considered from a global perspective i.e. as a function of the total number of exits on board. Here we consider the availability of exits within exit pairs. The accidents used during this analysis ignore all those where the aircraft have ended up in water or where substantial damage occurred to the aircraft fuselage, i.e. cases where there were significant breaks in the fuselage, and include only those accidents where information is known about all the exits. Unless an exit has actually been used by passengers, the exit is only considered to be 'available' when the exit and its evacuation assist means are physically and fully/safely functional, and passengers are authorised to use it by cabin crew. Using this definition, 12 accidents were found to be suitable for analysis, each one involving a narrow body aircraft with three pairs of exits. These cases included for the narrow body aircraft have a strict arrangement of exit pairs in forward, mid and aft positions.

It was concluded from these accidents, that at the FWD generalised location, two exits are available in the highest number of cases (50%), with a single exit available being the next most likely (42%) [2]. In the case of MID positioned exits, the results suggest that in most cases (59% of the time) both exits are available while 33% of the time one exit is available. In both the FWD and MID generalised location, it is unlikely for there to be no exits available (8% of the cases). Finally, the AFT positioned exits again show that having two exits available is most likely (42%) and having one exit available is next most likely (33%). However in a quite a significant number of cases, (25%) there are no exits available in the AFT position [2]. These results are summarised in Table 5-2.

Table 5-2: Proportion of exit availability in terms of generalised exit positions for three exit pair (narrow body) aircraft [2]

	Availability (%) of exit in exit pair.		
Exit Position	**No Exits**	**One Exit**	**Both Exits**
FWD	8%	42%	50%
MID	8%	33%	59%
AFT	25%	33%	42%

The evacuation certification trial criteria stipulate that only half of the available exits must be used. With no exceptions, where aircraft have exit pairs, only one exit out of each pair must be selected. If this scenario was realistic, we should expect to see the highest percentages in the "One Exit" column of Table 5-2. For aircraft with three exit zones, this data suggests that it is quite rare to have a situation in which no exits are available in the FWD or MID sections, but one in four cases involved no exits being available in the AFT section of the aircraft. Having one or both exits available in the AFT section is almost equally likely [2].

Based on this data, a list of more realistic exit combinations for aircraft with three exit pairs – while maintaining the certification required 50% availability condition – has been suggested [2]. These involve both exits in one of the exit positions and a single exit available in one other exit position. These realistic combinations of 'available' exits are based on the frequency data which is demonstrated in Table 5-2 with a decreasing order of likelihood [2]:

(i) A single forward exit, both overwing exits and no exits in the aft section available.

(ii) Both forward exits, a single overwing exit and no exits in the aft section available.

(iii) Both forward exits, no exits in the overwing section and a single aft exit available.

(iv) A single forward exit, no exits in the overwing section and both aft exits available.

(v) No exits in the forward section, a single overwing exit and both aft exits available.

Using the same definition as for the narrow body aircraft, analysis was undertaken for aircraft with four exit pairs [2] and this time there are eight aircraft deemed suitable. For all cases involved, there is a strict arrangement of exit pairs in forward, mid-forward, mid aft and aft positions. From this analysis, it was concluded that the moment prevalent combination is to have both exits (71%) in an exit pair available in the FWD position, both exits (71%) in the MID-FWD position, and one exit (57%) in the MID-AFT position and one exit (43%) in the AFT postion (see). From the cases examined, , no exits (0%) were available in the FWD and MID-FWD positions, but in three out of 10 cases, no exits were available in the MID-AFT and AFT positions [2]. These results can be see in Table 5-3 .

Table 5-3: Proportion of exit availability in terms of generalised exit positions for four-exit pair (wide body) aircraft [2]

	Availability (%) of exit in exit pair.		
Exit Position	**No Exits**	**One Exit**	**Both Exits**

FWD	0%	29%	71%
MID- FWD	0%	29%	71%
MID-AFT	29%	57%	14%
AFT	29%	43%	28%

This data for aircraft with four exit zones suggests that it is quite rare to have a situation in which no exits are available in the FWD or MID-FWD sections, but one in approximately 3.5 cases involved no exits being available in the MID-AFT and AFT sections of the aircraft. Having two exits available in the MID-AFT section is quite rare (14%) [2].

Based on this data, a suite of more representative exit combinations for aircraft with four exit pairs – while maintaining the certification required 50% availability condition – has been suggested [2]. These involve exits being available in only three out of four exit locations. Suitable combinations of exits based on the frequency data identified in Table 5-3 in decreasing order of likelihood include [2]:

(i) Both exits in the forward section, both exits in the mid-forward section available and no exits elsewhere.

(ii) Both exits in the forward section, one exit in the mid-aft section, one exit in the aft available and no exits elsewhere.

(iii) Both exits in the mid-forward section, one exit in the mid-aft section, one exit in the aft available and no exits elsewhere.

(iv) Both exits in the forward section, one exit in the mid-forward section one exit in the mid-aft section available and no exits elsewhere.

(v) Both exits in the forward section, both exits in the aft section available and no exits elsewhere.

5.2.2 A study of narrow bodied aircraft certification tests

The aircraft geometry used in the analysis of a narrow body aircraft with three exit pairs seating 149 passengers and containing three cabin crew can be seen in Figure 5-1. The aircraft configuration used in this analysis represents an actual aircraft which successfully passed the evacuation certification test. Three exits were used in the certification trial, all on the right side of the aircraft, consisting of two Type C exits (R1 and R3) and the over-wing Type III exit (R2). The L1 and L3 exits were Type B. It should also be noted that the over-wing exits are not placed in the middle of the aircraft as determined by the passenger distribution. There are 10 seat rows between the front and over-wing exits and 14 seat rows between the over-wing and aft exits (see Figure 5-1).

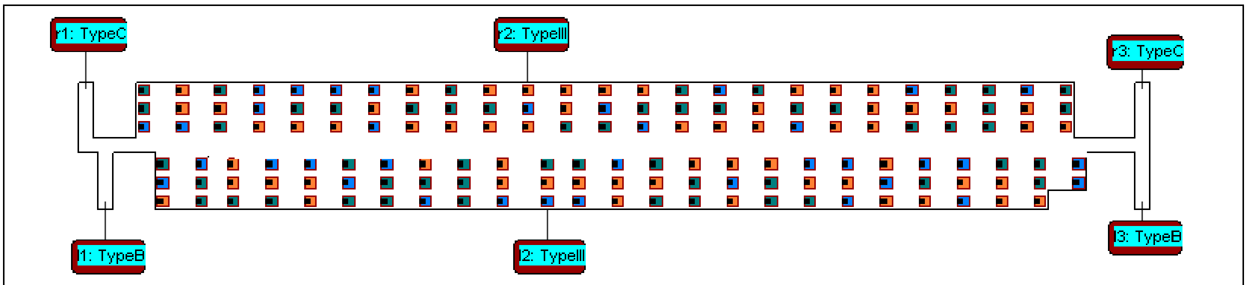


Figure 5-1: Schematic layout of the test aircraft showing seating configuration and exit location

In the narrow body simulations presented in this section, the default generalised passenger exit hesitation time distribution (assuming assertive crew) appropriate for the various exit types were used with default exit ready times of 8.2 s for the R1 and R3 exits, 12.0 s for the passenger operated R2 and L2 exits and 9.4 s for the L1 and L3 exits. Passenger attributes are set from the default certification parameter set. The airEXODUS parameter "Off-Time distribution" (i.e. the time required to descend the slide or wing) was also assumed to follow the default distribution appropriate for the various exit types. Other model parameters are set to achieve optimal distributions of passengers between exits with non-competitive behaviour e.g. seat jumping is not permitted.

Each scenario was run 1000 times using 10 different populations which fitted the scenario description (i.e. each population was run 100 times). Simulations which produced suboptimal results (simulations in which the exits failed to complete passenger flow within ten seconds of each other) were discarded and later re-run until optimal results were produced. The results from these narrow body simulations are intended to represent the best performance that the aircraft configuration is likely to produce under certification conditions.

A total of six exit combinations were examined as shown in

Table 5-4. These exit combinations, included the base case which represented the standard certification scenario and five additional cases which represent each of the exit combination already identified in section 5.2.1. Scenario 1 represents the most likely exit configuration based on data from the AASK database and Scenario 5 represents the least most likely of the five cases.

Table 5-4: Possible exit availability distribution assuming 50% of exits are available based on accident frequency data from [2] for a narrow body aircraft in descending order of likelihood

Scenario	Forward Exit Zone		Middle Exit Zone		Aft Exit Zone	
	R1 Type C (Forward Right)	**L1 Type B (Forward Left)**	**R2 Type III (Right Over Wing)**	**L2 Type III (Left Over Wing)**	**R3 Type C (Aft Right)**	**L3 Type B (Aft Left)**
1	Y	N	Y	Y	N	N
2	Y	Y	Y	N	N	N
3	Y	Y	N	N	Y	N
4	Y	N	N	N	Y	Y
5	N	N	Y	N	Y	Y
Base Case (Typical Certification scenario)	Y	N	Y	N	Y	N

5.2.3 Results and discussion of the narrow bodied aircraft simulations

The first scenario examined is the base case or actual evacuation certification scenario. As can be seen from Table 5-5 airEXODUS predicts that under strict evacuation certification conditions this aircraft is likely to produce on-ground times of between 67.0 s and 76.8 s with a mean of 71.2 s and a 95th percentile time of 73.8 s (see Figure 5-2). The time achieved by this aircraft in the actual certification trial falls on the predicted curve and is between the minimum and mean predicted times. This result, in addition to those presented in [8] suggests that the airEXODUS model is capable of predicting the likely outcome of evacuation certification trials.

From this analysis, it can be noted that the passengers and crew travel an average distance of 6.5 m and require an average of 39.6 s to exit the aircraft. On average, the passengers spend 24.7 s caught in congestion (Cumulative Wait Time or CWT) which suggests that on average a passenger wasted 62% of their PET (Personal Evacuation Time) in unproductive congestion.

Furthermore, unlike the certification process which (currently) only requires a single trial, these simulations suggest that the outcome of all 1000 optimal evacuation simulations were sub-90 seconds and so this aircraft with 154 passengers and crew and all the exits on the right hand side available comfortably satisfies the "intent" of the evacuation certification trial. However, the certification pass-fail criterion clearly does not take into account the possibility of multiple trial executions. In an attempt to address this point and in anticipation of the eventual use of evacuation simulation tools to assess aircraft evacuation performance for certification, Galea [9] has suggested a procedure for the use of evacuation simulation models as part of the evacuation certification process. As part of this process Galea suggests that the 95th percentile result from a distribution of simulated evacuation times should satisfy the 90 second criteria. Once again, clearly this aircraft undergoing the base case scenario clearly satisfies this condition producing a 95th percentile evacuation time of 73.8 s.

Table 5-5: airEXODUS optimal predicted results for base case scenario

Scenario		Out of aircraft time (s)	On-ground time (s)	Av. PET (s)	Av. CWT (s)	Av. DIST (m)
Base Case Certification (R1-R2-R3)	**Min**	65.5	67.0	37.8	23.1	6.4
	Mean	**69.3**	**71.2**	**39.6**	**24.7**	**6.5**
	Max	74.8	76.8	41.7	26.8	6.7
	95th%ile	71.7	73.8	40.8	6.6	25.8

Having established the certification performance of the aircraft we now turn our attention to the performance of the aircraft under certification conditions but with exit combinations as indicated in

Table 5-4. The results from these five scenarios are summarised in Table 5-6 with the distribution of evacuation times produced for each scenario displayed in Figure 5-2.

The results for Scenario 1, in which one exit was available in the front of the aircraft (R1) and two over-wing exits (R2 and L2) were available, suggest the aircraft can produce on-ground times of between 79.5 s and 99.6 s with a mean of 87.7 s and a 95th percentile time of 92.4 s. In this case we note that the mean on-ground time has increased by 23% when compared to the base case. We also note that passengers travelled an average of 8.5 m representing an increase of 2 m compared to the certification scenario. The average PET increases to 46.6 s, while the average CWT is 29.3 s. So while the average PET and CWT has increased when compared to the certification case, we find that 63% of the PET is wasted in congestion, only 1% greater than in the certification case.

Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 1 just fails the evacuation certification trial (see Figure 5-2).

The results for Scenario 2, in which two exits were available in the front of the aircraft (R1 and L1) and one right over-wing exit (R2) was available, suggest the aircraft can produce on-ground times of between 86.7 s and 112.3 s with a mean of 98.1 s and a 95th percentile time of 105.4 s. In this case we note that the mean on-ground time has increased by 38% when compared to the base case. We also note that passengers travelled an average of 10.2 m representing an increase of 3.7 m compared to the certification scenario. The average PET increases to 49.8 s, while the average CWT is 31.0 s. Once again we find on average 62% of the PET is wasted in congestion which is the same as in the certification case.

Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 2 clearly fails the evacuation certification trial (see Figure 5-2).

The results for Scenario 3, in which two exits were available in the front of the aircraft (R1 and L1) and one aft right exit (R3) was available, suggest the aircraft can produce on-ground times of between 73.5 s and 85.3 s with a mean of 77.7 s and a 95th percentile time of 81.4 s. In this case we note that the mean on-ground time has increased by 9% when compared to the base case. We also note that passengers travelled an average of 8.3 m representing an increase of 1.8 m compared to the certification scenario. The average PET for a passenger was 41.9 s, while the average CWT is 25.5 s. Therefore approximately 61% of the PET is wasted in congestion which represents a reduction by 1% when compared to the certification scenario.

Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 3 comfortably passes the evacuation certification trial, albeit with a smaller margin than the base case (see Figure 5-2).

Table 5-6: airEXODUS optimal predicted results for the five exiting scenarios

Scenario		Out of Aircraft time (s)	On-ground time (s)	Av.PET (s)	Av.CWT (s)	Av.DIST (m)
1 (R1-R2-L2)	**Min**	77.5	79.5	43.6	27.1	7.7
	Mean	**85.7**	**87.7**	**46.6**	**29.3**	**8.5**
	Max	97.4	99.6	50.3	32.6	8.8
	95th%ile	90.5	92.4	48.4	30.9	8.7
2 (R1-L1-R2)	**Min**	84.8	86.7	46.5	27.5	9.7
	Mean	**96.1**	**98.1**	**49.8**	**31.0**	**10.2**
	Max	110.9	112.3	54.8	35.9	10.6
	95th%ile	103.4	105.4	52.3	33.4	10.4
3 (R1-L1-R3)	**Min**	71.4	73.5	39.3	23.1	8.3
	Mean	**75.8**	**77.7**	**41.9**	**25.5**	**8.3**
	Max	83.0	85.3	45.9	29.4	8.4
	95th%ile	79.3	81.4	43.7	27.3	8.3
4 (R1-R3-L3)	**Min**	68.7	70.8	39.0	22.3	8.5
	Mean	**74.5**	**76.5**	**41.7**	**25.1**	**8.5**
	Max	82.5	84.5	45.2	28.8	8.6
	95th%ile	78.6	80.5	43.6	26.9	8.5
5 (R2-R3-L3)	**Min**	78.8	80.7	44.2	25.8	8.6
	Mean	**89.2**	**91.1**	**48.3**	**29.9**	**9.9**
	Max	102.2	103.7	55.3	37.1	10.5
	95th%ile	95.8	97.8	50.8	32.4	10.3

The results for Scenario 4, in which one exit was available in the front of the aircraft (R1) and two exits were available in the aft (R3 and L3), suggest the aircraft can produce on-ground times of between 70.8 s and 84.5 s with a mean of 76.5 s and a 95th percentile time of 80.5 s. These results are very similar to Scenario 3. In this case we note that the mean on-ground time has increased by 7% when compared to the base case. We also note that passengers travelled an average of 8.5 m representing an increase of 2.0 m compared to the certification scenario. The average PET for a passenger was 41.7 s, while the average CWT is 25.1 s. Thus in this case approximately 60% of the PET is wasted in congestion which represents a reduction by 2% when compared to the certification scenario.

Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 4 comfortably passes the evacuation certification trial, albeit with a smaller margin than the base case (see Figure 5-2).

The results for Scenario 5, in which one exit was available in the over-wing area (R2) and two exits were located in the rear (R3 and L3), suggest the aircraft can produce on-ground times of between 80.7 s and 103.7 s with a mean of 91.1 s and a 95th percentile time of 97.8 s. While the configuration is similar to Scenario 2, with the two forward exits in Scenario 2 replaced by two aft exits in Scenario 5, the results are considerably quicker than those produced by Scenario 2. In this case we note that the mean on-ground time has increased by 28% when compared to the base case.

We also note that passengers travelled an average of 9.9 m representing an increase of 3.4 m compared to the certification scenario. The average PET for a passenger was 48.3 s, while the average CWT is 29.9 s. Thus in this case approximately 62% of the PET is wasted in congestion which is identical to the certification scenario.

Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 5 convincingly fails the evacuation certification trial (see Figure 5-2).

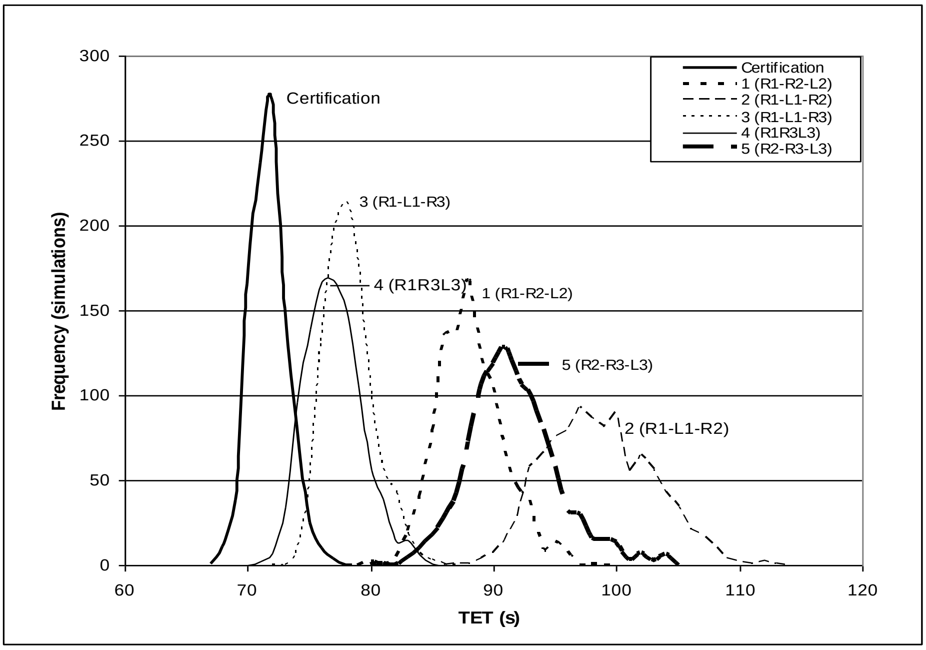


Figure 5-2: Frequency Distribution for TET (On- Ground Times) for all Scenarios

Furthermore, we note from Figure 5-2 the wide distribution in evacuation times produced by the various exit combinations. This figure emphasises the significant difference in egress times that can result from taking different combinations of 50% of the available exits. It also strongly emphasises that the certification combination of exits is the least challenging of the exit combinations.

From these results we note a number of interesting outcomes:

- The certification exit configuration produces the quickest on-ground times and is therefore the least challenging of the six configurations.
- The worst performing exit configuration which also fails to meet the certification criterion is the second most likely exit configuration i.e. Scenario 2.
- Three exit configurations produce on-ground times that actually fail to meet the certification criterion.
- The two most frequently occurring exit configurations i.e. Scenarios 1 and 2, fail to meet the certification criterion.
- Two of the exit configurations that fail the certification criterion have the same exit capacity as the certification case.

- Scenarios with greater exit capacity than the base case i.e. Scenarios 3 and 4 produce slower on-ground times albeit satisfying the certification requirement.
- Two scenarios with similar exit configurations i.e. Scenario 2 (two forward and one over-wing exit) and Scenario 5 (two aft and one over-wing exit) and hence similar exit capacities produce very different on-ground times.

At first sight these results may appear surprising but can be explained by the evacuation dynamics. Presented in Table 5-7 are the average exit flow rates achieved for each of the exits as predicted by airEXODUS. We note from this table that when there is a single exit operating out of an exit pair, the flow rates achieved by the exit is greater than when both exits in a pair are operating and the predicted average value is quite close to the expected values for the particular exit type. In particular we note that the Type III exit achieves an average flow rate of 37.2 ppm while the Type C exit achieves an average flow rate of 59.0 ppm. The predicted Type III exit is some 0.5% faster on average and the Type C is some 9% slower on average than the measured average from certification trials.

Table 5-7: Average flow rates for each exit in all scenarios

Scenario	Average Flow Rates (ppm) Forward Exit Zone		Average Flow Rates (ppm) Middle Exit Zone		Average Flow Rates (ppm) Aft Exit Zone	
	R1 Type C (Forward right)	L1 Type B (Forward Left)	R2 Type III (Right Over Wing)	L2 Type III (Left Over Wing)	R3 Type C (Aft Right)	L3 Type B (Aft Left)
Certification (R1-R2-R3)	**58.8**	0.0	**39.2**	0.0	**58.9**	0.0
1 (R1-R2-L2)	**58.7**	0.0	**32.9**	**33.8**	0.0	0.0
2 (R1-L1-R2)	**38.4**	**35.2**	**35.1**	0.0	0.0	0.0
3 (R1-L1-R3)	**41.2**	**38.0**	0.0	0.0	**59.0**	0.0

4 (R1-R3-L3)	**58.8**	0.0	0.0	0.0	**41.1**	**41.0**
5 (R2-R3-L3)	0.0	0.0	**37.5**	0.0	**41.5**	**41.4**

When we consider situations in which the both exits in a pair are available and there are not other complicating factors, such as proximity of another functioning exit, i.e. Scenarios 3 and 4 we note that the exits produce a considerably reduced average flow rate. In scenario 4 we note that the pair of exits, Type B and Type C in the rear produces an average flow rate of approximately 41.0 ppm, some 30% less than the flow rate for the Type C exit when functioning alone.

This reduced flow rate is a direct result of the single aisle feeding both exits. When only a single exit from a pair is functioning, the limiting factor on exit performance is the capacity of the exit, the aisle being able to feed sufficient passengers to keep the exit functioning at its full capacity. However, when two exits in a pair are functioning the single aisle cannot supply sufficient passengers to keep both exits working at full capacity and hence a drop in exit flow rate is achieved.

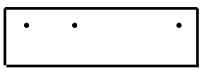
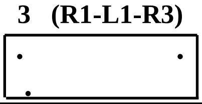
In Scenarios 2 a similar phenomenon occurs however, this configuration has the added complication that the two exits within the pair are off-set. Thus there is a slight added hesitation and conflict in the exit intersection region as some passengers are persuaded to go slightly forward to exit via the right exit rather than being drawn to the nearer left exit. This exit configuration appears to be less efficient than having two exits aligned in a pair and so the combined flow rate is slightly less than the configuration in the rear of the aircraft.

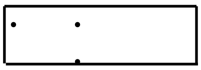
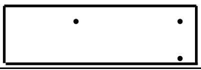
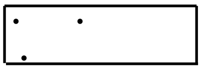
A similar situation occurs in Scenario 1 with the pair of Type III exits. In this case we find that the pair of Type III exits in the over-wing position produces an average flow rate of approximately 33.4 ppm, some 10% less than the flow rate for the Type III exit when functioning alone. The reduction in efficiency for the pair of Type III exits is considerably less than that noted for the pair of Type C/B exits. This is due to the flow capacity of the Type III exit being considerably less than that for the Type C/B exits. As a result the aisle feeding the Type III exit has considerably more capacity than can be accommodated by the single Type III exit. Therefore, in situations where a second Type III exit becomes available, the imbalance in aisle flow capacity feeding the exits and exit flow capacity of the two exits will be less than that for the pair of Type C/B exits resulting in the noted smaller decrease in net exit flow capacity.

Another surprising result is that two scenarios with similar exit configurations i.e. Scenarios 2 and 5 produce 95th percentile results which are some 8% different. Both scenarios involve a single overwing exit and a pair of Type C/B exits, Scenario 2 with the active pair in the forward position producing a slower evacuation then Scenario 5 which has the pair of Type C/B in the rear. This difference is due to the Type III exit not being located in the centre of the aircraft. The Type III exit is located closer to the front of the aircraft, being some 10 seat rows from the front and some 14 seat rows from the rear. The front exit pair therefore has a smaller catchment of passengers to readily supply the exits than the rear exit pair. As the pair of Type C/B exits has a greater flow capacity than the single Type III exit they require a greater supply of passengers in order to keep them functioning at full capacity. As a result, more passengers in Scenario 2 are required to bi-pass the over-wing exit to keep the exit pair working than in Scenario 5. This results in Scenario 2 being less efficient than Scenario 5. If the over-wing exit was more centrally located, the overall egress time for Scenario 2 would decrease, while that for Scenario 5 would increase.

The results are summarised in where the 95th percentile on-ground times are presented along with the average total exit flow rates for the six scenarios ranked from the fastest to the slowest evacuations.

Table 5-8: Average 95th Percentile on-ground times, average distance travelled and average total exit flow rate for the various configurations ranked from the fastest to the slowest

Rank	Scenario	95th Percentile on-ground time (s)	Av. Dist (m)	Av. Total Exit Flow rate (ppm)
Base case	(R1-R2-R3) 	73.8	6.5	156.9
1	4 (R1-R3-L3) 	80.5	8.5	140.8
2	3 (R1-L1-R3) 	81.4	8.3	138.2

3	**1 (R1-R2-L2)** 	**92.4**	**8.5**	**125.4**
4	**5 (R2-R3-L3)** 	**97.8**	**9.9**	**120.4**
5	**2 (R1-L1-R2)** 	**105.4**	**10.2**	**108.7**

With the above explanations of the evacuation dynamics, the ordering of the scenarios found in Table 5-8 and the noted interesting results can now be understood.

If a single exit from an exit pair is functioning, the flow rate achieved through the exit will be optimal. This is because a single cabin aisle cannot provide sufficient supply of passengers to maintain maximal flows through both exits in an exit pair. As a result, flows achieved through exit pairs are predicted to be on average 30% lower per exit for Type C exits and 10% less on average for Type III exits.

Thus for a narrow body aircraft with three exit pairs consisting of Type B/C/I exits in the forward and aft and a pair of Type III exits in the over-wing position, if only 50% of the exits are available, selecting a single exit from each exit pair is likely to produce the greatest overall exit flow rate. In addition, this distribution of exits will produce the smallest average travel distance for the passengers as it results in the most number of passengers being close to an exit. These two factors combine to produce the shortest total egress times.

Other combinations of two Type B/C/I exits and a Type III exit (i.e. Scenario 2 and 5) will produce significantly slower egress times due to the 30% reduction in exit efficiency for the paired Type B/C/I exits. For the particular aircraft examined, the combination involving the forward and over-wing configuration (i.e. Scenario 2) is likely to produce slower egress times due to the proximity of the Type III exit to the forward exit creating a greater need for exit by-pass in order to keep the forward exits working.

Combinations of three Type B/C/I exits (i.e. Scenarios 3 and 4) will produce better egress times than paired Type B/C/I exits and a single Type III exit (i.e. Scenarios 2 and 5) due to the greater flow rate achieved by the single Type B/C/I compared to the single Type III. There should be little difference between having the pair located in the front or the rear. However, in this particular case, the exit off-set in the front of the cabin made this case (Scenario 3) slightly less efficient than the case with the pair in the rear of the cabin (Scenario 4).

The configuration with a pair of Type III exits is more difficult to place (Scenario 1). The pair of Type III exits will only suffer a 10% degradation in performance due to being paired. However, this will produce a performance for the pair of Type IIIs which is less than that for a pair of Type B/C/I exits. Thus we would expect the performance of this configuration to be slower than that for the case with three Type B/C/I exits (i.e. Scenarios 3 and 4). While the pair of Type III exits will produce a slower flow rate than a pair of Type B/C/I exits, the single Type B/C/I exit (Scenario 1) will produce a much better flow rate than the single Type III exit (Scenario 2 and 5). We could therefore expect the configuration with a pair of Type III exits and single Type B/C/I (Scenario 1) exit to outperform the configurations with a pair of Type B/C/I exits and a single Type III exit (Scenarios 2 and 5). However, this result may not be generally true as it is affected by the particular configuration of exits found in this study i.e. none centrally located Type III exit and off set forward exits.

It should be remembered in viewing these results that they are all based on model simulations and not actual experiments. It is believed that full scale experiments have not been conducted (or at least reported in the academic or professional press) to substantiate the findings from these simulations. However, while the precise timings produced by these simulations might be questioned and as a result the precise resultant ranking of the scenarios, it is likely that the main conclusion that the exit configuration used in the current evacuation certification trial is neither representative of likely real accident scenarios nor particularly challenging is valid.

The findings of this work have implications as to the appropriateness of the current evacuation certification trial as a relevant and informative benchmark of egress performance and safety. Galea [9] has suggested that it would be more appropriate to investigate several exit combinations as part of the certification process using computer egress simulation. Furthermore, if 90 seconds is considered to be a real and valid measure of the required evacuation performance of aircraft in the event of a fire, these results convey even more significance.

5.2.4 A study of wide bodied aircraft certification tests

The aircraft geometry which was used during this analysis is of wide body aircraft with four exit pairs seating 440 passengers and containing 11 cabin crew. The aircraft configuration used during this analysis represents an actual aircraft which successfully passed the evacuation certification test. Four exits were used in the certification trial, all on the left side of the aircraft, which consisted of four Types A exits (L1, L2, L3 and L4). Two of the Type A exits included cantors (L2 and L3).

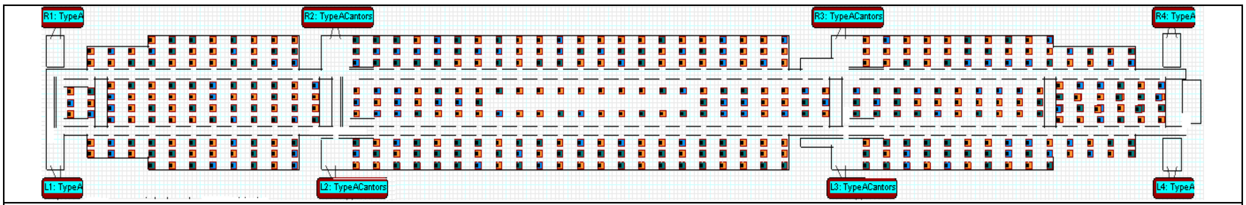


Figure 5-3:Schematic layout of the test aircraft showing seating configuration and exit location

In the wide body simulations presented during this section, the default generalised passenger exit hesitation time distribution (assuming assertive crew) appropriate for the various exit types were used with default exit ready times of 11.1 secs for the forward and aft exits, 12.3 secs for the mid-forward and mid-aft exits. Passenger attributes are set from the default certification parameter set. The airEXODUS parameter “Off-Time distribution” (i.e. the time required to descend the slide or wing) was also assumed to follow the default distribution appropriate for the various exit types. Other model parameters are set to achieve optimal distributions of passengers between exits with non-competitive behaviour e.g. seat jumping is not permitted.

Each scenario was run 1000 times using 10 different populations which fitted the scenario description (i.e. each population was run 100 times). Simulations which produced suboptimal results (simulations in which the exits failed to complete passenger flow within ten seconds of each other) were discarded and re-run until optimal results were produced.

The results from these simulations are intended to represent the best performance the aircraft configuration is likely to produce under certification conditions.

In total six exit combinations were examined as shown in Table 5-9. These are the base case, representing the standard certification scenario and five additional cases representing each of the exit combinations identified in Section 5.2.1. Scenario 1 represents the most likely exit configuration based on data from the AASK database and Scenario 5 represents the least likely of the 5 cases.

Table 5-9 : Possible exit availability distribution assuming 50% of exits are available based on accident frequency data from [2] for a wide bodied aircraft in descending order of likelihood

Scenario	R1 Type A (Forward Right)	L1 Type A (Forward Left)	R2 Type A-Cantors (Mid Forward Right)	L2 Type A-Cantors (Mid Forward Left)	R3 Type A-Cantors (Mid Aft Right)	L3 Type A-Cantors (Mid Aft Left)	R4 Type A (Aft Right)	L4 Type A (Aft Left)
1	Y	Y	Y	Y	N	N	N	N
2	Y	Y	N	N	Y	N	Y	N
3	N	N	Y	Y	Y	N	Y	N
4	Y	Y	Y	N	Y	N	N	N
5	Y	Y	N	N	N	N	Y	Y
Base Case (Typical Certification scenario)	N	Y	N	Y	N	Y	N	Y

5.2.5 Results and discussion of the wide bodied aircraft simulations

The first scenario examined is the base case or actual evacuation certification scenario. As can be seen from

Table 5-10 airEXODUS predicts that under strict evacuation certification conditions this aircraft is likely to produce on-ground times of between 70.9 s and 83.1 s with a mean of 76.9 s and a 95th percentile time of 80.0 s (See Figure 5-4). The time achieved by this aircraft in the actual certification trial falls on the predicted curve and is between the minimum and mean predicted times. This result, in addition to those presented in [12] suggests that the airEXODUS model is capable of predicting the likely outcome of evacuation certification trials.

We also note from this analysis that the passengers and crew travel an average distance of 9.0 m and require an average of 42.3 s to exit the aircraft. In addition, on average, the passengers spend 23.8 s caught in congestion (Cumulative Wait Time or CWT). This suggests that on average a passenger wasted 56% of their PET (Personal Evacuation Time) in unproductive congestion.

Furthermore, unlike the certification process which (currently) only requires a single trial, these simulations suggest that the outcome of all 1000 optimal evacuation simulations were sub-90 seconds and so this aircraft with 451 passengers and crew and all the exits on the left hand side available comfortably satisfies the “intent” of the evacuation certification trial. However, the certification pass-fail criterion clearly does not take into account the possibility of multiple trial executions. In an attempt to address this point and in anticipation of the eventual use of evacuation simulation tools to assess aircraft evacuation performance for certification, Galea [9] has suggested a procedure for the use of evacuation simulation models as part of the evacuation certification process. As part of this process he suggests that the 95th percentile result from a distribution of simulated evacuation times should satisfy the 90 second criteria. Once again, clearly this aircraft undergoing the base case scenario clearly satisfies this condition producing a 95th percentile evacuation time of 80.0 s.

Table 5-10: airEXODUS optimal predicted results for wide body base case scenario

Scenario		**Out of aircraft time (s)**	**On-ground time (s)**	**On-ground time for 95$^{th\%ile}$ of population**	**Av. PET (s)**	**Av. CWT (s)**	**Av. DIST (m)**
Base Case Certification (L1-L2-L3-L4)	**Min**	68.2	70.9	68.3	40.9	22.4	8.8
	Mean	**73.9**	**76.9**	72.1	**42.3**	**23.8**	**9.0**
	Max	79.7	83.1	77.2	44.5	25.9	9.3
	95$^{th\%ile}$	76.9	80.0	74.5	43.2	24.7	9.2

Having established the certification performance of the aircraft we now turn our attention to the performance of the wide body aircraft under certification conditions but with exit combinations as indicated in Table 5-9. The results from these five scenarios are summarised in Table 5-11 with the distribution of evacuation times produced for each scenario displayed in Figure 5-4.

The results for Scenario 1, in which both exits were available in the forward section of the aircraft (R1 and L1) and two in the mid-forward section (R2 and L2) were available and no exits elsewhere, suggest the aircraft can produce on-ground times of between 125.1 s and 155.6 s with a mean of 137.9 s and a 95th percentile time of 145.5 s. In this case we note that the mean on-ground time has increased by 79% when compared to the base case. We also note that passengers travelled an average of 16.9 m representing an increase of 7.9 m compared to the certification scenario. The average PET increases to 59.9 s, while the average CWT is 33.4 s. So while the average PET and CWT have increased when compared to the certification case, we find that 55.7% of the PET is wasted in congestion, only 0.3% lower than in the certification case.

Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 1 fails the evacuation certification trial (see Figure 5-4).

The results for Scenario 2, in which both exits were available in the front of the aircraft (R1 and L1) and one exit available in both the mid aft and aft sections (R3 and R4), suggest the aircraft can produce on-ground times of between 77.2 s and 93.9 s with a mean of 84.5 s and a 95th percentile time of 88.6 s. In this case we note that the mean on-ground time has increased by 10% approximately when compared to the base case. We also note that passengers travelled an average of 10.9 m representing an increase of 1.9 m compared to the certification scenario. The average PET increases to 45.8 s, while the average CWT is 25.3 s. Once again we find on average 55% of the PET is wasted in congestion which is 1 % lower than in the certification case.

Using the 95th percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 2 barely passes the evacuation certification trial (see Figure 5-4).

The results for Scenario 3, in which two exits were available in the mid forward section of the aircraft (R2 and L2) and one available exit in both the mid aft and aft sections (R3 and R4), suggest the aircraft can produce on-ground times of between 69.2 s and 81.7 s with a mean of 75.0 s and a 95th percentile time of 78.3 s. In this case we note that the mean on-ground time has decreased by 2.5% when compared to the base case. We also note that passengers travelled an average of 8.5 m representing a decrease of 0.5 m compared to the certification scenario. The average PET for a passenger was 41.8 s, while the average CWT is 24.0 s. Therefore approximately 57% of the PET is wasted in congestion which represents an approximate increase of 1% when compared to the certification scenario.

Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 3 comfortably passes the evacuation certification trial, albeit with a slightly greater margin than the base case (see Figure 5-4).

Table 5-11: air Exodus optimal predicted wide body results for the five exiting scenarios

Scenario		Out of Aircraft time (s)	On-ground time (s)	On-ground time for 98$^{th\%ile}$ of population	Av.PET (s)	Av.CWT (s)	Av. DIST (m)
1 (R1-L1-R2-L2)	Min	122.1	125.1	117.6	56.2	29.5	16.7
	Mean	**135.1**	**137.9**	**127.8**	**59.9**	**33.4**	**16.9**
	Max	152.7	155.6	139.5	63.6	37.1	17.6
	95$^{th\%ile}$	142.4	145.5	133.5	61.7	35.2	17.2
2 (R1-L1-R3-R4)	Min	74.1	77.2	74.5	43.8	23.4	10.7
	Mean	**81.5**	**84.5**	**79.6**	**45.8**	**25.3**	**10.9**
	Max	90.4	93.9	84.8	48.8	28.3	11.1
	95$^{th\%ile}$	85.5	88.6	82.5	47.0	26.5	11.0
3 (R2-L2-R3-R4)	Min	66.4	69.2	67.1	40.4	22.7	8.3
	Mean	**72.0**	**75.0**	**70.6**	**41.8**	**24.0**	**8.5**
	Max	78.3	81.7	75.6	43.8	26.1	8.7
	95$^{th\%ile}$	75.2	78.3	73.3	42.7	24.9	8.6
4 (R1-L1-R2-R3)	Min	82.1	84.9	82.9	45.9	24.2	11.4
	Mean	**92.1**	**95.1**	**88.4**	**48.1**	**26.5**	**11.9**
	Max	105.8	108.3	98.2	51.3	29.8	12.3
	95$^{th\%ile}$	97.1	100.3	91.9	49.3	27.7	12.1
5 (R1-L1-R4-L4)	Min	92.3	95.8	90.5	49.7	25.9	13.5
	Mean	**102.3**	**105.3**	**97.9**	**52.3**	**28.7**	**13.7**
	Max	114.0	117.4	107.1	55.3	31.5	13.9
	95$^{th\%ile}$	108.1	111.1	102.6	53.7	30.2	13.8

The results for Scenario 4, in which both exits were available in the front of the aircraft (R1 and L1) and one exit was available in both the mid forward right and in the mid aft right sections (R2 and R3), suggest the aircraft can produce on-ground times of between 84.9 s and 108.3 s with a mean of 95.1 s and a 95th percentile time of 100.3 s. In this case we note that the mean on-ground time has increased by approximately 24% when compared to the base case. We also note that passengers travelled an average of 11.9 m representing an increase of 2.9 m compared to the certification scenario. The average PET for a passenger was 48.1 s, while the average CWT is 26.5 s. Thus in this case approximately 55% of the PET is wasted in congestion which represents a reduction by 1% when compared to the certification scenario.

Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 4 fails the evacuation certification trial by approximately 10 s (see Figure 5-4).

The results for Scenario 5, in which both exits at the front section of the aircraft (R1 and L1) and both exits located in the rear (R4 and L4) were available, suggest the aircraft can produce on-ground times of between 95.8 s and 117.4 s with a mean of 105.3 s and a 95th percentile time of 111.1 s. In this case we note that the mean on-ground time has increased by 37% when compared to the base case.

We also note that passengers travelled an average of 13.7 m representing an increase of 4.7 m compared to the certification scenario. The average PET for a passenger was 52.3 s, while the average CWT is 28.7 s. Thus in this case approximately 55% of the PET is wasted in congestion which is a reduction by 1.4% in comparison to the certification scenario.

Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario 5 convincingly fails the evacuation certification trial (see Figure 5-4).

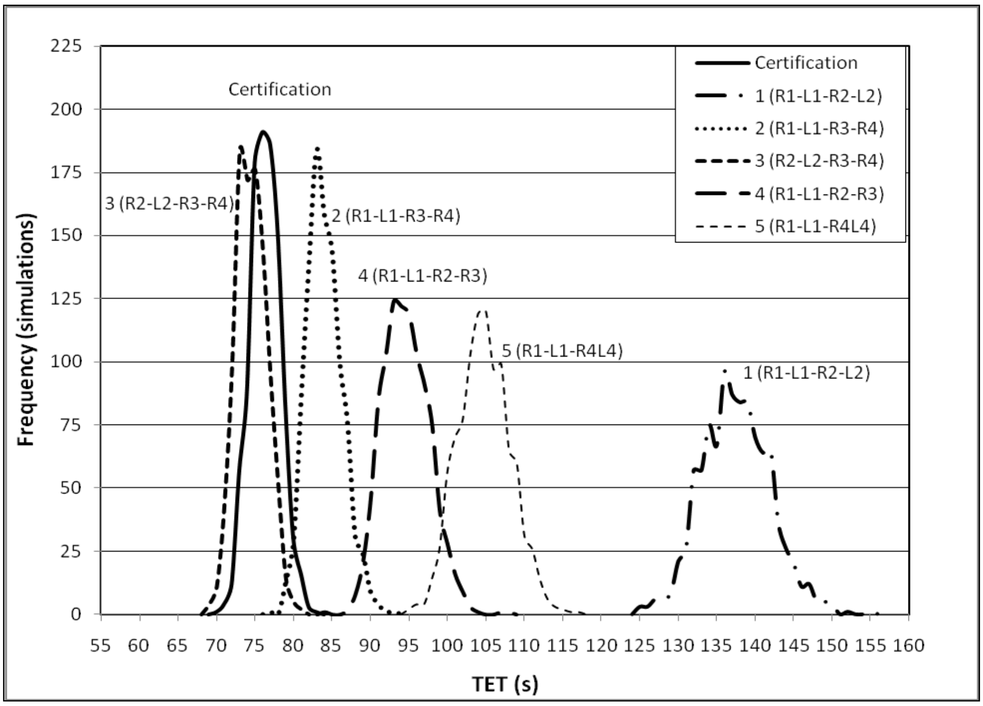


Figure 5-4: Frequency Distribution for TET (On-Ground Times) for all Scenarios

Furthermore, we note from Figure 5-4 that there is a wide distribution in evacuation times produced by the different exit combinations. Figure 5-4 emphasises the significant difference in egress times that can result from using different combinations of 50% of the available exits. Again as in the narrow body aircraft, it also strongly emphasises that the certification combination of exits is one of the least challenging of the exit combinations.

From these results we note a number of interesting outcomes:

- The certification exit configuration produces one of the quickest on-ground times and is therefore the second least challenging of the six configurations.
- The worst performing exit configuration which also fails to meet the certification criterion is the first most likely exit configuration i.e. Scenario 1.
- Four exit configurations produce on-ground times that actually fail to meet the certification criterion.
- Exit configurations i.e. Scenarios 1, 2, 4 and 5 fail to meet the certification criterion.
- Two exit configuration i.e. Scenario 1 and 4 that fail the certification criterion have the same exit capacity as the certification case.
- Scenario with greater exit capacity than the base case i.e. Scenarios 3 produces faster on-ground times albeit satisfying the certification requirement.

At first, these results may appear surprising but can be explained by the evacuation dynamics. Presented in Table 5-12 are the average exit flow rates that have been achieved for each of the exits as predicted by airExodus. From this table, we note that when there is a single exit operating out of an exit pair at the front or the aft of the aircraft, the flow rates achieved by the exit is greater than when both exits in a pair are operating and the predicted average value is quite close to the expected values for the particular exit type. In particular we note that the Type A located in the front and aft of the aircraft achieves an average flow rate of 111.6 ppm while the Type A exit with cantors located in the mid forward or mid aft sections achieves an average flow rate of 125.0 ppm. The Type A exit with cantors when operating in a pair does not appear to depreciate the flow rate of the exit. The flow rates achieved for operating alone and in a pair for the Type A exit with cantors are very similar expect in the case of Scenario 1 which has other complicating factors.

The predicted Type A exit with cantors is some 9.3% slower on average and the Type A without cantors which is some 25.7% slower on average than the measured average from the certification trial.

Table 5-12: Average flow rates acheived for each exit in all scenarios

	Average Flow Rates (ppm) Forward Exit Zone		Average Flow Rates (ppm) Mid-Forward Exit Zone		Average Flow Rates (ppm) Mid-Aft Exit Zone		Average Flow Rates (ppm) Aft Exit Zone	
	R1 Type A (Forward right)	L1 Type A (Forward Left)	R2 Type A with Cantors (Mid-Forward Right)	L2 Type A with Cantors (Mid-Forward Left)	R3 Type A with Cantors (Mid-Aft Right)	L3 Type A with Cantors (Mid-Aft Left)	R4 Type A (Aft Right)	L4 Type A (Aft Left)
Certification (L1-L2-L3-L4)	0.0	107.0	0.0	119.1	0.0	115.8	0.0	110.5
1 (R1-L1-R2-L2)	37.3	39.6	76.7	73.2	0.0	0.0	0.0	0.0
2 (R1-L1-R3-R4)	81.3	81.7	0.0	0.0	125.0	0.0	111.6	0.0
3 (R2-L2-R3-R4)	0.0	0.0	117.8	118.3	120.7	0.0	110.7	0.0
4 (R1-L1-R2-R3)	55.1	70.3	109.7	0.0	116.0	0.0	0.0	0.0
5 (R1-L1-R4-L4)	79.8	71.9	0.0	0.0	0.0	0.0	75.6	72.0

While considering situations in which both exits in a pair are available and there are no other complicating factors, such as proximity of another functioning exit, i.e. Particularly in Scenarios 5, we note that the Type A exit produces a much reduced average flow rate. In Scenario 5 we note that the pair of Type A exits located in the forward and aft sections of the aircraft; each individual exit produces an average flow rate of approximately 74.8 ppm, some 29.5% less than the flow rate for the Type A exit when functioning alone in the base case.

In Scenario 5, this reduced flow rate is a direct result of each of the four exits only being fed a single queue of passengers due to the well spread out positioning of the exits in the four corners. On the other hand in the base case, the forward and aft Type A exits are each fed by two queues of passengers while the mid forward and mid aft exits are each fed queues from three sides.

Another surprising result is; that three scenarios with similar exit capacity i.e. the base case and Scenarios 1 and 4 produce 95th percentile results which are some 82% different. All scenarios involve four Type A exits; two of them including cantors. Scenario 1 contains an active pair in the forward position and another active pair in the mid forward section. Scenario 4 on the other hand has an active pair of exits in the forward position along with a functioning exit in the mid forward and mid aft regions. Scenarios 1 and 4 produce slower evacuation times than the base case which is exclusive of exit pairs. Scenario 1 produces the longest mean on ground times from all scenarios, failing in every simulation.

In Scenario 1 the most commonly found situation, with both exits available in the forward section (R1and L1) and both exits available in the mid forward section (R2 and L2). Although these exits in Scenario 1 have the same exit capacity as the base case, the performance has greatly depreciated due to exit location. The average total flow rate has dropped by some 52% when compared with the base case (see Table 5-13). The flow rates of forward exit R1 and mid forward exit R2 have dropped by nearly 65% and 37% respectively when compared with exits in the same sections in the base case (see Table 5-12). In Scenario 1, the largest number of passengers, is closest to the mid forward exit location. Passenger by passing of the mid forward exits toward the forward exits is rarely required during this scenario as exits R2 and L2 cannot achieve full flow rate capacity. The flow rates of mid forward exits R2 and L2 are dependent on the flow rate of the aisle feeding them.

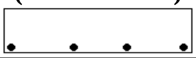
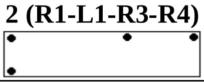
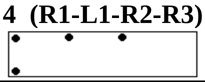
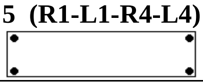
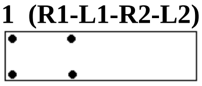
Scenario 2 is the second most likely situation with a 95th percentile ground time which passes. Scenario 2 ranks into third place just after the base case (see Table 5-13). This configuration includes three Type A exits and one Type A exit without cantors. During this configuration, the mid aft Type A exit with cantor (R3) achieves its best average flow rate with a 3.8% increase when compared to the average flow rate achieved for the same type of cantored exit in the base case. Scenario 2 incurs a net decrease in efficiency over the base case by 11.7%.

Scenario 3, the third most likely scenario gives the best overall ground time with an average total exit flow rate which has increased by some 3% over the base case (see Table 5-13). Scenario 3 is similar to the base case with the only difference being a forward exit being relocated to a mid-forward position. This makes a significant improvement to the average total exit flow rate and hence the total average ground time. In scenario 3, exit L2 can yield flow rates which are some 11% higher than exit L1 in the base case. This relocated, mid forward exit allows passengers to be fed from two sides whereas the forward exit in the base case can only being fed from one side.

In the Scenario 4 and the base case, three of the four exits have identical positioning apart from being on the opposite side of the fuselage. The main difference is that the one exit has moved from the aft section of the aircraft as in the base case to the forward part of the aircraft. This makes a significant impact on the overall ground time. The flow rate of forward exit (R1) has nearly halved in Scenario 4 in comparison with the forward exit used in the base case. Scenario 4 incurs a net decrease in flow rate of some 22% in comparison to the base case.

Mid forward exits and mid aft exits are achieving higher average flow rates than both the forward and aft exits in each scenario. The results are summarised in Table 5-13 where the 95th percentile on-ground times are presented along with the average total exit flow rates for the six scenarios ranked from the fastest to the slowest evacuations. With the explanations of the evacuation dynamics, the ordering of the scenarios found in Table 5-13 and the noted interesting results can now be understood.

Table 5-13: Average 95th Percentile on-ground times, average distance travelled and average total exit flow rate for the various configurations ranked from the fastest to the slowest

Rank	Scenario	95^{th} Percentile on-ground time (s)	Av. Dist (m)	Av. Total Exit Flow rate (ppm)
1	3 (R2-L2-R3-R4) 	78.3	8.7	467.5
2	Base Case (L1-L2-L3-L4) 	80.0	9.0	452.4
3	2 (R1-L1-R3-R4) 	88.6	10.9	399.6
4	4 (R1-L1-R2-R3) 	100.3	11.9	351.1
5	5 (R1-L1-R4-L4) 	111.1	13.8	299.3
6	1 (R1-L1-R2-L2) 	145.5	16.9	226.1

If a single exit from an exit pair is functioning in the front or the aft of the cabin, the flow rate achieved through this exit will be optimal. This is because a single exit will be supplied by two of the main aisles. A single cabin aisle on the other hand cannot provide a sufficient supply of passengers to maintain maximal flows through the single exit from an exit pair functioning in the front or the aft of the cabin. Flows achieved through exit pairs in the front or the aft cabin section are predicted to be on average 39.6% lower per exit for Type A exits.

Exit pairs located in the mid forward section (R2 and L2) as in Scenario 3 appear to be achieving a very good average flow rate of approximately 118.1 ppm which is very close to the average flow rate capacity achieved for this type of exit during the actual certification trial. In Scenario 1 however, the average flow rate of functioning, mid forward exit pairs (R2 and L2) has depreciated significantly in comparison with the mid forward exit in the certification trial to approximately 75 ppm. This is due to other complicating factors relating to poor location of other available exits in Scenario 1. These results also show that exit pairs located in the mid forward section of the cabin as in Scenario 3 can achieve on average near full exit capacity. No exit pairs located in the mid aft were tested during these scenarios.

Another combination of two Type A exits and a two Type A exits with cantors (i.e. Scenario 4) will produce significantly slower egress times due to the 39.6% reduction in average exit efficiency for the paired functioning Type A exits located either in the front or the aft of the cabin. Scenario 4 however achieves a worse than average flow rate reduction due to extra complicating factors of another closely located functioning exit in the mid forward section which interferes further with the already worsened flow rate. For the particular aircraft scenario examined, the combination involving the forward exit pair (R1 and L1), a mid-forward (R2) and mid aft (R3) exit configuration is likely to produce slower egress times due to the proximity of the exits (R1) and (R2) creating a greater need for exit by-pass in order to keep the forward exit working.

Thus for a wide body aircraft with four exit pairs consisting of a pair of Type A exits in the forward and aft and a pair of Type A exits with cantors in the mid forward and mid aft position, if only 50% of the exits are available, selecting exits which will be fed by two main aisles or will allow passenger travel from more than one direction is likely to produce the greatest overall exit flow rate. In addition, this distribution of exits will produce the smallest average travel distance for the passengers as it results in the largest number of passengers being close to an exit. These two factors combine to produce the shortest total egress times.

Situations where the exits are in close proximity to the largest number of passengers such as Scenario 3, seem to yield the best average total flow rate (see Table 5-13). It is expected that the average total flow rate of this scenario could be improved upon if all four exits were located in the mid forward and mid aft sections as this would give the closest passenger proximity than any other scenario tested. This would involve each of the four exits being fed from more than one direction.

It should be remembered in viewing of these results, that they are all based on model simulations and not actual experiments. Again as in the previous section relating to narrow body aircraft, it is believed that full scale experiments have not been conducted (or at least reported in the academic or professional press) to substantiate the findings from these simulations. However, while the precise timings produced by these simulations may be questioned and as a result the precise resultant ranking of the scenarios, it is likely that the main conclusion that the exit configuration used in the current evacuation certification trial is neither representative of likely real accident scenarios nor particularly challenging is valid.

The findings of this work have implications as to the appropriateness of the current evacuation certification trial as a relevant and informative benchmark of egress performance and safety. Galea [9] has suggested that it would be more appropriate to investigate several exit combinations as part of the certification process using computer egress simulation. Furthermore, if 90 seconds is considered to be a real and valid measure of the required evacuation performance of aircraft in the event of a fire, these results convey even more significance.

5.3 CONCLUDING REMARKS

This work has shown – through computer based evacuation simulation - that the certification practice of using half the available exits predominately down one side of the aircraft is neither statistically relevant nor challenging – at least for aircraft with three and four exit pairs.

For the narrow body aircraft cabin layout examined, of the six exit combinations investigated involving 50% of the available exits, the exit configuration used in certification trials produced the shortest egress times. Furthermore, three of the six exit combinations investigated resulted in (95^{th} percentile) egress times of greater than 90 seconds, suggesting that the aircraft would not satisfy the certification requirement under these conditions.

For the wide body aircraft cabin layout examined, of the six exit combinations investigated involving 50% of the available exits, the exit configuration used during certification trials produced one of the shortest egress times. Furthermore, three of the six exit combinations investigated resulted in (95^{th} percentile) egress times of greater than 90 seconds, suggesting that the aircraft would not satisfy the certification requirement under these conditions.

These results therefore draw into question the appropriateness of the current evacuation certification trial as a relevant and informative benchmark of egress safety. Demonstrating that the aircraft can be evacuated in 90 seconds using the current exit certification combination says little about how the aircraft is likely to perform in more realistic and challenging exit combinations. Using the current certification trial as a performance measure or “yard-stick” to guide aircraft design may obscure in-built design deficiencies which only come to light in more realistic accident situations. Indeed, if 90 seconds is considered to be a real and valid evacuation performance measure, demonstrating compliance using the current exit selection criteria may be considered as “setting the bar” too low!

By addressing issues associated with the certification and acceptance of aircraft configurations we may achieve the goal of producing safer aircraft, which the industry claim they desire and the traveling public certainly deserve.

6 A STUDY OF HOW PASSENGERS SELECT EXITS

6.1 INTRODUCTION

The exits selected by passengers during aircraft evacuation situations are of great interest to aviation regulators, who make rulings concerning exit separation, aircraft certification requirements, interior aircraft cabin layout, position of exits within the fuselage and the development of procedures for managing aircraft evacuation. It is often assumed that a passenger will have the tendency to select the exit from which they have entered the aircraft as this would be the most familiar to them. This is thought to be the case in building evacuation situations of which there is a considerable amount of evidence in support of this theory [21]. This theory on the other hand may not be valid for aircraft evacuations and indeed if it were to be true, in aircraft emergencies, the time required to evacuate a full load of passengers could be extreme. It is also considered that a passenger may prefer to move forward to an exit often forgetting or ignoring exits which could be behind them. Studies however using earlier versions of the AASK database - containing limited data - have suggested that this is not the case in aircraft situations [3, 22]. Further studies carried out using later versions of the AASK database [2] suggested 85% of passengers who reported exit usage; make use of their nearest exit which is a significant increase of 15% over that previously reported during analysis of the earlier version of the AASK database [3,22].

Analysis carried out [2] suggests that passengers in aircraft emergency situations are likely to use their nearest exit but it should be noted that analysis only includes those who participated in the interviews, providing a sufficient amount of information whilst also surviving the accident. Increased use of nearest exits could be the result of better aircraft design where exits are more noticeable and or passengers were more informed due to improvements in the pre-flight safety briefing carried out by crew. Those passengers choosing not to use nearest exits gave valid and rational reasons for not doing so [2].

Another commonly held belief is that passengers have a tendency to move forwards to the front of the aircraft. This belief has been supported by forward facing passengers therefore biasing passengers' choice of travel. Analysis [2] shows that 60 % of passengers travelled forward while approximately 35% travelled towards the rear and the remainder were seated by an exit row. However of those passengers choosing to travel forward, 64% selected their nearest exit, while of those preferring to travel towards the rear, 67% selected their nearest exit. These results suggest that many passengers travel in a forward direction because their nearest exit is in front of them.

This chapter will investigate the problem of passenger exit selection and how this is done within the Exodus model. The chapter will also discuss the model weakness in relation to how exits are currently selected by passengers and a solution will be given on how the problem will be addressed.

6.2 DESCRIPTION OF THE PASSENGER EXIT SELECTION PROBLEM

During aircraft accidents, which involve narrow body passenger aircraft, in which all thee exit pairs are available, a large number of passengers tend to select the centre over wing exit for evacuation. This is quite a phenomenon considering the centre exit is in fact the smallest passenger exit (otherwise known as a Type–III window or emergency exit) on board the aircraft and requires a significantly larger amount of time to traverse through than the forward or rear exits otherwise known as Type I/C exits. The Type-III exit requires the passenger to essentially climb through while the Type I/C exit allows the passenger to simply walk through. The average flow rates for the Type I/C exits are 65 persons per minute while for the Type–III exit, the average flow rate is 37 persons per minute. Surprisingly during controlled evacuations such as the certification trial, passenger use of the over wing exit is considerably smaller than found in real accidents and is almost optimal [105]. This close to optimal certification evacuation is thought to be achieved due to the intervention of cabin crew redirecting passengers to a larger and more efficient forward and rear exits.

During aircraft accidents, why do a large number of passengers tend to select the overwing exit instead of using the forward and rear exits? It is thought that in real emergency situations, many passengers utilise the overwing exit because they are unaware that the exit is smaller and hence slower. Paxs are merely moving towards their nearest exit without taking into consideration, its flow capability or size. There appears to be a biased trend to utilise exits in the mid sections of the aircraft and is shown to be much stronger in actual accidents (i.e. the nearest exit for the largest number of passengers) [2]. In the certification trials, the mean load on each of the exit pairs is often much more even with fewer passengers using the central exits which is the opposite of that seen in real accidents. The reason probably lies with the behaviour of passengers; who have a much higher motivation to escape during real accidents than they would have in experiments and certification trials, tend to escape by what they perceive as being the most direct method i.e. the nearest exit.

Cabin crew procedures used in evacuation experiments [23-25] and certification trials usually work well, achieving a well-balanced evacuation with most exits working efficiently. However in real accidents, passengers may have a choice of directions in which to escape. They may even choose to ignore crew commands or they may be totally unaware of crew commands due to poor environmental cabin conditions and head straight for the nearest exit. This would seem to be logical behaviour as it would be reasonable to assume that heading to the nearest exit would normally minimise your evacuation time given that all exits have similar flow capacities. While passengers may be aware of their nearest exit, they may not be aware of the variations in flow capabilities of all the available exits and hence are unaware that what could be their nearest exit could in fact have the poorest flow capability.

It is important to understand why passengers over utilise these exits in order to provide better safety briefings instructions for the passengers. This will later allow passengers to make a much more informed evacuation plan or decision. In order to improve the decision making models such as airExodus, it is important to understand the decision making process which is actually involved in the initial exit selection process. To actually understand the decision making process associated with passenger selection of exits, a questionnaire has been devised and submitted to 459 members of the travelling public (see Chapter 7).

6.2.1 Discussion of how passengers currently select exits in the airExodus model

The human behavioural characteristics displayed during aircraft evacuation can be categorised or split into three main groups for the development of a model [26] and are as follows,

- 90 second certification trials
- non-fire/external fire scenarios

- burn-through/internal fire scenarios

The human behaviour for each of these scenarios is very different and must be modelled separately. Crew redirection however was frequently witnessed in every category, although not necessarily effective for each of these scenarios. Seat climbing was most frequent in burn-through scenarios but hardly witnessed in other evacuation categories. Aisle swapping was surprisingly absent from the accounts of passengers involved in non/external burn through fire scenarios [14]. This does not necessarily mean that aisle swapping did not take place but that passengers did not consider it to be of great importance when filling in the questionnaires during accident investigation. In Chapter 5, passenger selection of exits was not of great importance. Certification scenarios were being run but, the main aim was to emulate a trial with optimal passenger usage of available exits (i.e. all exits finishing within 10 s of each other).

The main mechanisms which are common to the human behaviour in the three broad evacuation groups are,

- the collection of information
- the processing of information
- the actioning of any decision based on collection and processing of information

The realism and effectiveness of the modelled human behaviour varies according to the scenario or category. A good model should consider the three main processes involved in human behaviour and how or if they differ in the context of the three accident scenario groups.

6.2.2 Existing model and adjustments needed

The existing airExodus model is a complex model still under development. A passenger and crew redirection model has been developed [26] but still requires further research and testing.

During the simulations and testing of aircraft certification scenarios using the airExodus model (see Chapter 5), it was necessary to adopt a level of abstraction. Simulations were run using a potential map system to represent an optimal aircraft certification evacuation. The potential map system is part of the geometry sub-model and spatial definition within airExodus model. Movement within airExodus is generally determined through a series of nodes holding values calculated through this potential map system. This is a mechanism by which the merit of each node is determined and calculated according to the attractiveness of each exit as decided and supplied by the user [26]. Before a simulation can take place, the user should supply potential values to each available exit - these potential values represent the attractiveness of the exit. airExodus then assigns the new potential value to the exit and increments the potential value of all adjacent nodes. Passenger movement is determined simply by seeking nodes which have a lower potential value than the current node occupancy. A node with a lower potential value indicates that a passenger is moving closer towards an available exit and hence closer to safety. If two exits were active and available, the exit choice of passengers' is determined by the number of nodes that lie between them and the exit plus the initial potential values of the exits as supplied by the user. This simplistic potential map system alone however is not able to avail the required movement of passengers during complex aircraft geometries such as those involving cross aisles. Further functionality was therefore added into the airExodus model to remedy the problem in the form of ATTRACTOR and DISCHARGE nodes. These particular node types allow users to set specific potential values on the nodes hence enabling the flow of passengers to move towards another equally attractive direction possibly via a cross aisle or towards a less congested exit.

During narrow bodied aircraft simulations carried out in Chapter 5, potential values were imposed on all three available exits to emulate a certification case scenario with 50 % of exits used on one side of the aircraft only. The potential values of the exits had to be adjusted and balanced appropriately to allow each of the exits to finish within 10 seconds of each other which would indicate optimal performance. Evidence suggests that passengers tend to evacuate in an orderly manner during certification trials obeying the commands from cabin crew [14]. Optimal evacuation performance by passengers is more likely during a certification trial but less so during a real evacuation as the evacuation may be less orderly with passengers more likely to override the decisions and commands of crew members.

6.2.3 *Are these parameters right*

Balancing passenger usage of exits by adjusting and imposing the potential value of exits is not a realistic scenario for a certification trial or a real emergency evacuation. The passengers in the existing model are moving with false precision. Using the existing airExodus model in this way suggests that passengers will nearly always perform in optimal manner. It also suggests that passengers have full and complete spatial knowledge of the aircraft geometry. Chapter 8 discusses the results of a survey which analyses the public understanding of aircraft evacuation systems.

6.3 DISCUSSION OF MODEL WEAKNESS IN RELATION TO EXIT SELECTION

The airExodus model was recently enhanced with new features to accommodate the simulation of a more complex structure such as the BWB aircraft design. The following areas were highlighted for development.

- A novel scheme for passenger navigation, appropriate for BWB aircraft designs
- A modified model for passenger aisle swapping behaviour in the BWB aircraft
- A modified model to simulate cabin crew redirection procedures in the BWB aircraft.

6.3.1 *Is the model correct or are there other factors which must be considered*

Blake [14] proposed a passenger behaviour model for airExodus which would allow a form of passenger decision making when it came to selecting exits. Blake developed a number of models which were later simulated and the results analysed but these results were never validated against real data. In Blake's decision making model [14], the pax was able to consider the use of all available exits on board and make a relevant estimation to work out the time it would take to evacuate through each one. The pax would then opt to choose the exit which would pose the least evacuation time. There was an element of sophistication within the model which took other paxs waiting each of the exits into the estimation calculation. Although Blake's model sound likes a rather ideal solution, a number of assumptions were created for this model to work. Blake felt that the impact of the new model shifted the pattern of exit use from a **<u>nearest exit regime</u>** to **a <u>nearest exit regime which also considered the number of paxs stood at each exit</u>**. In theory, Blake's paxs decision making model [14] tried to reduce the personal evacuation of individual paxs. Blake [14] described how his model provided pax and crew with a simple scheme for simulating information gathering based on sight which was affected by the structure of the cabin geometry and other environmental conditions present in the cabin at the time of evacuation.

6.3.2 Factors that must be considered

In Blake's pax decision making model used for determination of the best exit for evacuation has assumed some factors. It assumed that all paxs had complete knowledge of exit location, size and flow rates within the aircraft cabin. Blake had described the model as allowing each pax to consider each and every available exit for use in a calculation before a final decision was made for a chosen exit. There is no data in literature to suggest that paxs are fully aware of configurational information about the aircraft cabin. It has been assumed in Blake's model that every pax has full configurational knowledge and will be able to process the decision using perfect information.

6.4 DISCUSSION OF HOW TO ADDRESS THIS ISSUE

Although Blake's decision model seemed like an ideal solution, the assumptions made would make this model rather difficult to verify. There was also no data available at the time of development for Blake's model [14] to be fully validated. Since that time however an analysis of exit availability, exit usage and passenger exit selections exhibited during real aviation accidents was made by Galea [2] and made use of data stored in the AASK database [3]. Although this analysis [2] was very useful, it didn't give much information related to passenger awareness of the configuration knowledge of the interior of an aircraft cabin. With this sort of available data, assumptions would not be required in terms of the percentage of paxs who had full configurational knowledge of the aircraft cabin.

This work of this thesis therefor suggests the need to use a questionnaire to determine the knowledge that paxs currently have on narrow bodied, domestic aircraft such as the B737-300 series. A wide bodied aircraft will not be used at this point in the quest for data relating to pax's cabin configurational knowledge and will be the subject of possible further work. Data gathered from the questionnaire can then be analysed and implemented into the airExodus model. Any implemented data can then be validated against what is currently know about how passengers use their nearest exit 85% of the time [2].

6.5 CONCLUDING REMARKS

During this chapter there has been an attempt to understand why a large number paxs opt to use the smaller over wing exit during an evacuation when larger and faster exits are available at the front and aft of the aircraft. This chapter also demonstrates the differences between how paxs select exits in certification trials versus real accidents. Evacuation models to date which include some simplistic form of decision making in terms of pax exit selection have not been properly validated. This chapter has suggested the use of a questionnaire to gather data which would determine paxs configurational knowledge of a narrow bodied domestic aircraft.

A discussion of how this questionnaire was designed and created will be discussed in Chapter 7 with the analysis of the data presented in Chapter 8. This analysed data will then be used in the development of airExous during Chapter 9.

7 THE QUESTIONNAIRE

7.1 INTRODUCTION

This chapter will firstly discuss how the questionnaire was created and what kind of answers it can give. It will discuss why and how the questions were designed and their relevance in how passengers select exits during an evacuation. It will also look at the participant groups questioned followed by the inclusion of the complete copy of questionnaire together with description of any necessary ethic's requirements.

In many real accident situations, the overwing Type III is often overused, even when other viable exits area available. This questionnaire is aimed at attempting to understand this type of passenger behaviour. In addition, in aircraft evacuation computer models, a number of key assumptions are made concerning the thought processes of passengers as they select an exit to use during an emergency. This research will provide some insight into the knowledge passengers have of exit capabilities and better inform the development of realistic computer egress models.

7.2 DISCUSSION OF HOW QUESTIONNAIRE WAS CREATED

7.2.1 Participant groups questioned

All participants of the questionnaire must be over 18 and have flown at least once. Analysis took place for groups such as male or female and different ages i.e. young (18-30), middle aged (35-50) and old (above 50). Analysis was made for further groupings for disabilities and the length of time since the participant's last flight and the frequency of flight.

7.3 THE QUESTIONNAIRE USED AND NECESSARY ETHIC'S REQUIREMENTS

7.3.1 Copy of questionnaire

A copy of the questionnaire and its questions can found in APPENDIX A and will be described fully within this chapter.

7.3.2 Description of ethic's proposal document required prior to questioning

Before questioning members of the public on the public understanding of aircraft evacuation, a proposal document was put forward to the Ethics Committee of the University of Greenwich. This proposal document outlined the background, aims and the objectives of the questionnaire. It discussed and presented the questions to be posed to participants and their relevance to the research being carried out. The proposal discussed how the questions would be carried out and any staff training required prior to undertaking the main study by way of a pilot study. The results of the pilot study were used to determine if any modifications to the questionnaire were required or whether any unforeseen ethical issues might have arisen. The proposal also discussed safe working locations for both the participant and staff members, the methods used such as all survey staff must have adequate identification such as University of Greenwich photo identification cards. The survey staff will have an agreed working location and time which will be known to other members of the team or work colleagues. The survey team must carry alarms and mobile phones. Phone numbers will be held by members of the team and work colleagues. Team members will agree to make regular phone calls to work colleagues and to report on their safety. The proposal described that strict confidentiality will be maintained throughout the study. Participants' identity will not be revealed during any part of the project. Participants' personal details (names and addresses) will not be collected and so data will be irreversible. All questionnaires will have a pre-assigned unique number. Only researchers will have access to the data collected and stored.

The data and information will not be used by the researchers for any other purpose other than the described study. Some of the analysed data may be published and shown in public fora. The rights and privacy of volunteers will be strictly protected.

The proposal described the data collection from participants and its analysis. It suggested that data for the whole group would be collected in a tabular form and then analysed using statistics such as mean and standard deviation etc. There was a suggestion that analysis would also take place for groups such as male or female and different ages i.e. young (18-30), middle aged (35-50) and old (above 50). There would also be further groupings for disabilities and the length of time since the participant's last flight.

Along with a proposal document submitted to the Ethics Committee, a participant information sheet was also submitted (See APPENDIX B) together with a participant consent sheet (See APPENDIX C). The participant information sheet was the document which was to be given to the intended participant to give them more information about the study into which they may become involved. This sheet would need to be read by the participant prior to undertaking the questionnaire as it gives more information about what the study is about. This sheet would be given to the participant to take away with them as it would allow them to re-contact the researcher if there were later any concerns regarding the study. The participant consent was a signed authority for the participant's details to used as part of the study. Without this signed document the questioning would not be considered valid and data could not be used.

7.4 WHY AND HOW QUESTIONS WERE DESIGNED AND THEIR RELEVANCE TO HOW PASSENGERS SELECT EXITS

7.4.1 What answers will or can it give?

The objectives of this research by way of questionnaire are to answer the following questions.

- Are passengers fully aware of all exits and their locations on board a common short haul aircraft?
- Do passengers distinguish between different exit types or are they oblivious to any differences?
- Are passengers aware of the performance levels various exits can achieve?
- Do passengers perceive the time for traversal through a Type III over wing exit (normally found on short haul aircraft) to be longer or shorter than the actual required time?
- How long does the passenger actually think it will take to traverse through a Type III over wing exit?
- Are passengers likely to take these considerations into account when making an exit selection?

Below is a list of questions which we will attempt to answer by questioning participants. The questionnaire will be split into the following sections A) ***Participants Experience*** and B).

A) PARTICIPANT'S EXPERIENCE

During the first section, air travel experience of each participant was requested which was later used for grouping purposes.

e.g.

How long has it been since your last flight?

☐ *Never flown*	☐ *Within the last 12 months*	☐ *1-2 years*
☐ *2-5 years*	☐ *More than 5 years*	☐ *Can't remember*

B) RESEARCH QUESTIONS

This section will look at the main research areas that needed to be addressed. These will be listed along with questions specifically created for the participants and reasons given as to their usefulness.

- **Are passengers fully aware of exit locations on board a common short haul aircraft?**

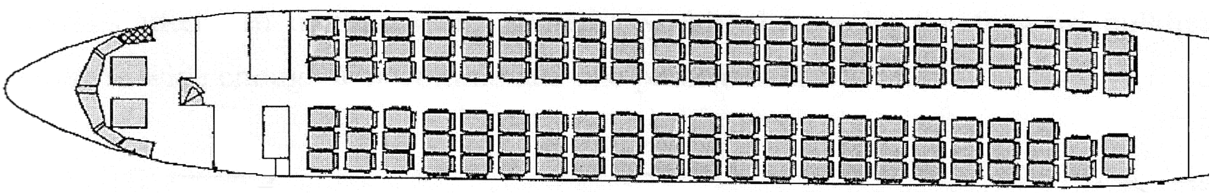


Figure 7-1: A typical short haul aircraft with seats in which the exits are not shown.

Question:
How many exits would you typically find on this aircraft?

☐*1* ☐ *2* ☐ *3* ☐ *4* ☐ *5* ☐ *6* ☐ *7* ☐ *8* ☐ *More than 8*

Question:
Please mark the approximate exit location/locations on the diagram above using crosses.

If the participant indicates the perceived number of exits on board and then marks the exit/exits location on the diagram, it is extremely useful in analysing whether passengers are truly aware of all exit points on the aircraft. Assessment can be made from these answers, whether the pre-flight briefing and flight card have been effective in describing all exit locations. The overall answer will assist in working out the percentage of passengers that are aware of all available exit locations in the event of an evacuation.

Do passengers distinguish between different exits types or are they completely oblivious to any differences?

Question:
Are all the exits that you have indicated approximately the same size?

☐ *Yes (Don't answer next question)* ☐ *No* ☐ *Don't Know (Don't answer next question)*

Question:

Please indicate on above diagram which exits are Large and which are Small?

> *Use the letter (**L**) on the diagram to indicate location of large exits and (**S**) to indicate small exits.*

Answers to these questions will assist in understanding what passengers really think and understand of exit sizes. It will be useful in determining whether passengers recognise both of these exits types and if they would be able to locate them on the aircraft during a real evacuation. If the passenger is aware of different exit sizes and their locations, then this could lead to a more optimal evacuation for the aircraft as a whole. If the participant cannot locate these exits properly on the diagram then further work may be required during the pre-flight briefing to make passengers more aware.

- **Are passengers aware of the performance levels various exits can achieve?**
- **Do passengers perceive the time for traversal through a Type III over wing exit (normally found on short haul aircraft) to be longer or shorter than the actual required time?**
- **How long does the passenger actually think it will take to traverse through a Type III over wing exit?**

Question:

To answer the remaining questions you require the following information. This type of aircraft typically has two sizes of exit: the larger - type L – is located at the front and rear; the smaller – type S – located in the centre.

Type L

Type S

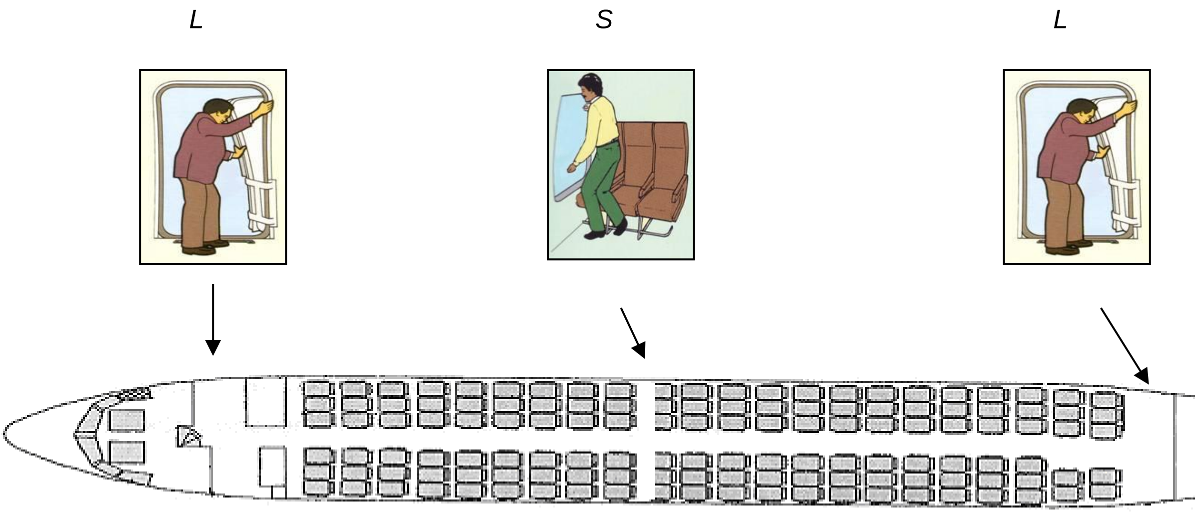


Figure 7-2: Exit L (Type C) and Exit S (Type III)

If it takes the average person about 1 second to pass through an* OPEN *type L exit, relative to this, approximately how long do you think it would take the average person to pass through an* OPEN *type S exit, assuming that they are standing in front of the exit and alone.
(Tick an approximate estimate for exit S below)

☐ *Much less* (*less than half as long*)
☐ *A little less* (*up to half as long*)
☐ *Approx. the same*
☐ *A little more* (*up to 2x as long*)
☐ *Much more* (*> than 2x as long*)

Answers to this question should assist in understanding if passengers are aware of different exit flow rate capabilities. If analysis yields a large percentage of participants believing that there is no difference in exit performance, then this could explain regular congestion around the Type III exit during real evacuations. Congestion of this nature inevitably causes a suboptimal evacuation of the aircraft. This is a very important question to be directed at the participant and may take quite some thought. If many participant estimates were to be a little less or much less then this again could explain why passengers create such congestion around the Type III exit.

- **Are passengers likely to take these considerations into account when making an exit selection?**

Question:
In an emergency situation, which exit would you use if you were alone and standing in the aisle half way between exit A and B at the position marked with a cross, assuming there is a slide at each exit?

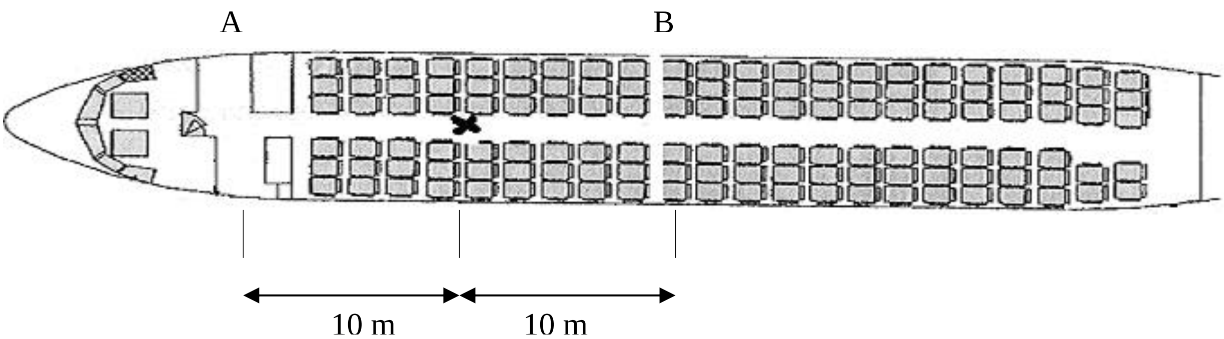


Figure 7-3: Aircraft geometry with exits marked (A & B) and starting passenger position marked with X

☐ *Exit **A*** ☐ *Exit **B*** ☐ *Don't Know*

The best answer that the participant could give here would be to use exit A. Although the exits are balanced at the start with the same number of passengers, exit A should finish sooner as it has a faster flow rate than exit B. If the participant does suggest exit B, then this could indicate passengers' inexperience of exits sizes and flow rates on aircraft.

Question:

In the previous question, what influenced your decision? (Tick all that apply)

☐ *Size of exit* ☐ *Distance to exit* ☐ *No seats in front of exit*

☐ *N^{O} of seats in front of exit* ☐ *Prefer front* ☐ *Prefer middle*

☐ *Faster exit* ☐ *Easier exit* ☐ *don't know*

☐ *other*

Results of this question should assist in determining which factors passengers use to influence and assess their preferred exit. It may be possible to ascertain if passengers think differently with regards to the perception for traversal through the exit. There is much repetition of the previous question during the proposed questionnaire, but using different available exits and then introducing queues of passengers at each available exit. This is done for both the front and aft of the aircraft to remove any uncertainty.

Responses for the questions above should indicate whether participants received correct information about available exits on board the aircraft and whether the briefing suggested the differing sizes of exits.

7.5 CONCLUDING REMARKS

Within aircraft evacuation models [1, 2, 3] it is necessary to make several key assumptions when modelling emergency evacuation. These are primarily concerned with passenger exit choice i.e. given a choice between two viable exits, which exit will a passenger select and on what basis is the passenger selecting the exit. Through analysis of past accidents it would appear that passengers simply select their nearest viable exit without consideration of the performance capabilities of the exit [4]. Thus passengers often make sub-optimal exit decisions. Are these decisions based on a lack of knowledge concerning the basic aircraft layout, a lack of understanding of the performance of aircraft exits, only considering exit proximity as a determining factor or a combination of these factors? Understanding the rationale behind these exit selection decisions will enable a more accurate representation within human behaviour models used by aircraft evacuation models [5].

This questionnaire based research aims to determine whether the travelling public understand the factors that control evacuation speed and efficiency and whether they are likely to utilise this understanding in making exit selection choices.

It is also assumed that the aircraft cabin crew, who are in control of the evacuation, direct passengers to the most appropriate exits as they are familiar with both the aircraft layout and the performance capabilities of the exits.

This knowledge will be used to better improve the theoretical basis of aircraft evacuation modelling tools and improve the accuracy of their predictions. The findings of this research may also be used to better inform passengers during pre-flight briefings, to improve the information provided on safety briefing cards and to improve cabin crew training.

8 A STUDY OF PUBLIC UNDERSTANDING OF AIRCRAFT EVACUATION SYSTEMS

8.1 INTRODUCTION

This chapter presents the results from a questionnaire study of participant awareness and suggested exit selection in the event of emergency evacuations involving narrow body aircraft. The study involved 459 participants with varying flying experience. Results of this study support the hypothesis that poor understanding by passengers of aircraft exit location and configuration may be a contributory factor in the resulting poor exit selection decisions made by passengers in emergency situations. These results have important safety implications for airlines and also provide insight to evacuation model developers regarding the decision making process in agent selection. Also presented will be a comparison of behaviours and parameters from the questionnaire results with those already being used in the airExodus model. A discussion will be given of correct and incorrect behaviour parameters used in the model.

8.2 QUESTIONNAIRES CARRIED OUT

A total of 488 members of the public were approached to complete a questionnaire, of which 459 people were considered eligible to take part in the analysis. The questionnaire consisted of 16 multi-part questions and required approximately 20 minutes to complete. The questionnaire focussed on narrow bodied aircraft with a single passenger aisle and a pair of large Type-C exits in the front and rear with a pair of Type III exits over wing as shown in Figure 8-1. Two pilot trials were conducted prior to launching the main campaign.

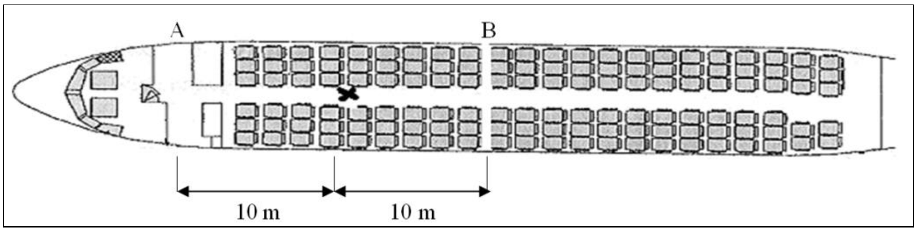


Figure 8-1: Aircraft layout as presented to the participants in Question 8 without exit size or type information. The "X" marks the location of the participant which is equi-distant between two exits.

The first pilot trial, involving 25 participants revealed some inconsistencies in the questions and highlighted several difficulties that the participants had in addressing the questions. These were corrected and a second pilot was conducted, again involving 25 participants which revealed that the questionnaire was acceptable. The first five questions in the questionnaire were intended to establish the flying experience of the participant; the next two questions were intended to ascertain the understanding the participant had of the aircraft layout with regards to the number of exits on board the aircraft, the location of the exits and the size of the exits. The participant was later told the correct number and location of the exits, but not the size of the exits, and the next four questions asked the participant to identify which exit they would use if they were placed at an equal distance between two exits (the position "X" in Figure 8-1). The question was asked twice, once with no other passengers in their way (to remove the complication of queuing) as in (i.e. question 8 for forward and over wing exit) and with eight other passengers queuing up at each exit (i.e. question 9 for the forward and over wing exit). This was repeated for the rear exits (i.e. questions 10 and 11). The participant was then told which were the large and small exits and was shown a picture of the various exits. The next two questions then repeated the exit selection questions relating to the forward two exits (i.e. question 12 without queuing passengers and question 13 with queuing passengers).

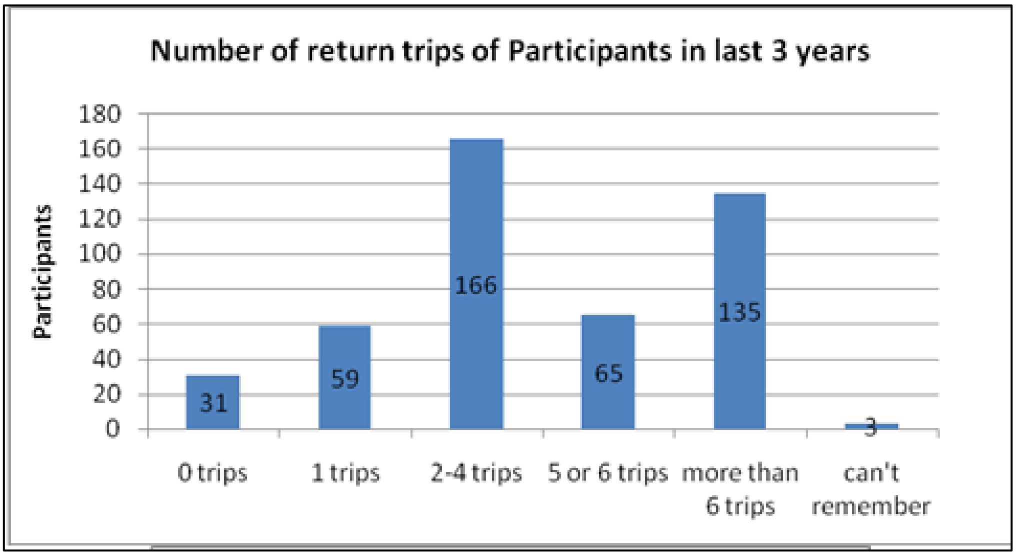


Figure 8-2: Number of return trips of participants in the last 3 years

The participant was then asked to estimate how long they thought it would take for a single person to exit through the smaller Type-III exit if they required 1 sec to pass through the large Type-C exit (question 14). This was intended to establish if the participant could come up with a reasonable estimate for the flow rate of the smaller exit. The participants were then told what the correct relative performance of each exit would be and were then asked to repeat the exit selection process for the forward exits (i.e. question 15 without queuing passengers and question 16 with queuing passengers).

The questionnaire was completed by 459 members of the public. The sample consisted of 61% (280) males and 39% (179) females with 25% (115) in the 18-30 year age bracket, 52% (240) in the 31-50 age bracket and 23% (104) in the over 50 age bracket. Over 93% of the sample had flown at least once in the past three years (Figure 8-2). Results were analysed as a function of age, gender, flight experience and aircraft knowledge. An overview of the results is presented in the following section.

8.3 RESULTS OF DATA GATHERED FROM QUESTIONNAIRES

8.3.1 Discussion of results

The analysis presented here will first consider the participants knowledge of the cabin layout and then will examine the exit choices made by the various participants. The analysis will be based on the participants' frequency of travel and knowledge of cabin layout.

Participant knowledge of cabin layout

Of the entire sample population, 78% (357) could correctly identify that there are three exit pairs on the aircraft while 75% (344) could correctly identify the location of the three exit pairs (see Table 8-1). ***This indicates that a quarter of the participants (25% or 115) did not know that the aircraft had three exit pairs and where they were located.*** Presented in Figure 8-3 is an example of some of the erroneous exit information provided by the participants.

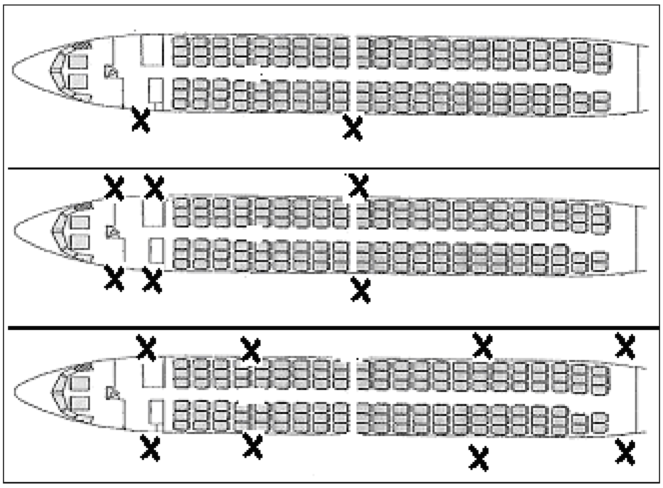


Figure 8-3: Example exit locations suggested by participants who did not know correct number and location of exits.

When asked if all the exits were the same size, only 37% (172) of the population realised that the exits were not the same size. This suggests that a significant proportion of the sample population - over three fifths (324) - did not know that the exits were of different sizes. ***Of greater concern was the fact that only just over one fifth of the entire population - 22% (99) – knew the number, location and relative sizes of the three exit pairs*** (see Table 8-1). These results clearly indicate that the sample population has a poor configurational awareness of the aircraft. It is suggested that this poor level of understanding is a contributory factor in the poor exit selection decisions made by passengers in emergency situations.

It is often claimed that frequent fliers have a good knowledge of the aircraft and that recent fliers also have a good knowledge of the aircraft layout. This possibility was examined by comparing the sub-populations who had flown in the past 12 months (367 participants) with those who had not flown in the past 12 months (92 participants), and frequent flyers who had flown in the past 12 months (194 Participants) with infrequent flyers who had flown in the past 12 months (173 Participants). For this analysis, frequent flyers are defined as those people who have flown five or more return trips in the past three years. From Table 8-1 we note that the results for the sub-population that have flown within the past 12 months ("recent flyers") are not significantly different to the results for the entire population. This is because 80% (367 participants) of the sample have flown within the past 12 months. Thus the conclusions drawn for the entire population apply equally well to those who have flown within the previous 12 months. In particular, ***just under a quarter of the "recent***

flyer" sub-population - 23% (84) – knew the number, location and relative sizes of the three exit pairs (see Table 8-1).

We can also compare the sub-population who has flown within the past 12 months (367 participants) with those who have not flown within the past 12 months (92 participants). Here we find that the correct knowledge of the number and location of the exits is almost identical, with the proportion of those having flown in the past 12 months only being some 3% greater than the proportion of those who had not flown in the past 12 months. ***Simply having flown recently does not convey good knowledge of the aircraft layout.***

Table 8-1: Knowledge of cabin configuration for various sub-populations

Configurational knowledge	Entire Sample (459 people)	Sub-population – flown in the previous 12 months (367 people)	Sub-population – NOT flown in the previous 12 months (92 people)	Sub-population – frequent flyers who have flown in the previous 12 months (194 people)	Sub-population – infrequent flyers who have flown in the past 12 months (173 people)
Correct number of exit pairs	78% (357)	79% (289)	74% (68)	89% (172)	72% (125)
Correctly locate the three exit pairs	75% (344)	76% (277)	73% (67)	82% (159)	68% (118)
Knew that exits were of different sizes.	37% (172)	40% (145)	30% (27)	45% (91)	31% (54)
Correctly identify number, location and size of exit.	22% (99)	23% (84)	16% (15)	27% (53)	18% (31)
If 1 sec to pass through L, a little more to pass through S	62% (285)	62% (228)	60% (55)	62% (121)	62%(107)
If 1 sec to pass through L, much more to pass through S	12% (55)	13% (46)	13% (12)	13% (25)	12%(21)
If 1 sec to pass through L, approx the same	19% (87)	19% (68)	22% (20)	18%(34)	20%(34)

to pass through S					

However, we find that those who have flown in the past 12 months have a better understanding of the difference in size of the exits than those who have not flown in the past 12 months, the difference in knowledge between the two groups being some 10%. We find however that this is not significantly different (note, all χ^2 analysis presented in this paper are two tailed and make use of the Yates correction, χ^2 test, X^2 = 3.32) at the 5% confidence limit, thus the null hypothesis, that having flown within the past 12 months does not imply better knowledge of the size of the available exits on the aircraft is supported. When we compare the complete configurational knowledge of the two sub-populations, we find that 7% more of the sub-population that has flown in the past 12 months could identify the three key configurational facts relating to; the number of exits, the location of the exits and that the central exits were smaller in size. This reduces from 23% (84) for the sub-population that has flown in the past 12 months to 16% (15) for the population that has not flown in the past 12 months (see Table 8-1). However, we find that this difference is not statistically significantly different (χ^2 test, X^2 = 2.034), which does support the null hypothesis that having flown within the past 12 months does not convey a better configurational knowledge. ***Once again, simply having flown recently does not imply that people will have a good knowledge of the aircraft exit layout and configuration.***

Comparing the response of frequent flyers who have flown in the previous 12 months (194 participants) ("recent frequent flyers") with infrequent flyers who have flown in the past 12 months (173 participants) ("recent infrequent flyers") does present some interesting differences. Of the recent frequent fliers sub-population, 89% (172) could correctly identify that there are three exit pairs on the aircraft compared with 72% (125) for the recent infrequent flyer sub-population – a difference of 24%. We find that this is statistically significantly different (χ^2 test, X^2 = 15.93) at the 0.01% confidence limit, thus there is a strong departure from the null hypothesis of no association between the flight frequency of those passengers who have flown in the last 12 months and the knowledge of the correct number of exits on the aircraft. The greater observed than expected result of the recent frequent flyers strongly suggests that they are likely to have better knowledge of the correct number of exits than do recent infrequent fliers. Furthermore, 82% (159) of the recent frequent fliers compared with 68% of the recent infrequent fliers could correctly locate all three exit pairs – a difference of 21%. We find that this is statistically significantly different (χ^2 test, $X^2 = 9.34$) at the 0.5% confidence limit, thus there is a departure from the null hypothesis of no association between the flight frequency of those passengers who have flown in the last 12 months and the knowledge of the correct location of the exits on the aircraft. The results strongly suggest that recent frequent fliers have a much better understanding of the exit locations than do recent infrequent fliers. ***More than four fifths (82%) of frequent fliers who have flown in the previous 12 months can locate the position of the three exit pairs.***

When asked if all the exits were the same size, only 45% (91) of the recent frequent fliers realised that the exits were not the same size, while only 31% (54) of the recent infrequent fliers knew. This suggests that over half the population of recent frequent fliers do not know that the exits are of different sizes. Furthermore, only 27% (53) of the recent frequent fliers could identify the three key configurational facts relating to; the number of exits, the location of the exits and that the central exits were smaller in size. This compared to only 18% (31) for the recent infrequent fliers. We find that this difference is statistically significant (χ^2 test, $X^2 = 16.79$) at the 0.005% confidence limit, thus there is a strong departure from the null hypothesis of no association between flight frequency of those passengers that have flown in the last 12 months and the knowledge of the number, location and size of the exits on the aircraft. The observed result of the recent frequent flyer is higher than its expected result, strongly suggesting that this type of flyer has a much better knowledge of the number, location and size of the exits on the aircraft.

Thus, simply having flown recently or simply being a frequent flyer does not in itself convey a better knowledge of the aircraft exit configuration and layout. However, being a recent frequent flyer does convey a better understanding of the aircraft exit configuration and layout. While being a recent frequent flyer conveys better knowledge of the aircraft exit configuration and layout, ***of great concern is the result that only a little more than a quarter of the recent frequent flier sub-population - 27% (53) - could correctly identify the number of exits, locate their position and identify their relative size*** (see Table 8-1). These results clearly indicate that even having flown recently and frequently does not mean that passengers will have a good configurational awareness of the aircraft.

When asked to estimate how much longer would it take to pass through the smaller over wing exit, approximately 62% correctly stated that it would take a little longer to pass through (up to twice as long). Approximately 13% thought it would take significantly longer (more than twice as long). These responses were uniform across all groups of participants. Thus approximately 75% of the population correctly estimated that it take longer to pass through the smaller over wing exit. This suggests that three quarters of the entire population (74% or 340 participants) understood that the smaller exit meant a slower egress time through the exit. ***However, a quarter of the entire population (26% or 119 participants) thought that the smaller exit would allow them to pass through in approximately the same amount of time or quicker than the larger exit. This result appears to be independent of flyer experience.***

Not only does approximately three quarters of the sample population have a poor configurational awareness of the aircraft, a quarter of the sample population does not appreciate that the smaller exit will produce a slower egress rate. It is suggested that this lack of knowledge contributes to poor exiting decisions in aircraft accidents.

Participant exit selection decisions

Thus far we have demonstrated that the participant population had a poor understanding of the exit configuration and layout. In this part of the analysis we investigate the exit choices the participants would make under a variety of conditions (see Table 8-2).

When asked which exit they would select if they were alone on the aircraft and equi-distant between the forward (Type-C) exit and the central over wing (Type-III) exit, 72% (333) of the entire population (459) correctly selected the forward exit (see Table 8-2). This exit is the correct exit to select as it is the larger of the two exits and has a better exit flow rate. When the question was repeated for the central over wing (Type-III) and rear (Type-C) exits, a smaller proportion, 52% (239) correctly selected the rear exit. ***On average almost two fifths (38% or 346 taking both forward and aft exits) of the entire population elect to use the centrally located smaller over wing exit rather than the larger forward/rear (Type-C) exits.*** When we consider the sub-population with the most flying experience, the "recent frequent flyer" group, the percentage electing to use the over wing exit decreases slightly to one third (33% or 129). However, we find that this difference is not statistically significantly different (χ^2 test, $X^2 = 2.35$) supporting the null hypothesis that flyer experience does not make a difference in exit choice.

The question is then repeated but this time, eight people are shown to be queuing at each exit. The correct reply to this question is that the larger forward/aft (Type-C) exits should again be used, in fact there is an even greater compulsion to use the large exits as the queue will take some time to pass through the centrally located smaller (Type-III) exit. We find that even fewer people elect to use the forward (Type-C) exit (68% or 310) and slightly more people elect to use the rear (Type-C) exit (54% or 247). ***Even with a queue at each exit, on average, almost two fifths (39% or 361 taking both forward and aft exits) of the entire population again elect to use the centrally located smaller over wing exit. These results clearly demonstrate that a significant proportion – two fifths - of the general population do not correctly perceive that it will take them longer to exit via the smaller over wing exit.***

However, it should be recalled that a significant number of the population are not aware of the differences between the exits and the implications that these differences may have on exit performance. To test whether or not the participants would change their answers if they were presented with detailed information concerning the size and flow rate these questions were repeated progressively providing the participants with more information concerning the exit configurations.

Table 8-2: Participant exit selection for various sub-populations based on frequency of flight

Which exit would you use?	Entire Sample (459 people)	Sub-population – flown in the previous 12 months (367 people)	Sub-population – NOT flown in the previous 12 months (92 people)	Sub-population – frequent flyers who have flown in the previous 12 months (194 people)	Sub-population – infrequent flyers who have flown in the past 12 months (173 people)
A - Forward Type I empty	72% (333)	74% (270)	69% (63)	78% (152)	68% (118)
A – Forward Type I queue	68% (310)	69% (253)	62% (57)	73% (141)	65% (112)
Large – forward Type I empty	88% (402)	89% (327)	82% (75)	90% (175)	88% (152)
Large – forward Type I queue	90% (415)	91% (335)	87% (80)	92% (178)	91% (157)
Large fast – forward Type I empty	91% (420)	92% (338)	89% (82)	92% (179)	92% (159)
Large fast – forward Type I queue	93% (427)	93% (342)	91% (84)	96% (186)	90% (156)
C - Rear Type I empty	52% (239)	52% (190)	53% (49)	55% (107)	48% (83)
C – Rear Type I queue	54% (247)	55% (201)	50% (46)	58% (112)	51% (89)

When the population is informed that the forward and rear exits are larger than the over wing exit, the proportion electing to use the forward Type-C exit increases to 88% (402), and further increases to 90% (415) when there is a queue at each exit (see Table 8-2). The population is then informed that the larger exit is also faster than the smaller over wing exit.

We now find that the proportion electing to use the forward Type-C exit increases to 91% (420) and further increases to 93% (427) when there is a queue present at each exit. When compared with the case where the participants are given no additional configuration information, we find that the proportion of participants selecting the larger exit is statistically significantly different (χ^2 test, $X^2 = 44.35$) at the 0.0000005% confidence limit, thus there is a very strong departure from the null hypothesis that providing additional exit configuration and performance information does not result in better exit selection. ***These results clearly show that the participants are capable of making an appropriate choice if they are provided with the appropriate configurational and exit performance information.***

All flight experience groups, produce similar results, suggesting even recent frequent flyers make significantly better decisions if they are provided with appropriate exit configuration and performance information. To better address the question of level of prior knowledge, the exit selection analysis was repeated with the analysis focusing on level of configuational knowledge rather than flight experience (see Table 8-3).

In Table 8-3 we present the breakdown of the exit choice decisions for the entire population (459), the sub-population with complete exit knowledge i.e. with knowledge of the number, location and sizes of the exits (99) and the sub-population with incomplete exit knowledge i.e. at least aspect of exit number, location or size unknown (360). We note from Table 8-3 that the sub-population with incomplete exit knowledge make similar exit choice decisions to those of the entire population while the exit choice decisions of those with complete exit knowledge appear to be different to those with incomplete exit knowledge.

Table 8-3: Participant exit selection for various sub-populations based on configurational knowledge

Which exit would you use?	Entire Sample (459 people)	Entire sample complete configurational knowledge (99 people)	Entire sample incomplete configurational knowledge (360 people)
A - Forward Type I empty	72% (333)	78% (79)	71% (254)
A – Forward Type I people	68% (310)	78% (77)	65% (233)
Large – forward Type I empty	88% (402)	87% (86)	88% (316)
Large – forward Type I people	90% (415)	91% (90)	90% (325)
Large fast – forward Type I empty	91% (420)	94% (93)	91% (327)
Large fast – forward Type I people	93% (427)	95% (94)	92% (332)
C - Rear Type I empty	52% (239)	71% (70)	47% (169)
C – Rear Type I people	54% (247)	73% (72)	49% (175)

When asked which exit they would select if they were alone on the aircraft and equi-distant between the forward (Type-C) exit and the central over wing (Type-III) exit, 78% (79) of the sub-population with complete exit knowledge (99) correctly selected the forward exit (see Table 8-3). When the question was repeated for the central over wing (Type-III) and rear (Type-C) exits, a slightly smaller proportion, 71% (70) correctly selected the rear exit. ***On average almost one quarter (24% or 24) of the population with complete exit knowledge elect to use the centrally located smaller over wing exit rather than the larger forward/rear (Type-C) exits.*** When we compare the responses of the sub-population with incomplete exit knowledge with the sub-population with complete exit knowledge, we find the difference is statistically significantly different (χ^2 test, X^2 = 16.50) at the 0.005%

confidence limit, thus there is a strong departure from the null hypothesis that there is no association between complete/incomplete exit knowledge and correct exit selection. Results suggest that having complete exit knowledge appears to result in significantly better exit selection.

The question is then repeated but this time, eight people are shown to be queuing at each exit. We find that the same number of people elect to use the forward (Type-C) exit (78% or 77) and slightly more people elect to use the rear (Type-C) exit (73% or 72). ***Even with a queue at each exit, on average, one quarter (25% or 25) of the sub-population with complete exit knowledge elect to use the centrally located smaller over wing exit. These results clearly demonstrate that a significant proportion – one quarter - of the sub-population with complete exit knowledge do not correctly perceive that it will take them longer to exit via the smaller over wing exit***

When the sub-population with complete exit knowledge is informed that the forward and rear exits are larger than the over wing exit, the proportion electing to use the forward Type-C exit increases to 87% (86), and further increases to 91% (90) when there is a queue at each exit (see Table 8-3). The population is then informed that the larger exit is also faster than the smaller over wing exit. We now find that the proportion electing to use the forward Type-C exit increases to 94% (93) and further increases to 95% (94) when there is a queue present at each exit. When we compare the case where the participants are given no additional configuration information with the case where the participants are given complete configurational information for the sub-population who have complete exit knowledge, we find that the proportion of participants selecting the larger exit is statistically significantly different (χ^2 test, X^2 = 8.68) at the 0.5% confidence limit, thus there is a strong departure from the null hypothesis that providing additional exit configuration and performance information does not result in better exit selection, even for the sub-population that has complete exit knowledge.

These results clearly demonstrate that even participants with a good knowledge of the exit configuration are capable of making a more appropriate exit choice if they are provided with configurational and exit performance information.

8.3.2 *Discussion of correct and incorrect behaviour parameters used in model*

The behaviour parameters used in the airExodus V4.0 model are correct to some extent but some basic factors were missing leading to possibly, unrealistic results. The algorithm used in airExodus V4.0 to calculate the best path makes use of parameters which are distances and penalties. There are three separate penalties and two separate distances.

Penalty 1 counts the number of pax going in the opposite direction, Penalty 2 counts pax going to another exit but the same direction whilst Penalty 3 counts contra flow passengers (0 or 1). Penalty 3 is given the value of one, if the passenger is located in the vestibule and there is an obstruction directly in front of them such as a passenger. Penalty 3 also has the value of one, if the passenger is in the vestibule and the first aisle (first node) that they enter is occupied then value is penalised more heavily. If there is a contra flow in the vestibule, then penalise more heavily. The distances included are seen distances and unseen distances; the distance that a passenger can see and the distance that the passenger can't see respectively.

In the airExodus V4.0 model, the path weight or value is calculated as the length of the path plus any penalties. This path weight however does not include any penalty for passengers that could be waiting in the seat rows ahead and possibly enter the aisle first. This missing penalty could cause the path weight algorithm to be seriously flawed and unrealistic.

8.4 CONCLUDING REMARKS

The main findings of this work can be summarised as follows. Regarding participant knowledge of the aircraft exit configuration:

- Just under a quarter - 23% (84) – of the sub-population, "people who had flown in the previous 12 months", had good understanding of the aircraft exit layout and configuration i.e. knew the number, location and relative sizes of the three exit pairs.
- Having flown recently (within the previous 12 months) does not imply a better understanding of the aircraft exit layout and configuration when compared with those who have not flown recently.

- Being a recent frequent flyer does imply a significantly better understanding of the aircraft exit layout and configuration when compared with being a recent infrequent flyer.
- However, just over a quarter - 27% (53) - of the sub-population, “people who have flown recently who are also frequent flyers”, knew the number, location and relative sizes of the three exit pairs.

These results are of great concern as they suggest that of the most experienced fliers (recent frequent fliers) a little more than a quarter understand the aircraft exit layout and configuration prior to boarding. This inherent lack of exit knowledge is likely to have a negative impact on overall evacuation efficiency and hence passenger safety. From a general view of aircraft passenger safety, it is suggested that the pre-flight safety briefing should more strongly emphasize the location and type of exits available on the aircraft. Furthermore, rather than simply point out the location of the exits on board; the affordance of the exits should be enhanced, perhaps through lighting systems that could be used to emphasize the location of the exits to seated passengers. For example, a halo of lights could be used to surround the exit frame and in addition, an arch of lighting could be placed in the aisle perpendicular to the exit plane. In addition, these results clearly demonstrate that even the frequent flier community – who has a tendency to ignore pre-flight briefings because of their perceived “experience” and “knowledge” – lack a detailed understanding of the exit configuration on board aircraft. The pre-flight briefing should emphasize that even frequent flyers do not fully appreciate the nature of the exit configurations and so they should take note of the briefing. Finally, the safety cards used on board aircraft should focus on emphasizing the location and type of exits available on board the aircraft.

From an evacuation modeling view, these results are extremely important as they suggest that the majority of passengers (approximately 75%) have poor inherent exit knowledge. Agent based decision models used to select which exit an agent may decide to use must reflect this lack of inherent exit knowledge. Factors such as opportunistically “seeing” an exit, following the crowd, following instructions or simply going to the nearest exit may be appropriate drivers for the majority of passengers/agents.

Regarding participant exit choice:

- On average two fifths – 39% (361) – of the entire population (459) would elect to use the centrally located smaller over wing exit rather than the larger forward/rear exits, even when faced with a queue at each exit.
- Being a recent frequent flyer – the most experienced sub-population – does not statistically significantly alter this decision.
- When provided with complete exit information (size and flow rate), less than one tenth – 7% (32) – of the entire population elect to use the centrally located smaller over wing exit rather than the larger forward exit, even when faced with a queue at each exit.
- On average one quarter – 25% (25) – of the sub-population (99) with complete exit knowledge would elect to use the centrally located smaller over wing exit rather than the larger forward/rear exits, even when faced with a queue at each exit.
- Having complete exit knowledge does statistically significantly alter the decision to use the centrally located smaller over wing exit.
- Providing the sub-population "with the best exit knowledge" with information relating to the size and flow rate capability of the exits resulted in only a twentieth – 5% (5) - of the sub-population electing to use the centrally located smaller over wing exit rather than the larger forward exit, even when faced with a queue at each exit.

These results are of great concern as they suggest that irrespective of participant flight experience, two fifths (39% or 361) of the participants would elect to use a sub-optimal exit. This high number of participants electing to utilise the over wing exit supports the observation from real accidents that a significantly high number of participants elect to utilise the over wing exit. Perhaps of greater surprise, a quarter (25% or 25) of the sub-population that demonstrated complete knowledge of the aircraft exit layout and configuration also elected to use a sub-optimal exit. ***However, it was shown that by providing the participants with complete knowledge of the size and performance capabilities of the exits, the proportion making sub-optimal exit decisions could be reduced to less than one tenth (7% or 32) of the population.*** A similar result was found even for the knowledgeable sub-population. When this sub-population was provided with additional information relating to the exit size and performance capabilities, the proportion electing to use the sub-optimal exit fell to only one twentieth (5% or 5) of the sub-population.

These findings support the hypothesis that poor understanding of cabin layout is a contributory factor to sub-optimal exit selection decisions made by passengers in emergency situations. Furthermore, the results demonstrate that providing participants – even apparently knowledgeable participants – with additional information concerning the size and flow capabilities of the exits greatly improves the exit selection capabilities of the participants. Even providing information simply related to the relative size of the exits significantly improves exit selection capabilities. These observations support the earlier suggestion of improving the nature of the pre-flight briefing, the affordance of exits and the safety cards provided on aircraft. From an evacuation modeling perspective, these results suggest that as many as 39% of passengers will make sub-optimal exit selection decisions. It is suggested that these poor exit decisions are due to poor understanding of the exit layout and performance capabilities. It is further suggested that these factors should be taken into consideration when developing agent decision models concerned with identifying which exit to use.

The results from this survey suggest that even the most experienced fliers - recent frequent fliers – have little inherent understanding of aircraft exit configuration – only 27% (53) correctly knew the number, location and relative sizes of exits on narrow body aircraft. Furthermore, irrespective of flight experience, a substantial number (39% or 361 considering both forward and aft exits) of participants would elect to use a sub-optimal exit in the event of an emergency evacuation. It was shown that by providing participants with good knowledge of the exit layout, involving location, relative size and performance of the exits, the proportion making sub-optimal exit decisions could be dramatically reduced (to 7% or 32). These results have important safety implications for airlines and the nature of the pre-flight briefing and to evacuation model developers.

9 DEVELOPMENT OF airEXODUS EVACUATION MODEL USING QUESTIONNAIRE RESULTS

9.1 INTRODUCTION

During the development of the airExodus path evacuation model, the geometry of a narrow bodied aircraft which has four Type C exits and two Type III emergency exits will be used. A simple, aircraft geometry of a B737-300 (see Figure **9-4**) will be used while developing the system and validating the data gathered from the questionnaires described in the previous chapters. During the development discussion, a set of base cases will be constructed and used for comparison, namely 100% and 85% nearest exit scenarios will be referred to as Model 1a and Model 1b (See Table 10-2). A further base case constructed and used for comparison was the Optimal Exit Scenario.

The 85% nearest exit scenario (Model 1b) is most likely the closest model to accident cases which have been described in the AASK database [3]. As part of the development of the airExodus evacuation model, a number of models have been developed which are used to test the results from the analysis of questionnaire data in Chapter 8. These models include **Model 2** where the pax will use the incorrect estimate of the exit flow rates in their estimation of the best path to take towards exiting the aircraft. By using wrong exit flow rates, pax will assume that all exits on the aircraft are the same size and will therefor apply the same flow rate in their estimation of the path value for purposes of evacuation. In the path value estimation, the pax will apply a static Type C exit flow rate to all available exits including the over wing emergency exit. The pax knowledge will be modelled in a way which will make them ignorant of the differences of exit sizes hence the differences in exit flow rates.

Model 3 will be a more sophisticated model where all pax will have the knowledge that exits are of different sizes with different flow rates. Paxs in **Model 3** will be given knowledge which is close to approximate exit flow rates. The data for these exit flow rates has been taken from reports from certification trials of aircraft which involved both Type C and Type III exits.

The data chosen to be validated within the model was gathered from the sub group "***recent frequent flyers***" including 194 participants where 27% were able to correctly identify the number, location and size of the exits on the aircraft. This number was re-analysed and reduced further to 23% of paxs in this sub group being also able to identify the correct flow rates. The original intention of this survey was to carry out questionnaires on paxs who had only just disembarked an aircraft but this became difficult due to recent security restrictions at airports within the United Kingdom. The "***recent frequent flyers***" sub group was chosen as this group most closely represented the original intention of the survey.

During **Model 4,** data from survey (See Chapter 8) results will be included suggesting that a subsection (23 %) of the pax have perfect knowledge of the exit locations and flow rates while the rest of the pax (77%) will use the base case **Model 1 a** (nearest exit case) to choose the best evacuation path.

During **Model 5,** data from survey results will also be included as in **Model 4** which suggested that a subsection 23% of the pax will have perfect knowledge (**Model 3**) in terms of exit location and flow rate while, the other pax (77%) will use **Model 2** (uniform flow rates for all available exits) to estimate the most efficient evacuation path out of the aircraft.

Models 2-5 will also allow the switching on and of a redirection option where the paxs will be allowed to change direction and redirect to another available exit if they find that they have made a poor initial choice in their estimation of a path calculation value to evacuate. Each pax will only be permitted to redirect once during each evacuation simulation. Redirecting only once will assure that the evacuation of the aircraft progresses without paxs redirecting over and over again.

Models 2-5 have been developed with 2 separate phases which will both be tested separately against an accident case from the AASK database. Phase 1 involves the decision making pax taking account of other paxs ahead of them into the path value estimation, which are located in the aisle only. Phase 1 doesn't allow the decision making pax to consider pax who may get ahead but who are still located in the seat rows. Phase 2 permits the decision making pax to include other passengers ahead into their path value estimation which are located both in the aisle and in the seat rows ahead.

These models and their development are described within this chapter (See Table 9-1 and Table 9-2) and their validation against accident cases taken from the AASK database will be discussed in Chapter 10.

9.2 MODELS DEVELOPED

Model 1 will be constructed as a simple nearest exit case and used as a base case for the other models in both phases 1 and 2 which are described below in
Table **9-1** and Table 9-2.

9.2.1 Phase 1

Table 9-1: Phase 1 models developed

Model Name	Model Description	Redirection Available (ON/OFF)	Maximum number of aisle redirections permitted per pax
Model 2a	Paxs assess the path value using **incorrect** flow rates	OFF	N/A
Model 2b	Paxs asses the path value using the **incorrect** flow rates	ON	1
Model 3a	Paxs assess the path value using the **correct approximate** flow rates	OFF	N/A
Model 3b	Paxs assess the path value using the **correct approximate** flow rates	ON	1
Model 3c	Paxs assess the path value by using a CPS (census point) which provides pax exact value of the aisle flow rate	ON	1
Model 4a	23% of pax assess exit path using **Model 3a** while 77% of pax use **Model 1a**	OFF	N/A
Model 4b	23% of pax assess exit path using **Model 3b** while 77% of pax use **Model 1a**	ON	1
Model 4c	23% of pax assess exit path using **Model 3c** cwhile 77% of pax use **Model 1a**	ON	1
Model 5a	23% of pax assess exit path using **Model 3a** while 77% of pax use **Model 2a**	OFF	N/A
Model 5b	23% of pax assess exit path using **Model 3b** while 77% of pax use **Model 2b**	ON	1
Model 5c	23% of pax assess exit path using **Model 3c** while 77% of pax use **Model 2b**	ON	1

9.2.2 Phase 2

Table 9-2: Phase 2 models developed

Model Name	Model Description	Redirection Available (ON/OFF)	Maximum number of aisle redirections permitted per pax
Model 2a	Paxs assess the path value using **incorrect** flow rates	OFF	N/A
Model 2b	Paxs asses the path value using the **incorrect** flow rates	ON	1
Model 3a	Paxs assess the path value using the **correct approximate** flow rates	OFF	N/A
Model 3b	Paxs assess the path value using the **correct approximate** flow rates	ON	1
Model 3c	Paxs assess the path value by using a CPS (census point) which provides pax exact value of the aisle flow rate	ON	1
Model 4a	23% of pax assess exit path using **Model 3a** while 77% of pax use **Model 1a**	OFF	N/A
Model 4b	23% of pax assess exit path using **Model 3b** while 77% of pax use **Model 1a**	ON	1
Model 4c	23% of pax assess exit path using **Model 3c** cwhile 77% of pax use **Model 1a**	ON	1
Model 5a	23% of pax assess exit path using **Model 3a** while 77% of pax use **Model 2a**	OFF	N/A
Model 5b	23% of pax assess exit path using **Model 3b** while 77% of pax use **Model 2b**	ON	1
Model 5c	23% of pax assess exit path using **Model 3c** while 77% of pax use **Model 2b**	ON	1

9.3 DISCUSSION OF HOW MODEL WAS UPDATED USING QUESTIONNAIRE RESULTS

9.3.1 *Discussion of implementing new parameters and behaviours within airExodus*

The parameters from the questionnaire survey data were implemented into Models 4 (a, b and c) and 5(a, b and c) for both phases. Models 2 and 3 were simply developed with assumed scenarios which were tested and used for comparison and validation of the survey data.

Terms of reference used in the discussion of how model was updated

- During this discussion relating to the new behaviour within the evacuation, pax deciding on the most optimal exit to choose during an evacuation will be referred to as the "**decision making pax**".
- The number of pax who have moved from the seat row nodes into the aisle (aisle nodes) and are between the decision making pax and the exit in question will be referred to as "**in a queue**".
- The front and back of the queue will be referred to as the "**head**" and "**tail**" respectively.

The previous algorithm used in airExodus to estimate the best path makes use of penalties. There are three separate penalties being used (See (Equation 9-1).

Penalty 1: *number of paxs going in the opposite direction*
Penalty 2: *another exit but same direction*
Penalty 3: *contra flow count 0 (same direction with "**decision making pax**")*
*or 1 (for contraflow to "**decision making pax**")*

(Equation 9-1)

Penalty 3 has the value of 1 if the pax is in a vestibule and there is an obstruction (i.e. another pax) directly in front of them. Penalty 3 also has the value of 1 if the person is in the vestibule and the first aisle (first node) they enter is occupied then penalise the pax heavily. If there is a contra flow in a vestibule then penalise more heavily.

The path weight is calculated as the path length plus any confluence penalties (See (Equation 9-2):

*(seen_dist + unseen_dist) + (3.0f * penalty_1 + 1.5f *penalty_2 + 999.0f * penalty3)*

seen_dist: *distance that a pax can see*

unseen_dist: *distance that a pax can't see*

(Equation 9-2)

This model does not take into account the possibility of seated paxs ahead who could reach the aisle ahead of the decision making pax. The algorithm only includes pax who are in the aisle or vestibule which is wholly unrealistic and does not include the complete picture. This model is less dynamic and doesn't really take into account the fact that the pax in the vestibule or aisle may have moved once the decision making pax arrives at the last pax waiting in the aisle queue.

New Passenger Behaviour to be used for the initial Simple Model

Before implementing the data from the survey results into the models (see Table 9-1 and Table 9-2) an initial simple model will be presented with two separate phases. Variations of the simple model will be used as a foundation for Models 2-5 which will follow.

- **Phase 1**

  -Reassessment of the path will be made every time step but only allowing pax redirection once more after entering into the aisle.

  -Only paxs already positioned in the aisle will be used in the algorithm for determining the best exit choice.

  -Paxs waiting in seat row nodes ahead of the decision making pax will not be considered during phase 1.

- **Phase 2**

  Paxs who will potentially be in contra flow to the decision making should contribute to the travel time factor. This is not happening in the current version of airExodus V4.0

  -Include pax located in seat rows ahead during contribution to the travel time factor.

  -Include seated pax as a fraction of pax already in the aisle.

Pax Behaviour to be included in the Simple Model during Phase 1

- At the start of the evacuation, when a decision making pax is situated in a seat row node they will initially head towards the nearest aisle (aisle node).
- Once the decision making pax reaches the seat row node adjacent to an aisle node (seat before the aisle), he/she can then start to evaluate which exit to choose for the most optimal evacuation.

- Whilst the decision making pax is situated in the seat row node adjacent to the aisle node, they may re-evaluate their optimal choice of exit as many times as they wish. However, once this pax enters the aisle for purposes of heading towards a chosen available exit, this pax is then restricted to making one further redirection decision which should prevent the agent from changing direction too many times. Once this pax has exhausted the maximum redirection decisions allowed (1) whilst in the aisle, they must remain with their final exit decision.

- When a decision making pax is choosing the most optimal exit to use, they should evaluate and compare each available exit in the following way. This decision making pax must firstly assess the number of other paxs standing on the aisle nodes (queue) between themselves and the available exit being assessed.

- The decision making pax must assess the time it would take to travel the distance along the aisle to the next pax standing at the tail of the queue. This time should then be compared with the time it would take all of the pax in the queue to get out of the available exit. If the time to travel to the pax at the tail of the queue takes longer than the time for the all of the pax in the queue to leave the exit, then the time for the decision making pax to evacuate would be the total distance to the target exit divided by the decision making pax's fast walk speed. This would indicate that the decision making pax's travel speed would be slower than that of the queue.

- If the time for the decision making pax to travel to the pax at the tail of the queue is less than the time for the whole queue to evacuate through the available exit, this would indicate that the flow rate of the decision making pax to be faster than that of the queue, implying that he/she would easily catch up.

- The total time for the decision making pax to leave the aircraft would therefore be the travel time along the aisle to the pax standing at the tail of the queue in the direction being assessed, combined with the time for the whole queue to evacuate plus one (themselves).

- If the decision making pax is assessing the use of the middle exit and attempting to count the number of paxs between themselves and the middle exit, they must also consider any paxs who may be travelling to the exit but from the opposite side of the vestibule. If paxs are travelling from the opposite side then the decision making pax must assess if the number of paxs is larger on the other side than on their own side. The number of paxs in front and behind the aisle should be compared with each other (See Figure 9-1).

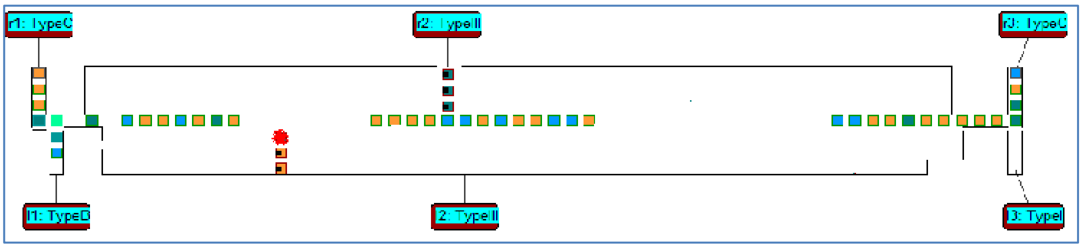


Figure 9-1: Pax count on the opposite side of over wing exit larger with decision making pax shown in red

This is simply based on a count of the number of paxs travelling along the aisle on both sides of the vestibule. If the number of pax on the opposite side of the middle exit is bigger by at least one pax then an assumption should be made that the number of paxs waiting on the other side is twice that on their own side. An assumption should also be made that there is an even flow rate of passengers in front and behind of the middle exit (one pax from path in front of exit and one pax from path behind exit).

- When counting the number of paxs in the aisle ahead, this path evaluation model assumes that the decision making pax never makes mistakes. In future development of this model, it may be useful to bring in a level of randomness during the counting of the pax standing in the aisle.

<u>Pax Behaviour to be included in the Simple Model during Phase 2</u>

- While the decision making pax is making an assessment of the path towards an available exit, consideration should be given to other paxs still located in the seat rows ahead between themselves and the available exit. Paxs located in the seat rows ahead may make it into the aisle first and in front of the decision making pax. Consideration must also be given to the fact that these seat row paxs have not yet embarked on a direction of travel and could travel in contra flow when they do finally enter into the aisle (See Figure 9-2). A penalty may be imposed by the decision making pax on these contra flow passengers, which would make travelling in a particular direction less attractive. This will only be considered during phase 2 of the simple model 1. Phase 1 will not concern itself with passengers still in the seated areas during the decision making process.

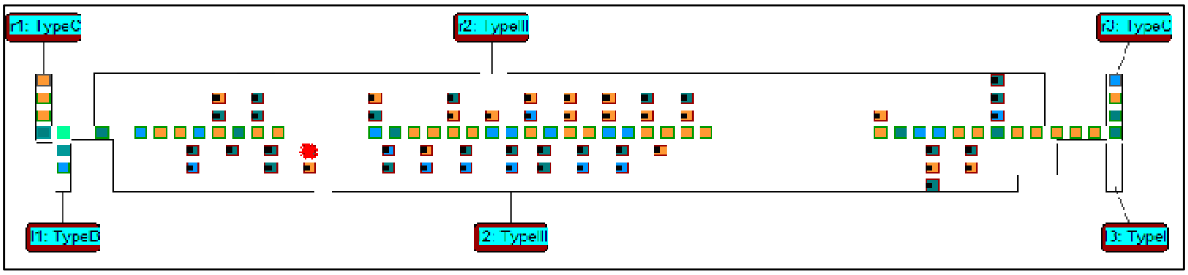


Figure 9-2: Paxs still located in seat rows ahead of decision making pax shown in red

- During phase 2 we will assume that the paxs located and waiting in the seat row nodes will take the travel direction of a pax who is already on the adjacent aisle node. If the aisle node adjacent to the seat row nodes is empty then the pax on those seat row nodes should make use of the potential distance map to choose the direction of travel. The decision making pax must also work out if the paxs waiting in the seat row nodes will get into the aisle queue before he/she does. The decision making pax may need to make an assumption that a fraction of the seated paxs are likely to enter the aisle ahead of them. When taking into consideration the paxs who are still positioned, responding and waiting in the seat row nodes ahead we must consider how this would affect the decision making pax's choice of direction. There are two possible options available to do this.

Option 1

Pax making a decision every n times step may solve the problem of the seated paxs who may be ahead and eventually join the queue.

Option 2

-Taking a fraction (50%) of the seated paxs, ahead of agent, as likely to enter the aisle first. A possible assumption could be that 50% of pax still located in the seat rows ahead will get into the aisle first. These additional pax will more than likely increase the predicted time for the decision making pax to evacuate from the possible, target, available exit.

Option 2 was the method used during this development of the path evaluation method. The 50% fraction used is an assumption, which may cause Phase 2 models to be less reliable, therefore the results should be considered with caution. Further work needs to be done to develop the use of Option 1 for its reliability.

The Development of Simple Model Algorithm

In the Simple Model, the decision making pax is faced with assessing which is the best available exit to use. It is not as simple as working out the **number of pax in the aisle** divided by **exit flow rate** combined somehow with the **shortest distance**. The decision making pax must work out the time to travel to the next pax on the aisle between themselves and the available target exit plus the time for all paxs in front plus one to evacuate plus themselves (See (Equation 9-3). While all of this is happening, many other new paxs could have also entered the aisle from the seat rows ahead complicating the scenario. This however will not be included until Phase 2 of the simple model algorithm.

If the decision making pax finds that there are already paxs waiting in the aisle to evacuate, then the following type of formula should be used to work out the length of time to evacuate through a target exit:

(Distance to next pax ahead in aisle / Pax fast walk speed) +

(Number of Paxs in aisle ahead + 1/ flow rate of target exit)

(Equation 9-3)

If the decision making pax's travel time to the next pax waiting on the aisle (tail of queue) between themselves and the external exit was less than the flow time of the whole queue to evacuate through the target exit, then the total time to evacuate for the decision making pax would be based on the travel time for agent to get to the next pax waiting on the aisle plus the time for the queue on the aisle ahead plus one to evacuate (See (Equation 9-3). A comparison must then be made for all other available exits.

If the aisle ahead is empty then the following equation (See (Equation 9-4) should be used by the decision making pax to estimate the amount of time it will take to get to the available target exit.

Travel time to target exit = Distance to Exit / Fast Walk Speed of Decision Making Pax

(Equation 9-4)

The previous two algorithms will only work for exits placed at the end of the narrow bodied aircraft. If the decision making pax is assessing an exit located in the centre of the aircraft, then this is more complicated as additional paxs will join the aisle from the opposite side of the exit. The calculation of the following variables will be more complex as waiting pax must be counted from the opposite side of the middle exit.

Census Points used during the Simple Model

There were two separate versions of the simple model, one where the census points were used to determine the flow rate of the aisle and used in the algorithm by decision making paxs in Model 3c, 4c and 5c for both Phase 1 and 2, where the census points were only used to determine whether the decision pax was located between the census point and the available exit and if so then the use of path evaluation algorithm would not be necessary as the pax was too close to the exit in question to consider travelling to another. Therefore the decision making pax located between a census line and available exit will not use any algorithm to choose the best path (See Figure 9-3).

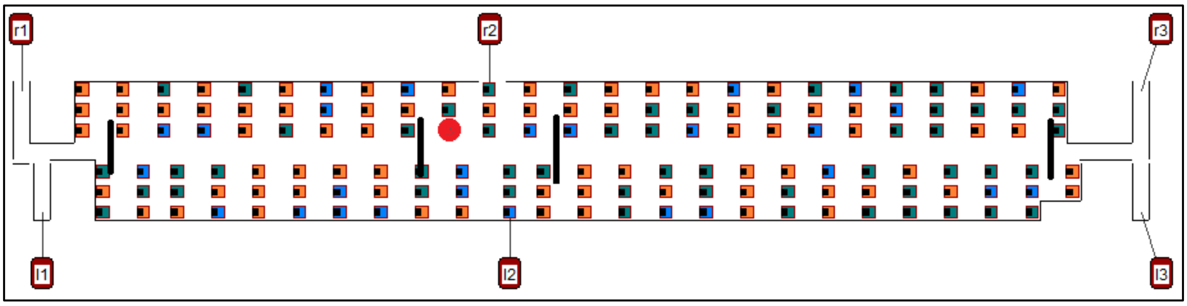


Figure 9-3: Decision making pax shown in red and located between census line and over wing exit

In the first version discussed in the previous paragraph, Census Points will be used to determine the actual flow rate or speed of the queue in the aisle. These census points will be located approximately 3 seat rows away from each of the exits and will be used to estimate the flow rate of the queue at that particular point and hence provided to the algorithm for path value estimation.

Three separate scenarios must be considered since may arise during an evacuation when using Census Points to determine the aisle flow rate:

1. At the start of the evacuation when the flow rate of the queue or census point will be 0 as no paxs are located in the aisle (see Figure **9-4**).

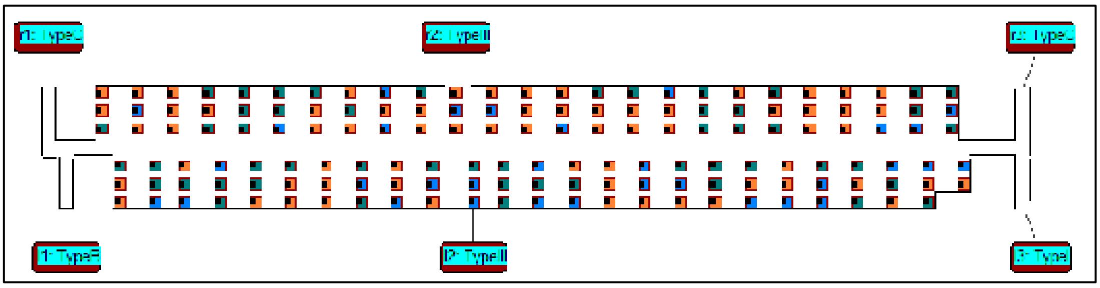


Figure 9-4: Start of an evacuation where flow rate at the census point will be 0 ppm

At the start of the evacuation, the census point will have a 0 ppm flow rate as paxs have not moved into the aisle. If the census point reads 0 ppm and the number of paxs on the aisle in front at this time is 0 then it means that there is freedom to travel the target exit providing it is available. If the flow rate is 0 ppm and the number of pax in ahead in the aisle is 0, then if the exit is available, this could be a very good exit to choose.

2. The middle of the evacuation where the aisle is full of paxs and census point flow rate reading will be greater than 0 ppm.

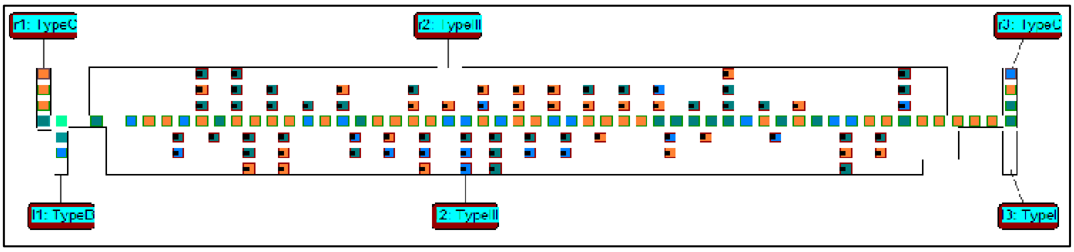


Figure 9-5: The middle of an evacuation where the aisle is full of paxs

During the middle of an evacuation (see Figure **9-5**), the census point reading could provide a high flow rate, while the number of pax ahead on the aisle could also be high. This high flow rate of the census points suggests that there is no blockage and pax ahead on the aisle will be able to move freely through the exit.

3. The end of the evacuation is when the flow rate of the queue or census point may again be 0 ppm (See Figure 9-6). Which will then be the best exit to choose?

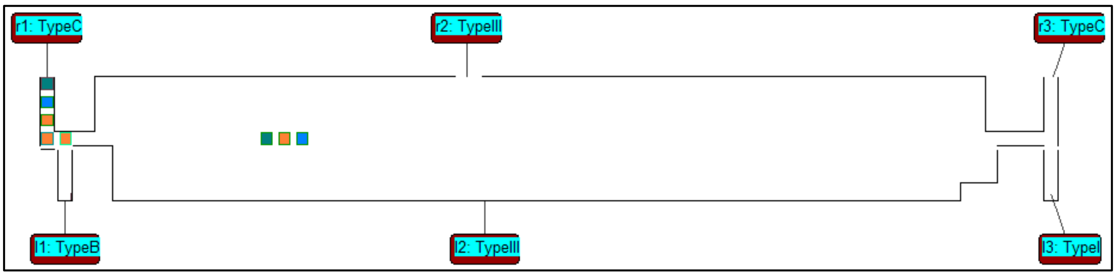


Figure 9-6: The end of an evacuation where the aisle becoming empty

If an exit has a number of paxs waiting to evacuate but the flow rate of the census point is 0 ppm, then this could indicate congestion or a blockage and the decision making pax will be more like to avoid this exit completely even if it is closer.

<u>Methods and rules to used in the Simple Model</u>

The method used during the Simple Model development was to consider $Tpath_i$ and $Tpath_j$ to be separate evacuation paths to be evaluated by the decision making pax (See Figure 9-7).

$Tpath_i$ = *Total predicted time to travel on path i*

$Tpath_j$ = *Total predicted time to travel on path j (alternative path)*

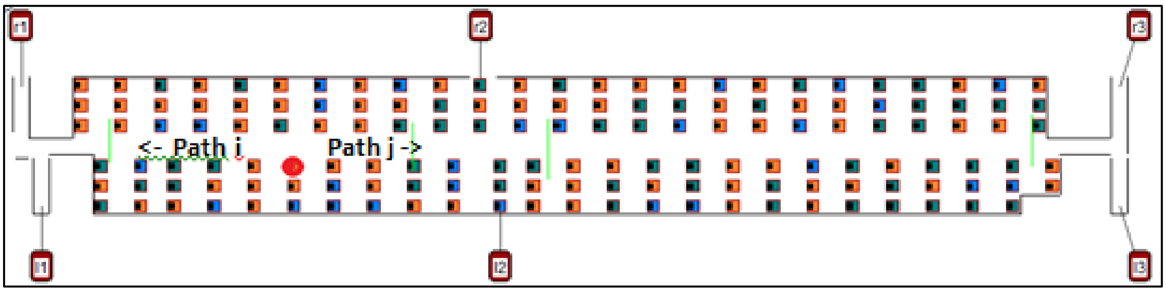


Figure 9-7: Direction of Path i and Path j to be considered by decision making pax shown in red

The following rules must then be used during the development of the path evaluation algorithm (See (Equation 9-5).

1 Calculate every n time step
2 Only allow m re-direction *(m = 1 after entering into the aisle)*
3 Only redirect if $Tpath_i - Tpath_j \geq$ critical value

$$\downarrow$$

$$\frac{Tpath_i - Tpath_j}{Tpath_i}$$

(Equation 9-5)

9.3.2 Attributes and Descriptions used in the development of the Simple Model for Models 2-5

The simple model was first developed and then adapted for Models 2-5 with Phases 1 and 2 (see Table 9-1 and Table 9-2) with the following list of attributes and their descriptions:

R^{pax} =*Number of redirections made by decision making pax*

D^{pax} = *Distance to next pax on aisle when decision point initiated*

D^{exit} = *Distance to exit*

FWS^{pax} = *Pax fast walk speed*

N^{pax} = *Number of pas in aisle ahead*

NJS^{pax} = *Number of pax ahead joining aisle from seat rowss*

TN^{pax} = *Total number of pax to get ahead*

F^{exit} =*Flow rate of exit (persons per second)*

FRE^{paxs} =*Flow rate of paxs ahead*

TQ^{pax} = *Time for queue of pax*

PTT^{exit} =*Personal travel time to exit*

PTT^{pax} = *Travel time to next pax on aisle ahead when decision point made*

CPS^{aisle} =*Census point speed of aisle (persons per second)*

$BECP^{pax}$ =*Passenger location between exit and census line*

$NACF^{paxc}$ = *Number of pax ahead in aisle and in contra flow*

$NJSCF^{pax}$ = *Number of pax ahead joining aisle from seats in contra flow*

$TNCF^{pax}$ =*Total number of pax in contra flow from aisle and seats rows ahead.*

TCP^{pax} =*Total contra flow penalty all pax ahead in queue*

(Equation 9-6)

9.3.3 Development of model 2 phase 1

Model 2 was the most simple of the path evaluation models developed. It was developed in such a way to switch pax redirection on and off. In Model 2a pax can assess the path value while located in the seat row only and every second of the simulation, while in Model 2b, the pax can assess the path value every second while located in the seat row and then once more after entering the aisle. Limiting the option of redirection in Model 2b to once after the pax enters the aisle was an assumption made. This assumption may need further research and rethinking for future models developed as redirecting only once may be inaccurate. In Model 2, it was assumed that pax have very basic knowledge of exit sizes and their flow rates. During the algorithm developed for Model 2, pax assume that all exits on the aircraft are the same size and have the same flow rate. Pax will not distinguish the difference in size between the Type C exit and the over wing emergency Type III exit and will apply an approximate flow rate of 1.2 s for each pax that passes through the exit. During Model 2a when the pax is still located in a seat row they can reuse this algorithm for every second of the simulation but in Model 2 b, the pax can use the algorithm every second when located in the seat row but once entering the aisle, there is only one further opportunity to reuse the algorithm and redirect to a better exit. The pseudo code for the Model 2 (a and b) for Phase 1 can be seen below:

Pseduo Code with Attributes used for Model 2 (a and b) Phase 1

F^{exit} = 1.2; //1.2s Type I exit flow rates only

If($BECP^{pax}$ = 1) *//if pax between census line and exit*
{
Return(-1.0f); *//No Assessment of exits required as pax too close to exit*
}
Else //Pax not between census line and exit
{
If(N^{pax} == 0) *// aisle is empty and clear*
{
$PTT^{exit} = D^{exit} / FWS^{pax} + F^{exit}$;
//PaxTargetExitForward_Dist/Fast Walk Speed +1.2 s

Return (PTT^{exit});

}
Else *//aisle ahead not empty need to use flow rate estimate*
{
If($D^{exit} / FWS^{pax} >= N^{pax} * F^{exit}$) *//pax ahead faster or same speed*
{

$PTT^{exit} = D^{exit} / FWS^{pax} + F^{exit}$;

Return (PTT^{exit});
}
Else *//pax ahead slower*
{
$PTT^{exit} = (D^{pax} / FWS^{pax}) + ((N^{pax} + 1) * F^{exit}$);
Return (PTT^{exit});
} //end else

} //end else
}//end else
} //End if

Algorithm 9-1:Psedo code used for Model 2a and b for Phase 1

The code displayed in Algorithm 9-1 calculates the PTT^{exit} *(personal travel time to the exit)* of the decision making pax. This model code does not include paxs still located in the seat rows ahead. This will only be included in Phase 2 of this model.

9.3.4 Development of model 2 a and b phase 2

Phase 2 of Model 2 (a and b) is a more sophisticated version of the same model in Phase 1. During this phase, paxs still located in the seats rows ahead will be taken into consideration by the decision making pax using the best path evaluation algorithm. Only Model 2b, will allow pax redirection during phase 2. The main difference between Model 2 (a and b) during Phase 2 is the switching on and off of pax redirection. The pseudo code for the Model 2 (a and b) Phase 2 which calculates the PTT^{exit} of the decision making pax is displayed in
Algorithm **9-2**.

Pseudo Code for Model 2 (a and b) Phase 2

```
F^exit = 1.2; //Set all exits use Type I flow rates 1.2 s per pax

    If( BECP^pax ) //if pax located between census line and exit no assessment of path value required
    {
        Return(-1.0f); //No Assessment of exits required as pax too close to exit
    }
    Else //Pax not between census line and exit
    {
        If( N^pax == 0 ) // aisle is empty and clear
        {
            If(SeatsRowsEmpty)
            {
                If(CurrentTarget)
                {
                    Return (-1.0f); //No redirection
                }
                Else
                {
                    PTT^exit = D^exit / FWS^pax + F^exit ;
                    //PaxTargetExitForward_Dist/Fast Walk Speed +1.2 s

                    Return ( PTT^exit );
                }
            }
            Else // Passengers still in seat rows ahead
            {
                    TN^pax = NJS^pax * 0.5
    //Total number of pax to get ahead = Number of pax ahead who may join aisle from seats * 0.5
            TQ^pax = (TN^pax / F^exit ); //Estimated Time for queue of pax
                    //Total number of pax in contra flow from seats
```

F^{exit} = 1.2; //Set all exits use Type I flow rates 1.2 s per pax

$$TCP^{pax} = NJSCF^{pax} * \text{contra flow penalty}$$

//Total contra flow penalty of pax in queue ahead =
*Total number of pax in contra flow from seats * contra flow penalty*

$$PTT^{exit} = ((D^{exit} / FWS^{pax}) + (F^{exit})) + (TN^{pax} / F^{exit}) + (TCP^{pax});$$

The total time for pax to get out of exit including 50% pax from seats to get ahead plus a contra flow penalty.

Return (PTT^{exit});

}//end else pax still in seat row ahead
} //end aisle is empty and clear
Else *//aisle ahead not empty*
{

$$TN^{pax} = N^{pax} + (NJS^{pax} * 0.5)$$

$$TQ^{pax} = (TN^{pax} / F^{exit});$$ //Time for queue

$$TNCF^{pax} = (NACF^{pax} + NJSCF^{pax})$$

//Total number of pax in contra flow from aisle and seats

$$TCP^{pax} = TNCF^{pax} * \text{contra flow penalty}$$

//Time penalty for those pax in contra flow

If($D^{exit} / FWS^{pax} >= (TQ^{pax} + TCP^{pax})$) *//pax ahead faster or same speed*
{

$$PTT^{exit} = D^{exit} / FWS^{pax} + FWS^{pax};$$

Return (PTT^{exit});
}
Else *//pax ahead slower*
{

$$PTT^{exit} = (D^{pax} / FWS^{pax}) + (TN^{pax} + 1.0F + / F^{exit}) + TCP^{pax};$$

Return (PTT^{exit});

} //end else pax ahead slower

} //end else *aisle ahead not empty*
}//end else

Algorithm 9-2: Pseudo code used for Model 2a and b for Phase 2

9.3.5 Development of model 3Phase 1

In Model 3 it was assumed that all pax had full knowledge of exit sizes and flow rates. The model was developed in to same way as Model 2 with the option to switch pax redirection on (Model 3a) and off (Model 3b). In Model 3a pax can assess the path value while located in the seat row only every second of the simulation, while in Model 3b, the pax can assess the path value every second while located in the seat row and then once more after entering the aisle. Limiting the option of redirection in Model 3b to once after the pax enters the aisle was an assumption made. As with Model 2b, this assumption may need further research for future models developed as pax may redirect more than once in a real incident. In Model 3, it was assumed that pax have very good knowledge of exit sizes and their flow rates. During the algorithm developed for Model 3, pax assume that forward Type C exits are larger and faster than the smaller slower over wing emergency exit. Pax will be able distinguish the difference in size between the Type C exit and the over wing emergency Type III exit and will apply an approximate flow rate of 1.2s for each pax that passes through the exit Type C exit and 2.2s per pax that travels through over wing exit. During Model 3a when the pax is still located in a seat row they can apply this algorithm for every second of the simulation but in Model 3b, the pax can use the algorithm every second only while located in the seat row and only once on entering the aisle.

Much of the code for Model 3 (a and b) for Phase 1 (See
Algorithm 9-3) is identical to Model 2 (a and b) for Phase 1 (See Algorithm 9-1). The only difference is the setting of the parameters for the flow rate of the exit. In Model 2 the pax assumed that all exits were the same size so before entering into the algorithm, F^{exit} attribute was set to *1.2s.* In Model (3a and b) for Phase 1, the paxs know the differences between the exit sizes and flow rates. Setting the value of F^{exit} is a little more complex as the exit type will need to be distinguished first by the decision making pax

.

The pseudo code for the Model 3(a and b) for Phase 1 is as follows:

Pseudo Code for Model 3 (a and b) Phase 1

```
Bool ExitType; //1 for large Type I and 0 for small

        ExitType = GetExitType(Exit); // A Function to determine the type of exit

        If (ExitType = 1)
        {
                F^exit = 1.2; //Large exit flowrate
        }
        Else //ExitType = 0
        {
                F^exit = 2.2; //Small exit flowrate
        }

                {

                Call algorithm code for Model 2 (a or b) Phase 1……… (See
        )

                }
```

Algorithm 9-3: Pseudo code used for Model 3a and b for Phase 1

Model 3c Phase 1 (See Table 9-1) calculates the flow rate of the aisle using census points so there is no need to set the F^{exit} flow rate variable statically as in models 3 (a and b) as this will be done dynamically and provided to variables within the algorithm.

9.3.6 Development of model 3 Phase 2

Much of the code for Model 3 (a and b) for Phase 2 is identical to Model 2 (a and b) for Phase 2 with the same option to switch pax redirection on (Model 3a) and off (Model 3b). The main difference between the models is the setting of the parameters for the flow rate of the exit. In Model 2 and its variations, paxs assumed that all exits were the same size and therefore prior to entering into the path evaluation algorithm, the F^{exit} attribute was set to ***1.2s.*** In Model (3a and b) for Phase 2, the paxs know the differences between the exit sizes and flow rates. Setting the value of the F^{exit} parameter is a little more complex as the type of exit will first need to be distinguished by the decision making before they can work out which flow rate to apply. The main difference between Phase 1 and 2 for Model 3 (a and

b) is that during Phase 2, paxs still located in the seat rows ahead of the decision making pax are taken into consideration within the path evaluation algorithm. The pseudo code for the Model 3 (a and b) for Phase 2 (See Algorithm 9-4) is as follows:

Pseudo Code for Model 3 (a and b) Phase 2

Bool ExitType; //1 for large Type I and 0 for small

ExitType = GetExitType(Exit); // A Function to determine the type of exit

If (ExitType = 1)
{
F^{exit} = 1.2; //Large exit flow rate 1.2 sec per person

}
Else //ExitType = 0
{
F^{exit} = 2.2; //Small exit flow rate 2.2 sec per person

}

{

Call algorithm code for Model 2 (a or b) Phase 2……… (See Algorithm 9-2*)*

}

Algorithm 9-4: Pseudo code used for Model 3a and b for Phase 2

Model 3c Phase 2 (See Table 9-2) calculates the flow rate of the aisle using census points as it did in model 3c Phase 1 so there is no need to set the F^{exit} flow rate constant as in Models 3 (a and b) for Phase 2 as this will be done dynamically and provided automatically to variables in the algorithm.

9.3.7 *Development of model 4 phase1*

During Model 4 Phase 1 and its variations (a, b and c), some the data from the survey results is used within the path evaluation algorithm. As with other models developed, the same option to switch pax redirection on (Model 4a) and off (Model 4b) exists. Model 4c calculates the flow rate of the aisle using census points as it did during Model 3c for Phase 1 and 2. This dynamic aisle flow rate is then provided automatically to the path evaluation algorithm. The survey identified that 23% of pax that had flown in the last 12 months were able to correctly identify the location, the size and the flow rate of the exits. Model 4 was constructed in such a way that paxs were using 2 separate behaviours. Just over three quarters of the population (77%) used their nearest exit and hence used Model 1 a while 23 % used a variation of Model 3 (a, b or c). The combination of the models used to develop Model 4 Phase 1 and its variations can be seen from the flow charts depicted below (See Figure 9-8: Flow chart for pax behaviour in Model 4a Phase **1** 1, Figure 9-9 and Figure 9-10).

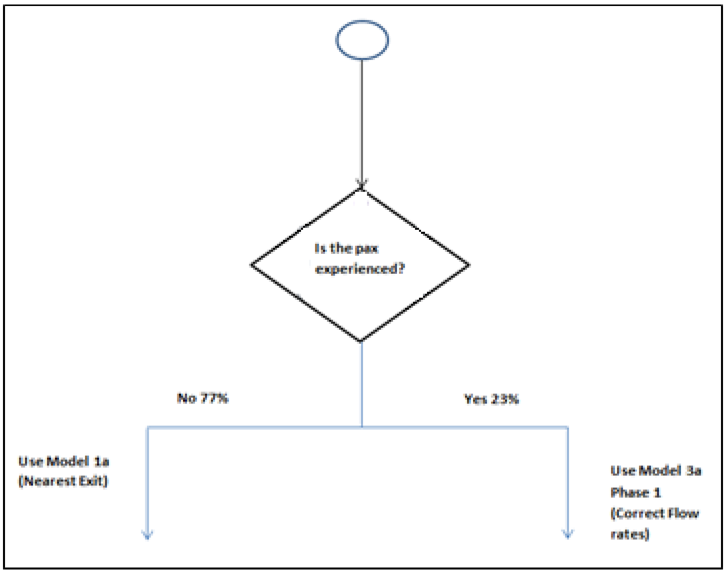


Figure 9-8: Flow chart for pax behaviour in Model 4a Phase 1 for path value assessment

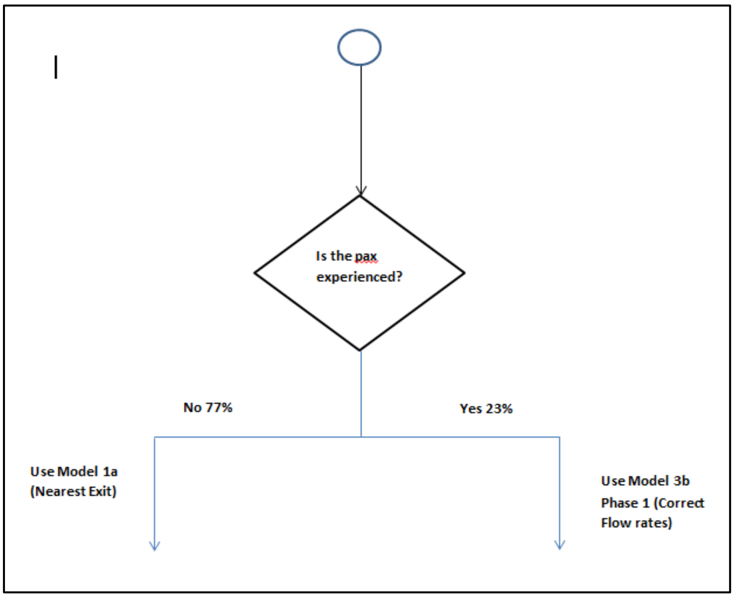


Figure 9-9: Flow chart for pax behaviour in Model 4b Phase 1 for path value assessment

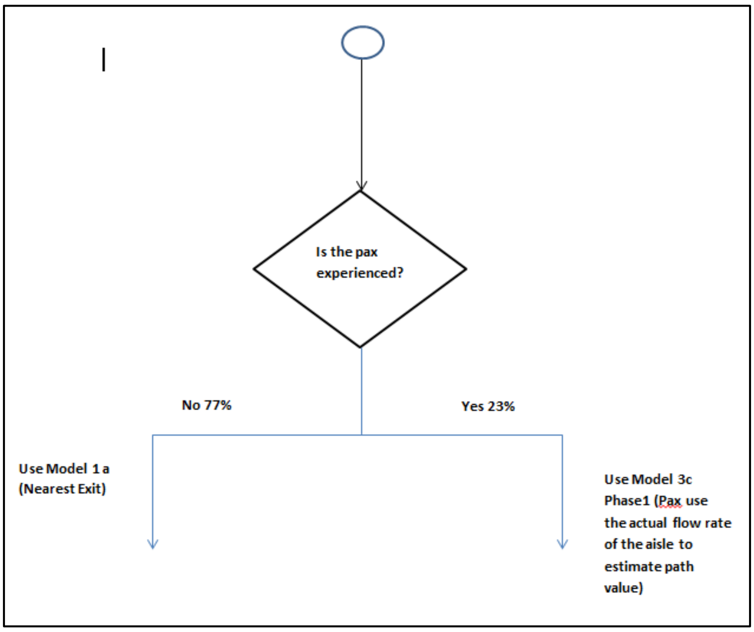


Figure 9-10: Flow chart for pax behaviour in Model 4c Phase 1 for path value assessment

During the development of Model 4 Phase 1, the percentage of the population using a particular behaviour was set according to these flow charts. In the development of Model 4 Phase 1, 23% would use a variation of Model 3 Phase 1 while the rest of the population would use their nearest exit. Any pax using Model 1a or Model 3a would not be allowed to redirect. Paxs using Model 3 (b or c) were permitted to redirect. As airExodus is a stochastic model, during each simulation run, the allocation of the 23% using a variation of Model 3 would be randomised.

9.3.8 Development of model 4 phase2 (Model 4a, 4b and 4c)

In Model 4 Phase 2 and its variations (a, b and c) was developed using some data from the survey results. Paxs in Model 4 Phase 2 are again using 2 completely separate behaviours as in Phase 1. The breakdown of the pax population using their nearest exit (77%) or a variation of Model 3 Phase 2 (23%), are identical to those in Phase 1. As with other models developed, the same option to switch pax redirection on (Model 4a) and off (Model 4b, 4c) still exists. Model 4c Phase 2 calculates the flow rate of the aisle using census points as it did during Model 4c for Phase 1. The combination of the models used to develop Model 4 Phase 2 and its variations can be seen from the flow charts depicted below (See Figure 9-11, Figure 9-12 and Figure 9-13).

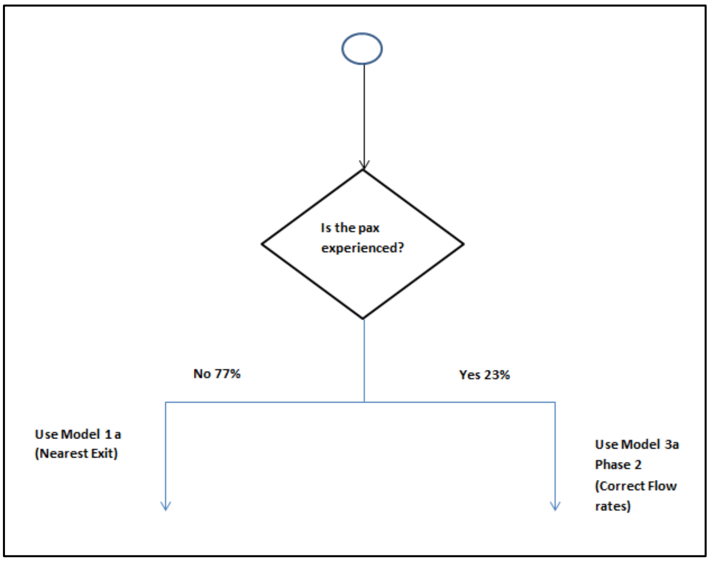


Figure 9-11: Flow chart for pax behaviour in Model 4a Phase 2 for path value assessment

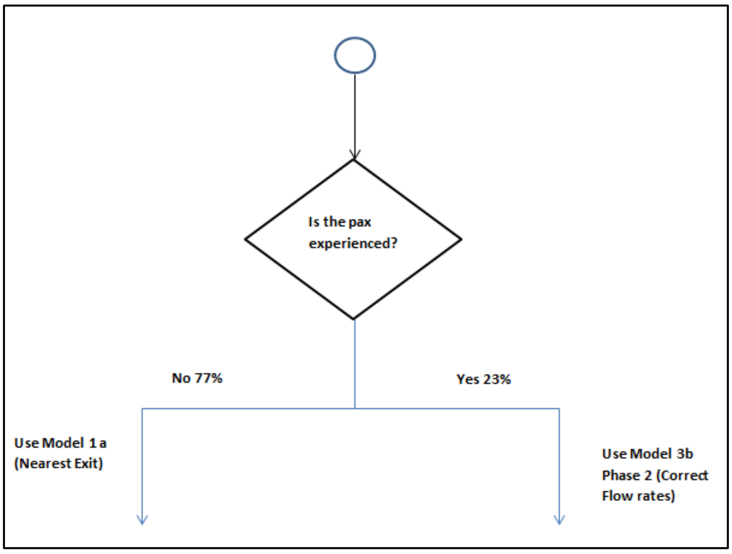


Figure 9-12: Flow chart for pax behaviour in Model 4b Phase 2 for path value assessment

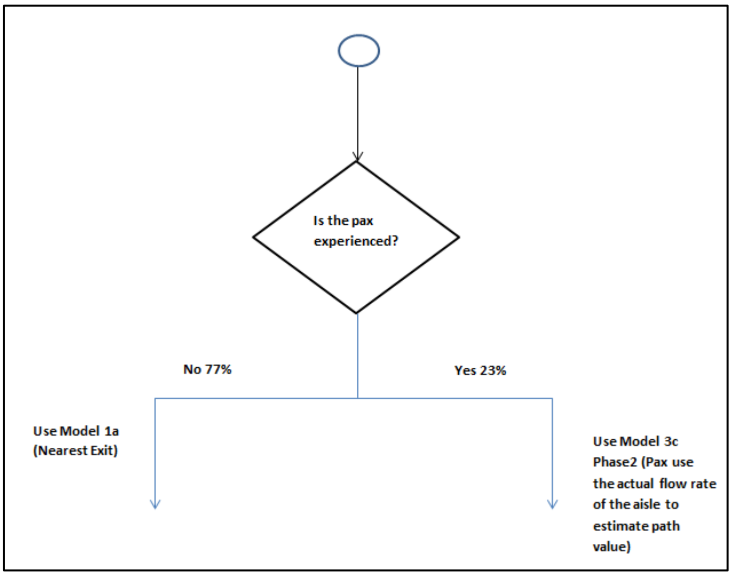


Figure 9-13: Flow chart for pax behaviour in Model 4c Phase 2 for path value assessment

During Model 4 Phase 2, the allocation of 23% of the population using a variation of Model 3 (a, b or c) as would be randomised for each simulation run due to the stochastic nature of airExodus.

9.3.9 Development of model 5 phase 1

During Model 5 Phase 1 and its variations (a, b and c), some of the data from the survey results is used within the path evaluation algorithm. The same option to switch pax redirection off (Model 5a) and on (Model 5b, 5c) exists as in other models. In Model 5c the flow rate of the aisle is retrieved using census points as it did during Model 3c and 4c for Phase 1 and 2. This dynamic aisle flow rate is then provided to the path evaluation algorithm. The survey told us that 23% of pax that had flown in the last 12 months were able to correctly identify the location, the size and the flow rate of the exits. The pax in Model 5 have the option of using 2 separate behaviours. Just over three quarters of the population (77%) used their nearest exit and hence used Model 1 a while 23 % used a variation of Model 3 (a, b or c). The combination of the models used to develop Model 5 Phase 1 and its variations can be seen from the flow charts depicted below (See Figure 9-14, Figure 9-15 and Figure 9-16).

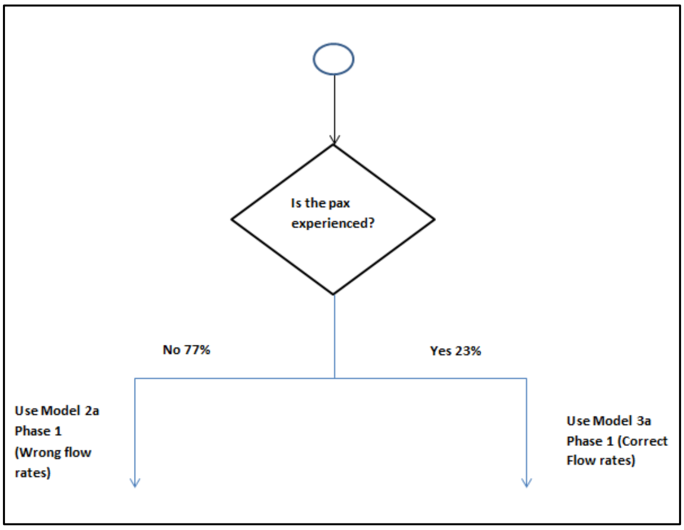


Figure 9-14: Flow chart for pax behaviour in Model 5a Phase 1 for path value assessment

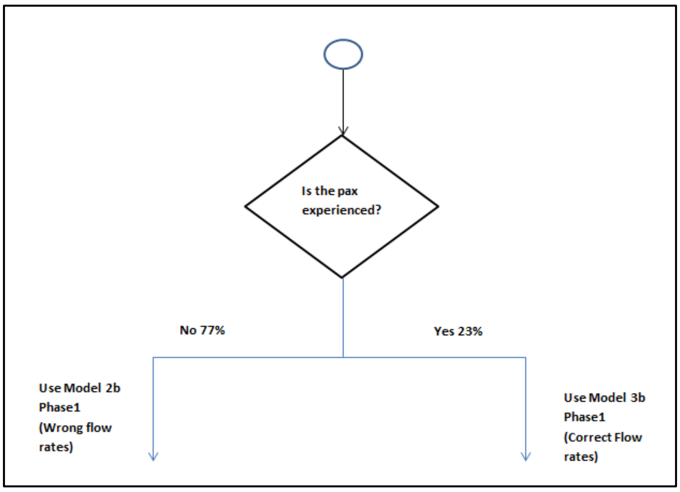


Figure 9-15: Flow chart for pax behaviour in Model 5b Phase 1 for path value assessment

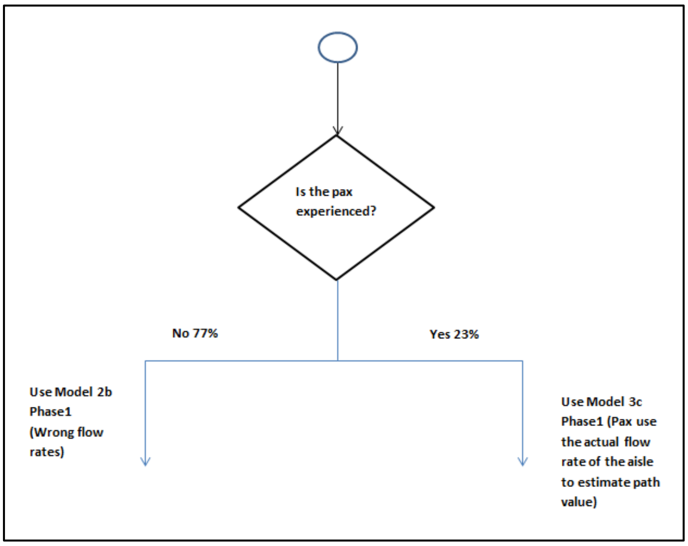


Figure 9-16: Flow chart for pax behaviour in Model 5b Phase 1 for path value assessment

During Model 5 Phase 1, the allocation of 23% of the population using a variation of Model 3 (a, b or c) as would be randomised for each simulation run due to the stochastic nature of airExodus. This also applies to the 77% of the population using Model 2b for Phase 1.

9.3.10 Development of model 5 phase 2

During Model 5 Phase 2 and its variations (a, b and c), some of the data from the survey results is used within the path evaluation algorithm as in Phase 1 of Model 5. The same option to switch pax redirection off (Model 5a) and on (Model 5b, 5c) exists as in other models. In Model 5c for Phase 2 the dynamic aisle flow rate is retrieved using census points on the aisle and then provided to the path evaluation algorithm as done in Model 5c Phase 1. The same survey data quantities are used for Model 5 Phase 2 as were used in Phase 1 with pax having the option of using 2 separate behaviours. Just over three quarters of the population (77%) use Model 2b, while 23 % used a variation of Model 3 (a, b or c) for Phase 2. The combination of the models used to develop Model 5 Phase 2 and its variations can be seen from the flow charts depicted below (See Figure 9-17, Figure 9-18 and Figure 9-19).

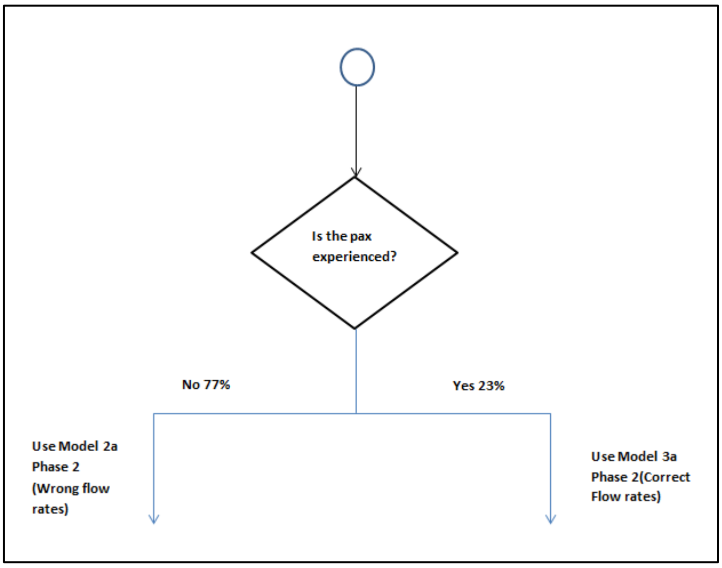


Figure 9-17: Flow chart for pax behaviour in Model 5a Phase 2 for path value assessment

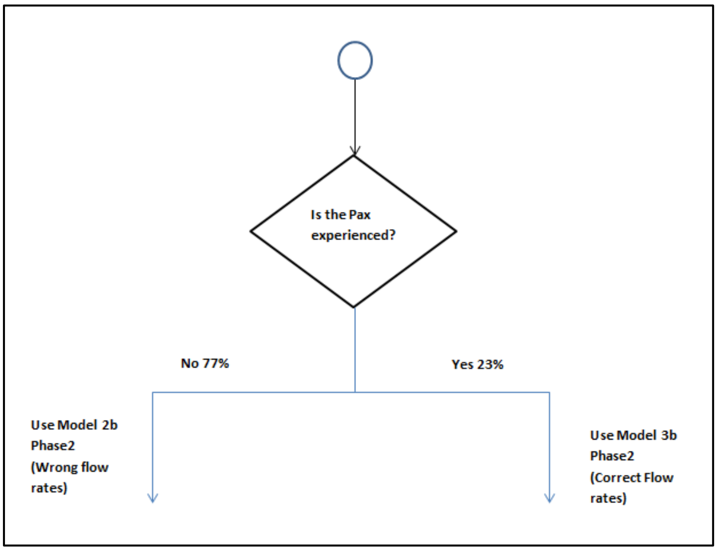


Figure 9-18 : Flow chart for pax behaviour in Model 5b Phase 2 for path value assessment

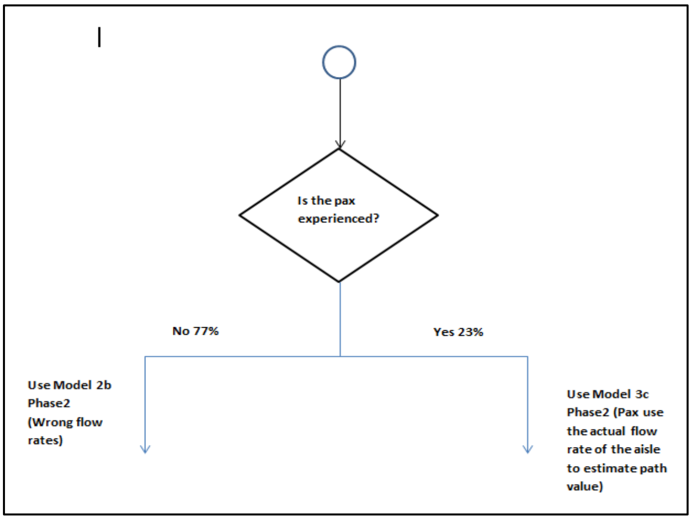


Figure 9-19: Flow chart for pax behaviour in Model 5c Phase 2 for path value assessment

During Model 5 Phase 2, the randomisation of the model allocation to the population works in exactly the same way as it did in Phase 1 for Model 5.

9.4 CONCLUDING REMARKS

This chapter looked at the development of the models used to validate the data gathered in from the survey discussed during Chapter 7 and 8 and addresses research Question 2 in Chapter 1 of this thesis. Not all of the data mined from the participant survey has been used or validated in these models due to the volume of analysis which took place. The main emphasis on development for validation purposes was placed on the data from a sub population of frequent flyers who have flown in the previous 12 months (194 people). In this sub population analysed, 27% of the pax knew the exit location and difference in exit sizes. The percentage dropped further to 23% when the respondents were asked to identify the correct flow rates of the exits.

The development of the algorithm for the path evaluation model was applicable for use in simulations relating to narrow bodied aircraft only. Extending the development of the model for wide bodied aircraft and VLTA is the subject of further work. A total of 22 separate models were developed (11 for Phase 1 and 11 for Phase 2). The algorithm developed for Phase 1 models being more simplistic than those of Phase 2. Although Phase 2 models have more complexity, some assumptions were made in the development of this additional functionality which may need some further research and validation. These assumptions included included taking 50 % of pax located in the seat rows ahead as making it into the aisle before decision making pax. This 50% value is an approximation for which there is no proof. This value may be much higher or lower. Video evidence from a 90 s certification trial may not be useful for gathering data on this topic as intervention is made in directing pax to best available exits by the crew members trying to optimise the evacuation. This may involve a further questionnaire distribution to establish some more accurate figures.

In both Phases 1 and 2 there is a an assumption that it takes **1.2s** for each pax to travel through the larger Type C exit and **2 s** to travel though the smaller Type III emergency exit. Although these approximations are very close to what the value should be they may not be exact. This also could be the subject of further research and validation through questionnaires. In Model 2 (a and b) for both Phases however, the pax assumes that there is no difference in the size of the exits within the aircraft and applies the Type C exit speed to all available exits.

The development of the path evacuation model didn't include any differences in behaviour for gender or differences of age grouping within gender groups. This is indeed the subject of further work on the enhancement of this model. The cross section of the populations which will be used during simulation and validation of these models in Chapter 10 will be between the ages of 18 to 60 years old. This is the age range currently used within the 90 s certification process and therefor this must be maintained for good validation to take place. Children, pensioners and family groups will be excluded from the simulation and validation of these developed models but is in great need of research for the possibility of reconstructing accidents with a more realistic cross section of air paxs for both business and leisure purposes.

10 VALIDATION OF UPDATED AIREXODUS MODEL

10.1 INTRODUCTION

In this chapter, the aim will be to validate the models which have been implemented using the data gathered from questionnaire results discussed in Chapter 8. Two separate phases (Phase 1 and 2) of the airExodus Model were developed with Phase 1 excluding the paxs still located in the seat rows for a pax calculation and decision of the most efficient route to take during the evacuation of the aircraft. Phase 2 which is the more advanced phase will include in its calculation, paxs still located in the seat rows that may get into the aisle ahead. These models and their differences between the separate phases must first be validated before achieving any confidence and hence greater use of computer simulation in aircraft accident reconstruction.

Confidence in a computer model can only be achieved through being able to predict or reconstruct what happens in reality with a good deal of accuracy [104]. Software validation is something that needs to be an on-going task and aircraft evacuation software is no exception to this rule. Software validation procedures have been outlined and adopted by the building and maritime industries for their equivalent software but these can be used and adapted for purpose in the aviation industry. These four forms of validation that evacuation models should conform to are as follows component, functional, qualitative and quantitative validation [104]. Although all four forms of validation are important, quantitative validation is possibly the most important and is the form of validation that will be paid most attention to within this chapter. The purpose of quantitative validation is to prove and demonstrate that the newly developed evacuation model is able to reproduce human behaviour which has been previously measured. It may be important for our quantitative validation to consider suitable acceptance levels of the results produced by 5% or 50% of previously measured values but this may greatly depend on the type or nature of application intended. There are two main types of quantitative validation which are namely (1) using historic data for validation of model and (2) using a model for predictive 'blind' simulations where no historical data exists [104]. Validation of predictive blind simulations can be quite complex and less trusted. It may be dependent on the sophistication of the evacuation model and whether validation using historic data may have already taken place.

Quantitative validation of aircraft evacuation models is mostly achieved by comparing model output results to the results of experiments, 90s trials or real emergency aircraft evacuation situations. The greatest confidence in an aircraft evacuation model may be gained by comparing to organised and controlled experiments which can be repeated many times. The next most trusted is data source for model validation is using the results from the 90s certification trial. Unfortunately this type of trial only produces one result or data point and is not repeated many times. Real emergency evacuations are very difficult to use for quantitative validation as firstly there is only one possible data point and the aircraft conditions plus final evacuation times provided to the data modeller may not be as accurate as required for model validation purposes.

10.2 DEMONSTRATION OF NEW MODEL VALIDATION ON A SET OF CASES USING NEW BEHAVIOURS AND PARAMETERS FROM QUESTIONNAIRE RESULTS

10.2.1 Selection of certification trial cases to be used for model validation

The certification trial case used for validation of these newly implemented models was that of a narrow bodied aircraft with 149 paxs (see Figure 10-1) similar to the Boeing 737-300 [105]; widely used for domestic travel with 6 exits (two forward exits , two aft exits and two over wing emergency exits). The forward and aft exits are the larger Type C exits while the over wing exits are the smaller Type III exits. Type C exits are operated by cabin crew during the certification trial while Types III exits are normally operated by the row of paxs siting alongside. The 90 seconds certification trial case is normally close to the most optimal split of passengers between the available exits. The results obtained will be used to compare the new models with the optimal case often seen in the 90 second certification trial of an aircraft. For a case to be considered optimal, each of the available exits must exhaust the pax travelling through within 10 seconds of each other [104].

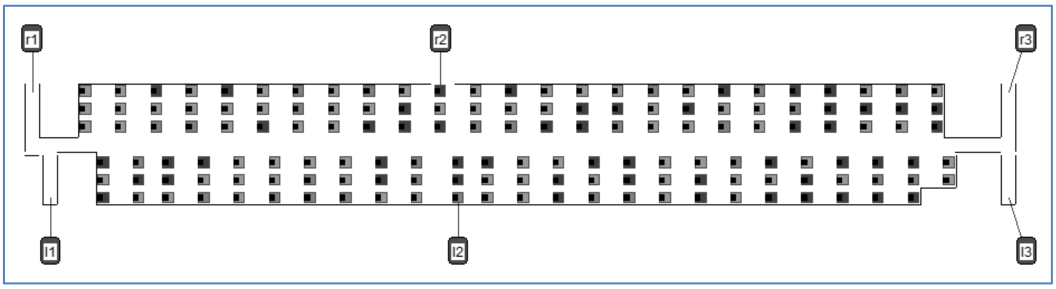


Figure 10-1: Aircraft configuration with seats and aisle including 149 pax cabin plus 6 exits (Only 3 available during simulation)

10.2.2 Selection of real accident cases to be used for model validation

Studies carried out using the AASK database [2] suggested 85% of passengers who reported exit usage; make use of their nearest exit during a real accident. To validate the models developed, it will be important to check each model against the results of a case which has 85% of paxs using the nearest exit usage. To demonstrate this, the simulation of a case similar in some respects to the certification case in terms of available exits (R1, R2 and R3) will be used with 85% of the paxs sent to the nearest available exit irrespective of whether the exit is in front or behind their seating location. While this will also be run under FAR 25.803 conditions, the result is expected to be sub-optimal.

10.2.3 Populations used to validate models in Phases 1 and 2

The 90 second population (referred to as target population) as specified in FAR 25.803 was used during the simulations for this chosen aircraft configuration. Each population for the aircraft configuration was made up of non-connected individuals who began each simulation from within the configurations specified in Figure 10-1 with every pax member of the population starting the simulation from a seat. Each population contained individuals with different movement capabilities reflecting different age groupings and ability levels. For each of the model validations carried out, 5 different population mixes were used (i.e. 5 different populations satisfying the 90 second criteria). Each of the 5 population mixes was run 100 times for each model scenario being validated, with pax seating allocations being swapped for every run (all other population characteristics were kept constant for each of the 100 repeat simulations). Thus, a total of 500 simulations were performed for each Model relating to this aircraft configuration.

10.2.4 Exit Ready Time Parameters

This is an input parameter specified by the user in airExodus as part of the scenario specification for each exit used during an evacuation simulation. It is a measure of the time required to make the exit ready for use and is measured from the start of the evacuation process to the point where the exit is made ready for use. For crew operated exits, it measures the time from the first touch of the exit to the point where the crew has opened the exit and made ready any evacuation assist means e.g. slide. For pax operated exits such as the Type III over wing exit, it measures the time from the first touch of the exit opening mechanism to the point where the passenger has opened the exit and made the exit ready. The exit ready times for the exits used during the simulations for the models being validated are as follows:

R1 (Type-C exit – Forward Right) = 8.2 s
R2 (Type-III exit – Over-wing) = 12.0 s
R3 (Type-C exit –Aft Right) = 8.2 s

10.2.5 Response Time for Passengers

The paxs defined in airEXODUS were created using the 90-second population function available in the software. This function generates the required numbers of paxs according to the specified mix (in terms of age and gender) as set out in FAR [1]. In airEXODUS, simply specifying the age and gender of each passenger is not enough. The population tools in airEXODUS, allows a range for the response time attribute to be specified, so that when a person is created, the response time attribute is assigned a random value between the limits set.

The 90-second population consists of four separate population groups, Males 18-50, Males 50-60, Females 18-50 and Females 50-60. The response time attribute parameters for these groups are distributed as indicated in Table 10-1.

Table 10-1: Response time attribute ranges for the 90-second populations used in simulations

Attribute	Group	Min	Max
Response Time	Males 18-50	0.0	5.0
	Males 50-60	4.0	7.0
	Females18-50	0.0	6.0
	Females 50-60	5.0	8.0

10.2.6 Off-Times Used

The Off-Times (the time between leaving the exit and touching the ground) for the aircraft configuration used to validate the models in this study are as follows:

R1 (Type-C exit – Forward Right) = 1.3 - 2.6 s
R2 (Type-III exit – Over wing) = 1.3 - 2.6 s
R3 (Type-C exit –Aft Right) = 1.3 - 2.6 s

The off-times used for the configuration were taken from the 90-second certification report for B737-300 [105]. Off-times were only available for the forward and aft exits. It is possible that the over wing exit may have a larger of time due to the over wing positioning of the exit.

10.3 RESULTS OF MODEL SIMULATION

In this section, the results of the simulations carried out will be presented (see Table 10-2, Table 10-4 and Table 10-6) and discussed for the 100% and 85% nearest exit cases (Model 1a and b respectively), the optimal case and all implemented Models 2-5 for Phases 1 and 2. A description of these models was previously given in Table 9-1and Table 9-2 in Chapter 9. Each model simulation will be compared to a number of output results plus the average pax use of the nearest exit.

10.3.1 Nearest Exit and Optimal Results

For each of the models presented for nearest exit and optimal results (see Table 10-2) 500 simulations were run with paxs changing the starting seat location for each new simulation. Each model scenario was run using 5 different populations with each of the populations used to run 100 stochastic simulations. These 5 populations were also reused for all of the newly developed and simulated models 2-5 which are being validated (see Table 10-4 & Table 10-6). A total of 1500 simulations were run for the Nearest Exit and Optimal cases presented in Table 10-2. Paxs in the nearest exit and optimal simulations were unable to redirect to an alternative exit and therefore maintain their target exit throughout the simulations.

The 100% Nearest Exit model simulations (Model 1 a) are set up to make all paxs travel to and evacuate through their nearest available exit. The results for the Nearest Exit Model, suggest the aircraft can produce on-ground times of between 123.9 s and 155.8 s with a mean of 139.6 s and a standard deviation of 5.6s. In this case we note that passengers travelled an average of 5.3 m. The average PET (out of aircraft time) displayed in Column 5 (Table 10-2) was 51.4 s, while in the next column, the average CWT (Cumulative Wait Time) is 38.6 s. During the 100 % Nearest Exit simulations, we find that 75.1% of the PET is wasted in congestion. The average use of the nearest exit by passengers was 97.2%.

A second set of simulations was then carried out for the 85% Nearest Exit model which will be referred to as Model 1b. This model represents what survivors have reported from real accidents and emergencies in the AASK database [2] and will be used to validate other models against. Model 1 b simulations were constructed to make only 85% of paxs travel to and evacuate through their nearest available exit. The results for this model (see Table 10-2), suggest the aircraft can produce on-ground times of between 95.6 s and 124.2 s with a mean of 107.9 s and a standard deviation of 4.9s. In this case we note that paxs travelled an average of 5.6 m. The average PET (out of aircraft time) was 40.1 s, while the average CWT is 27.3 s. During the 85% Nearest Exit model (Model 1b) simulations, it should be noted that 68.1% of the PET is wasted in congestion. The average use of the nearest exit by passengers in the simulations carried out was 85.8 %. When comparing this 85% Nearest Exit model (Model 1b) to the 100% model there is a reduction in the mean on ground time by 23.7 % while the average distance travelled by paxs is increased by 5.7%. The average PET has reduced by some 22% when comparing to the 100% model while the Average CWT has decreased by 29.3%. In Model 1b, paxs travel slightly further on average (0.3 m) to get to an available exit which improves the overall performance of the evacuation.

Table 10-2: Nearest Exit and Optimal Results

Model Name		Out of Aircraft time (s)	On-ground time (s)	Av.PET (s)	Av.CWT (s)	Av.DIST (m)	Av. CWT Ratio	Av. Use of Nearest Exit%
Model 1a 100% Nearest Exit	Min	123.9	126.1	46.2	33.4	5.3	0.6	95.3
	Mean	**139.6**	**141.5**	**51.4**	**38.6**	**5.3**	**0.6**	**97.2**
	Max	155.8	158.3	57.5	44.8	5.4	0.7	99.3
	Stdev	5.6	5.6	1.9	1.8	0.0	0.0	0.8
Model 1b 85% Nearest Exit	Min	93.9	95.6	37.0	24.2	5.5	0.6	84.6
	Mean	**106.0**	**107.9**	**40.1**	**27.3**	**5.6**	**0.6**	**85.8**
	Max	122.8	124.2	44.3	31.5	5.7	0.6	88.6
	Stdev	4.9	4.9	1.3	1.3	0.0	0.0	0.8
Model Optimal Exit	Min	58.1	59.5	32.2	19.1	6.4	0.5	65.8
	Mean	**63.8**	**65.8**	**34.6**	**21.4**	**6.5**	**0.6**	**67.5**
	Max	70.6	72.9	38.2	24.9	6.6	0.6	69.1
	Stdev	2.0	2.0	0.9	0.9	0.1	0.0	0.8

A third set of simulations were carried out using the Optimal Exit Model. This model will be the closest representation of the 90 s certification trial where the pax exit usage will be split in the most optimal manner so that exits finish within 10s of each. During the simulations for this model, if a particular simulation was sub optimal (finishing time of available exits greater than 10 s), then the simulation was discarded and rerun.

The results for this model (see Table 10-2 and Figure 10-2) suggest that this aircraft can produce on-ground times of between 59.5 s and 72.9 s with a mean of 65.8 s and a standard deviation of 2.0s. In this case it is noted that paxs travelled an average of 6.5 m. The average PET (out of aircraft time) was 34.6 s, while the average CWT is 21.4 s. During the Optimal Exit model simulations, we find that 61.9% of the PET is wasted in congestion. The average use of the nearest exit by passengers in the simulations carried out was 67.5%. When comparing this Optimal Exit Model to Model 1 (85 % Model) there is a reduction in the mean on ground time by 39% while the average distance travelled by paxs is increased by 18.2%. The average PET has been reduced by some 13.7% when comparing to the Model 1b while the Average CWT has decreased by 21.6%. In the Optimal Exit Model, paxs travel further on average (0.9 m) to get to an available exit which improves the overall performance of the evacuation by 39% when compared to Model 1b (85 % nearest exit model).

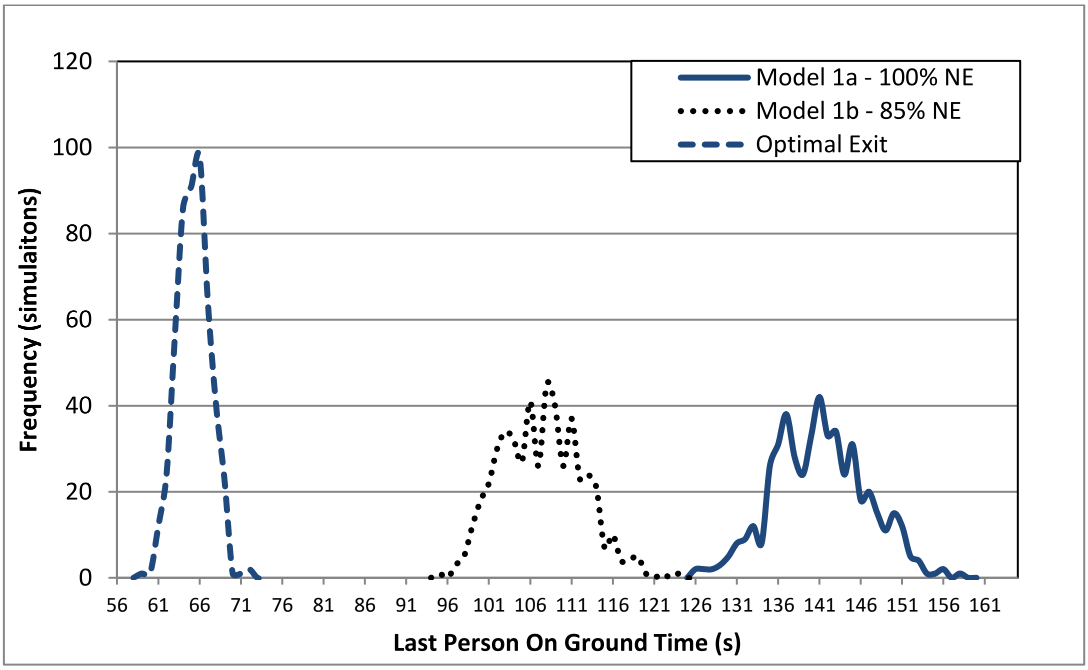


Figure 10-2: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1a, Model 1b and Optimal Exit Scenarios Distributions

Flow rates achieved for each of the exits as predicted by airExodus for the model scenarios listed in **Table 10-3** correspond well with these exits types on this type of narrow bodied aircraft. The Type III exit achieves an average of 38.p ppm which is approximately 3.8% faster than the measured average from the certification trial from certification trials [105]. The larger Type C exits achieve 65.1 ppm which is 0.2% faster the measured average.

Table 10-3: Achieved Exit flow rates (persons per minute) and time for last pax to use each exit for 149 pax aircraft for Models 1a, 1b and Optimal Exit

Model Name	Door	Type C R1 Flow Rate (ppm)	Type III R2 Flow Rate (ppm)	Type C R3 Flow Rate (ppm)	Type C R1 Out of Aircraft Time (s)	Type III R2 Out of Aircraft Time (s)	Type C R3 Out of Aircraft Time (s)
Model 1a 100% Nearest Exit	Min	53.0	33.7	55.5	28.8	123.9	38.3
	Mean	**64.4**	**38.2**	**64.9**	**34.6**	**139.6**	**43.9**
	Max	77.1	43.5	76.3	41.4	155.8	50.4
Model 1b 85% Nearest Exit	Min	55.1	32.9	56.4	42.8	93.9	41.2
	Mean	**65.1**	**38.3**	**65.0**	**48.5**	**106.0**	**49.2**
	Max	74.6	43.3	78.0	55.3	122.8	56.1
Model Optimal Exit	Min	57.9	31.9	58.0	53.3	52.5	55.1
	Mean	**65.3**	**38.8**	**65.8**	**60.6**	**62.2**	**61.6**
	Max	74.9	47.7	74.7	67.6	70.6	68.5

10.3.2 Results and discussion of model validation for Phase1

Models 2 to 5 were developed and simulated for Phase 1. During Phase 1, paxs still located in the seat rows will be excluded from the path value calculation. Phase 1 Definitions for each of the Phase 1 models can been found in Table 9-1, Chapter 9. The results for these models can be found in Table 10-4. The results from the base case models (see Table 10-2) will be used to validate all Phase 1 models.

Table 10-4: Phase 1 Results

Model Name		Out of Aircraft time (s)	On-ground time (s)	Av.PET (s)	Av.CWT (s)	Av.DIST (m)	Av. CWT Ratio	Av. Use of Nearest Exit%
Model 2a	Min	86.6	89.1	37.3	24.3	5.6	0.6	75.8
	Mean	**104.8**	**106.8**	**41.0**	**27.7**	**5.8**	**0.6**	**82.6**
	Max	125.5	128.1	46.1	32.6	6.1	0.6	88.6
	Stdev	6.7	6.8	1.7	1.6	0.1	0.0	2.0
Model 2b	Min	81.5	83.8	36.0	22.5	5.7	0.6	74.5
	Mean	**96.1**	**98.0**	**39.3**	**25.9**	**6.0**	**0.6**	**79.8**
	Max	116.6	118.8	43.6	30.4	6.3	0.6	85.9
	Stdev	5.8	5.8	1.4	1.3	0.1	0.0	2.0
Model 3a	Min	64.4	66.9	33.2	20.2	6.0	0.5	68.5
	Mean	**76.3**	**78.6**	**35.7**	**22.5**	**6.3**	**0.6**	**72.2**
	Max	90.4	95.6	38.7	25.5	6.5	0.6	77.2

	Stdev	4.4	4.6	1.0	1.0	0.1	0.0	1.4
Model 3b	Min	63.1	64.8	33.1	20.0	6.0	0.5	67.8
	Mean	**75.9**	**77.8**	**35.6**	**22.4**	**6.3**	**0.6**	**72.1**
	Max	97.6	99.6	38.8	25.5	6.6	0.6	77.2
	Stdev	5.0	5.0	1.0	1.0	0.1	0.0	1.6
Model 3c	Min	64.6	66.6	32.7	19.6	6.0	0.5	67.8
	Mean	**75.8**	**77.7**	**35.6**	**22.4**	**6.3**	**0.6**	**72.1**
	Max	87.3	89.6	39.2	25.5	6.6	0.6	77.2
	Stdev	4.4	4.4	1.0	1.0	0.1	0.0	1.5
Model 4a	Min	110.4	112.2	41.5	27.8	5.4	0.6	83.2
	Mean	**127.1**	**129.1**	**48.3**	**34.7**	**5.6**	**0.6**	**89.8**
	Max	147.7	149.6	55.8	42.4	5.9	0.6	96.0
	Stdev	7.0	7.0	2.2	2.2	0.1	0.0	2.1
Model 4b	Min	104.1	105.8	41.1	27.8	5.4	0.6	81.9
	Mean	**123.7**	**125.7**	**47.1**	**33.5**	**5.7**	**0.6**	**89.1**
	Max	149.4	151.9	53.1	39.9	6.0	0.6	95.3
	Stdev	6.6	6.6	2.0	2.0	0.1	0.0	2.2
Model 4c	Min	105.4	107.6	41.9	27.9	5.5	0.56	82.6
	Mean	**123.9**	**125.9**	**47.1**	**33.5**	**5.7**	**0.60**	**89.2**
	Max	147.1	148.5	54.7	41.3	6.0	0.63	94.6
	Stdev	7.0	7.0	2.0	2.1	0.1	0.01	2.2
Model 5a	Min	86.6	88.9	35.9	22.6	5.7	0.6	71.8
	Mean	**105.3**	**107.2**	**42.2**	**28.5**	**6.0**	**0.6**	**79.1**
	Max	132.4	134.4	48.2	34.3	6.3	0.6	85.2
	Stdev	7.1	7.1	2.0	1.9	0.1	0.0	2.5
Model 5b	Min	74.6	76.9	34.7	21.3	5.9	0.5	72.5
	Mean	**90.4**	**92.3**	**38.2**	**24.6**	**6.2**	**0.6**	**77.8**
	Max	110.4	112.8	43.0	29.5	6.5	0.6	83.2
	Stdev	5.7	5.7	1.3	1.3	0.1	0.0	2.0
Model 5c	Min	74.8	76.7	35.1	21.9	5.8	0.5	71.8
	Mean	**91.6**	**93.6**	**38.4**	**24.8**	**6.1**	**0.6**	**78.3**
	Max	121.2	122.8	46.4	32.3	6.5	0.6	83.9
	Stdev	5.9	5.9	1.4	1.4	0.1	0.0	2.0

Presented in **Table 10-5** are the out of aircraft times for each of the exits (R1, R2 and R3) as well as the flow rates achieved as predicted by airExodus for the model scenarios. The flow rates for the Type III exit (R2) corresponds well with what is expected for this type of narrow bodied aircraft. The Type III exit achieves an average of 37.2 ppm which is only 0.5 % faster than the measured average from certification trials [105]. The larger Type C exits (R1 and R3) achieve much lower flow rates on average than expected 44.5 ppm in Phase 1 models which is 31.5% slower than the measured average [105]. Of course each model scenario must be analysed individually for the flow rates achieved as pax behaviour in each of the models is often very different. It should also be noted that the out of aircraft time for exits R1 and R3 always finish before the R2 exit in all cases shown in **Table 10-5** which suggests that the over wing R2 exit is being oversubscribed with pax.

Table 10-5: Achieved Exit flow rates (persons per minute) and time for last pax to use each exit for 149 pax aircraft for Phase 1 Models

Model Name	Door	Type C R1 Flow Rate (ppm)	Type III R2 Flow Rate (ppm)	Type C R3 Flow Rate (ppm)	Type C R1 Out of Aircraft Time (s)	Type III R2 Out of Aircraft Time (s)	Type C R3 Out of Aircraft Time (s)
Model 2a	Min	35.0	30.5	28.8	36.9	86.6	46.6
	Mean	**41.0**	**36.6**	**44.1**	**67.9**	**104.8**	**79.4**
	Max	46.0	42.7	73.9	110.7	125.5	110.6
Model 2b	Min	25.5	30.9	34.3	39.9	81.5	47.2
	Mean	**46.0**	**37.1**	**51.6**	**64.8**	**96.1**	**72.1**
	Max	72.5	43.6	68.3	98.5	116.6	95.3
Model 3a	Min	37.5	31.3	46.9	42.5	64.4	55.4
	Mean	**61.2**	**36.9**	**63.6**	**54.5**	**76.1**	**67.2**
	Max	76.0	43.0	75.5	82.4	90.4	87.7
Model 3b	Min	37.9	29.6	47.7	43.5	63.0	54.6
	Mean	**60.4**	**37.2**	**63.8**	**55.3**	**75.7**	**66.7**
	Max	73.9	43.4	73.3	81.1	97.6	85.2
Model 3c	Min	38.0	30.7	49.4	43.1	64.5	55.9
	Mean	**60.9**	**37.2**	**63.9**	**54.8**	**75.6**	**66.5**
	Max	74.9	43.7	73.8	84.2	87.3	80.0
Model 4a	Min	13.2	31.8	19.8	31.0	110.4	40.3
	Mean	**29.4**	**37.7**	**31.7**	**82.3**	**127.1**	**96.0**
	Max	77.1	43.3	73.9	140.3	147.7	137.7
Model 4b	Min	13.5	30.3	20.3	33.7	104.1	40.3
	Mean	**29.2**	**37.7**	**33.6**	**82.7**	**123.7**	**93.1**
	Max	71.0	43.4	74.6	137.4	149.4	135.4
Model 4c	Min	14.8	30.4	19.9	30.5	105.4	43.4
	Mean	**28.9**	**37.7**	**32.7**	**83.6**	**123.9**	**95.0**
	Max	76.8	42.7	69.9	139.5	147.1	133.5
Model 5a	Min	16.4	31.4	26.8	39.9	86.6	47.8
	Mean	**37.2**	**36.6**	**41.6**	**75.2**	**105.2**	**85.4**
	Max	67.3	42.3	70.3	118.2	132.4	117.0
Model 5b	Min	27.3	28.0	32.9	42.2	74.6	51.0
	Mean	**47.9**	**37.2**	**53.1**	**63.7**	**90.3**	**72.9**
	Max	69.3	44.5	69.0	98.7	110.4	100.0
Model 5c	Min	25.0	30.7	35.5	39.7	73.1	47.2
	Mean	**47.4**	**37.2**	**52.8**	**64.0**	**91.6**	**72.8**
	Max	66.6	44.8	72.7	99.8	121.2	96.8

Presented in Table 10-5 are the out of aircraft times for each of the exits (R1, R2 and R3) as well as the flow rates achieved as predicted by airExodus for the model scenarios. The flow rates for the Type III exit (R2) corresponds well with what is expected for this type of narrow bodied aircraft. The Type III exit achieves an average of 37.2 ppm which is only 0.5 % faster than the measured average from certification trials [105]. The larger Type C exits (R1 and R3) achieve much lower flow rates on average than expected 44.5 ppm in Phase 1 models which is 31.5% slower than the measured average [105]. Of course each model scenario must be analysed individually for the flow rates achieved as pax behaviour in each of the models is often very different. It should also be noted that the out of aircraft time for exits R1 and R3 always finish before the R2 exit in all cases shown in Table 10-5 which suggests that the over wing R2 exit is being oversubscribed with pax.

In Model 2a Phase 1 (Table 9-1), pax have poor understanding of exit sizes, flow rates assuming that all exits are the same size and thus have the same flow rates. This model doesn't allow paxs to redirect during the evacuation. The results for model 2a Phase 1 (see Table 10-4 and Table 10-5) suggest that this aircraft model can produce on-ground times of between 89.1 s and 128.9 s with a mean of 106.8 s and a standard deviation of 6.7s. In this case it is noted that paxs travelled an average of 5.8 m. The average PET (out of aircraft time) was 41.0 s, while the average CWT is 27.7 s. During this model's simulations for Phase 1, we find that 67.6% of the PET is wasted in congestion and the average use of the nearest exit by passengers was 82.6%. The Type III exit R2 achieves an average of 36.6 ppm which is only 1.1 % slower than the measured average from certification trials [105]. The larger Type C exits (R1 and R3) achieve much lower flow rates on average than expected with 42.6 ppm (see Table 10 5) which is 34.5% slower than the measured average [105].

When comparing Model 2a Phase 1 results to those of Model 1b where approximately 85 % of pax use their nearest exit (see Table 10-2) we find that there is a very slight reduction in the mean on ground time by 1% while the average distance travelled by paxs is increased by 3.6%. The average PET has been slightly increased by some 2.2% when comparing to the Model 1b while the Average CWT has slightly increased by 1.5%. In the Model 2a Phase 1, paxs travel further on average (0.2 m) to get to an available exit which improves the overall performance of the evacuation by 1% when compared to Model 1b. Model 2a Phase 1 has a larger standard deviation and has a greater span between the minimum and maximum values of the on ground times (89.1 s and 128.1 s respectively) in comparison to

Model 1 b. The majority (94.8 % or 474 simulations) of the distribution results for Model 2a fall within the distribution results for Model 1 b (see Figure 10-3).

- **Model2a Phase 1 has a very close resemblance to the performance of Model 1b meaning pax are travelling further 0.2m to get to an available exit on average. Some differences still exist between the models such as very slight increases in the average PET and CWT. This model could possibly be considered a reliable model for what paxs might do in a real accident situation as nearly 94.8 % of the distribution of results corresponds with those in Model 1b.**

The paxs in Model 2b Phase 1 have a poor understanding of exit location, size and flow rates and as in Model 2a but the main difference is that paxs are given the ability to redirect during the evacuation (see Table 9-1). Each pax can only redirect once during an evacuation. The results for Model 2b Phase 1 (see Table 10-2,

A third set of simulations were carried out using the Optimal Exit Model. This model will be the closest representation of the 90 s certification trial where the pax exit usage will be split in the most optimal manner so that exits finish within 10s of each. During the simulations for this model, if a particular simulation was sub optimal (finishing time of available exits greater than 10 s), then the simulation was discarded and rerun.

The results for this model (see Table 10-2 and Figure 10-2) suggest that this aircraft can produce on-ground times of between 59.5 s and 72.9 s with a mean of 65.8 s and a standard deviation of 2.0s. In this case it is noted that paxs travelled an average of 6.5 m. The average PET (out of aircraft time) was 34.6 s, while the average CWT is 21.4 s. During the Optimal Exit model simulations, we find that 61.9% of the PET is wasted in congestion. The average use of the nearest exit by passengers in the simulations carried out was 67.5%. When comparing this Optimal Exit Model to Model 1 (85 % Model) there is a reduction in the mean on ground time by 39% while the average distance travelled by paxs is increased by 18.2%. The average PET has been reduced by some 13.7% when comparing to the Model 1b while the Average CWT has decreased by 21.6%. In the Optimal Exit Model, paxs travel further on average (0.9 m) to get to an available exit which improves the overall performance of the evacuation by 39% when compared to Model 1b (85 % nearest exit model).

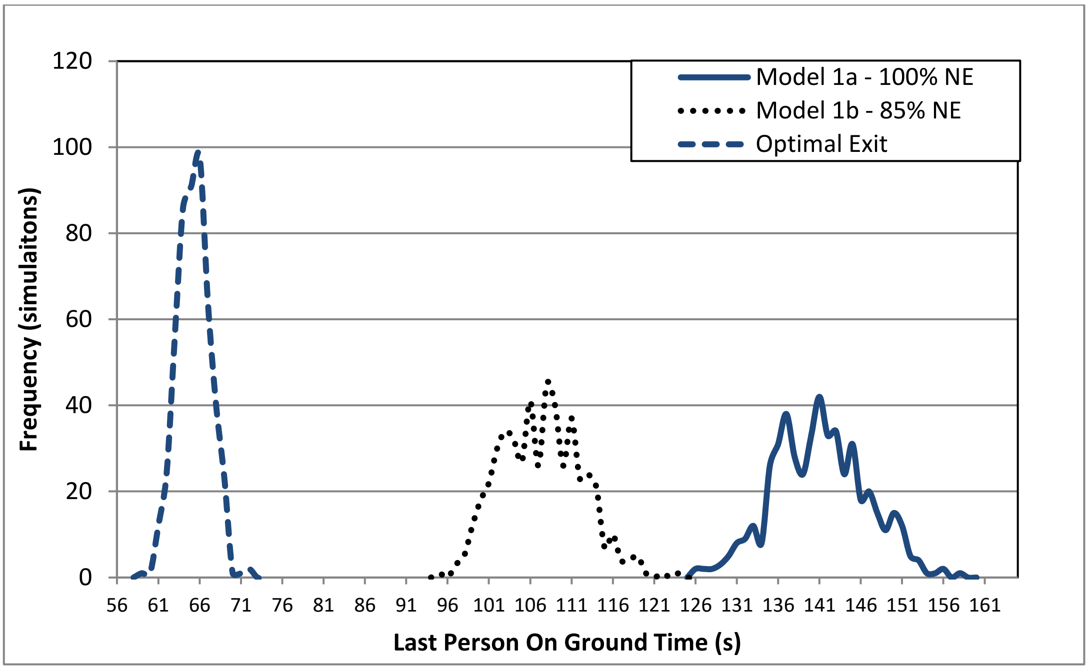


Figure 10-2: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1a, Model 1b and Optimal Exit Scenarios Distributions

Flow rates achieved for each of the exits as predicted by airExodus for the model scenarios listed in **Table 10-3** correspond well with these exits types on this type of narrow bodied aircraft. The Type III exit achieves an average of 38.p ppm which is approximately 3.8% faster than the measured average from the certification trial from certification trials [105]. The larger Type C exits achieve 65.1 ppm which is 0.2% faster the measured average.

Table 10-3 and Figure 10-3) suggest that this aircraft model can produce on-ground times of between 83.8 s and 118.8 s with a mean of 98.0 s and a standard deviation of 5.8s. In the simulations for this model, it is noted that paxs travelled an average of 6.0 m. The average PET (out of aircraft time) was 39.3 s, while the average CWT is 25.9 s. During the Model 2b model simulations for Phase 1, we find that 65.9% of the PET is wasted in congestion. The average use of the nearest exit by passengers in the simulations carried out was 79.8%. The Type III exit R2 achieves an average of 37.1 ppm, only 0.3% faster than the measured average from certification trials [105]. The larger Type C exits (R1 and R3) achieve much lower flow rates on average than expected with 42.5 ppm (see Table 10-5) which is 34.6% slower than the measured average [105].

When comparing the results of Model 2b during Phase 1 to Model 1 b b (Table 10-2) we find that there is a reduction in the mean on ground time by 9.2% while the average distance travelled by paxs is increased by 7.1%. The average PET has been slightly decreased by some 2.0% when compared to the Model 1 b while the Average CWT has slightly decreased by 5.1%. In the Model 2b for Phase 1, paxs travel further on average (0.4 m) to get to an available exit which improves the overall performance of the evacuation by 9.2% when compared to Model 1 b (85 % nearest exit model). Model 2b for Phase 1 presents a number of differences to Model 1 b which suggests that what is constructed in this model may not be close to the way paxs behave in real emergencies. The majority (65.6 % or 328 simulations) of the distribution results for Model 2b fall within the distribution results for Model 1 b (see Figure 10-3). Model 2a for Phase 1 presents a number of similarities to Model 1b but approximately a third of the distribution of results were lower than those of Model 1b.

- **Model2b Phase 1 bares quite a close resemblance to the performance and results of the Model 1b - but with a lower average use of the nearest exits meaning pax are travelling 0.4m further to get to an available exit but this is making the overall evacuation too efficient with slight decreases in the average PET and CWT. The Model 2b could be considered a reliable model as nearly 65.6 % of its distribution of results, correspond with those of Model 1b.**

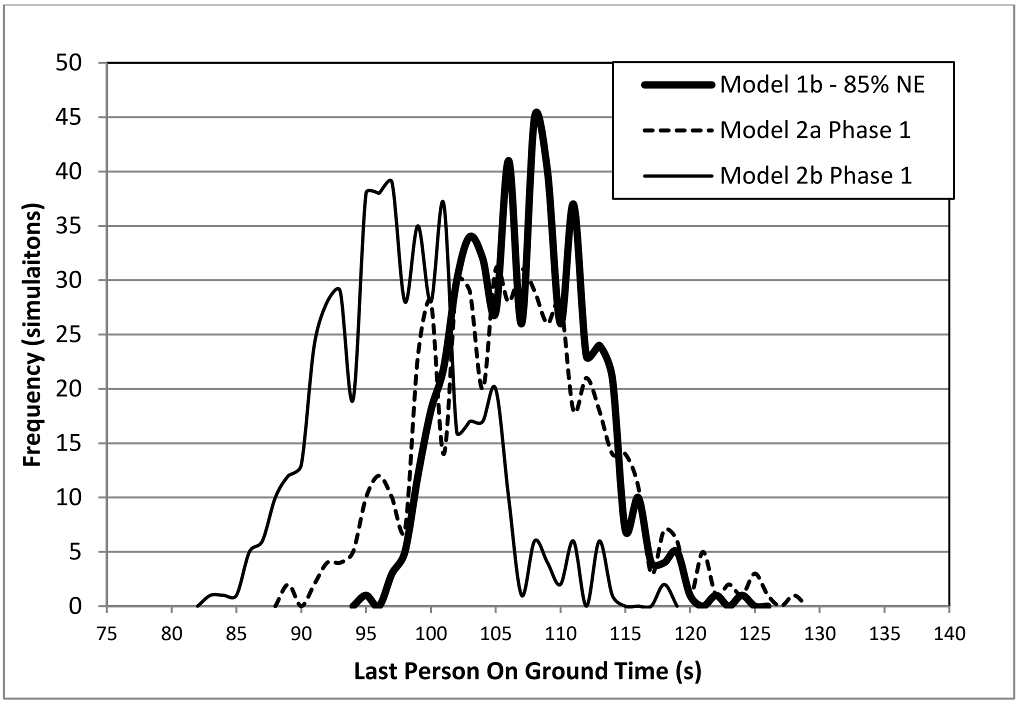


Figure 10-3: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 2a and Model 2b Distributions for Phase 1

The paxs in Model 3a Phase 1 have a perfect understanding of exit location, sizes and flow rates and are able to assess the path value using the correct flow rates. During the estimation of the best path to take, pax will have the knowledge of exit flow rates which are prescribed from the certification trials [105]. This model doesn't allow paxs to redirect during the evacuation. The results for model 3a Phase 1 (see Table 10-4) suggest that this model can produce on-ground times of between 66.9 s and 95.6 s with a mean of 78.6 s and a standard deviation of 4.6s. It is noted that paxs travelled an average of 6.3 m, the average PET was 35.7 s and the average CWT is 22.5 s. During the Model 3a Phase 1, 63% of the PET is wasted in congestion while the average use of the nearest exit by passengers in the simulations carried out was 72.2%. The Type III exit R2 achieves an average of 36.9 ppm at only 0.3 % slower than the measured average from certification trials [105]. The larger Type C exits (R1 and R3) achieve flow rates on average with 62.4 ppm (see Table 10-5) which is only 4 % slower than the measured average [105].

When comparing Model 3a during Phase 1 to Model 1 b (85 % Model) we find that there is a reduction in the mean on ground time by 27.2% while the average distance travelled by paxs is increased by 12.5%. The average PET has decreased by some 11% when comparing to the Model 1 b while the Average CWT has decreased by 17.6%. In the Model 3a for Phase 1, paxs travel further on average (0.7 m) to get to an available exit which improves the performance of the evacuation by 27.2% when compared to Model 1 b. Model 3a Phase 1 presents few similarities to Model 1 b. The majority (100 % or 500 simulations) of the distribution results for Model 3a are lower than those for Model 1 b (see Figure 10-3).

- **Model 3a Phase 1 has a greater resemblance to the performance and results of the optimal exit case (see Table 10-2) which is similar to that of the 90 s certification trial for the narrow bodied aircraft. This model should not be considered a reliable model for what pax would do in a real accident situation as 100% of the simulation results were lower than those of Model 1b**

The paxs in Model 3b Phase 1 behave in a similar way to Model 3a but the main difference is that the paxs are able redirect during the evacuation. The results for Model 3b Phase 1 (see Table 10-4) suggest that this aircraft model can produce on-ground times of between 64.8 s and 99.6 s with a mean of 77.8 s and a standard deviation of 5.0s. In this case it is noted that paxs travelled an average of 6.3 m with average PET of 35.6 s, while the average CWT is 22.4 s. During Model 3b model simulations, 62.9% of the PET is wasted in congestion and the average use of the nearest exit by pax in the simulations carried out was 72.1%. The Type III exit R2 achieves an average of 37.2 ppm which is only 0.5 % faster while Type C exits (R1 and R3) achieve average flow rates of 62.1 ppm (see Table 10-5) which is only 4.5% slower than the measured average in certification trials [105].

When comparing Model 3b Phase 1 to Model 1 b, there is a reduction in the mean on ground time by 27.9% while the average distance travelled by paxs is increased by 12.5%. The average PET and Average CWT have decreased by 11.2% and 17.9% respectively. Pax in Model 3b Phase1 travel further on average (0.7 m) to get to an available exit improving the overall performance of the evacuation by 27.9% in comparison to Model 1 b. Model 3b for Phase 1 presents very few similarities to Model 1 b. Pax redirection makes very little difference in the performance between this model and Model 3a during Phase 1. Model 3b Phase 1 has a greater resemblance to the performance and results of the optimal exit case (see Table 10-2). The majority (99.8 % or 499 simulations) of the distribution results for Model 3b are lower than those for Model 1 b (see Figure 10-3).

- **Model 3b Phase 1 has a greater resemblance to the performance and results of the optimal exit case (see Table 10-2). This model should not be considered a reliable model for what pax would do in a real accident situation as 99.8% of the simulation results were lower than those of Model 1b.**

The paxs in Model 3c Phase 1 behave in a similar way to pax in Model 3b. The main difference is that flow rates of the aisle are measured using census points located close by the exits and then provided to the pax for estimating the best path value. This is quite sophisticated model and paxs still have the ability to redirect. The results for model 3c Phase 1 (see Table 10-4) suggest that this aircraft model can produce on-ground times of between 66.6 s and 89.6 s with a mean of 77.7 s and a standard deviation of 4.4s. In this case it is noted that paxs travelled an average of 6.3 m. The average PET (out of aircraft time) was 35.6 s, while the average CWT is 22.4 s. During Model 3c Phase 1 simulations, we find that 62.9% of the PET is wasted in congestion and the average use of the nearest exit by passengers in the simulations carried out was 72.1%. The Type III exit R2 achieves an average of 37.2 ppm which is only 0.5 % faster while Type C exits (R1 and R3) achieve average flow rates of 62.4 ppm (see Table 10-5); only 4 % slower than the measured average in certification trials [105].

When comparing Model 3c during Phase 1 to Model 1 b (85 % Model) we find that there is a reduction in the mean on ground time by 28% while the average distance travelled by paxs increases by 12.5%. The average PET and Average CWT have both decreased by some 11.2% and 17.9% respectively (see Table 10-2 and Table 10-4). Paxs travel further on average (0.7 m) to get to an available exit improving the overall performance of the evacuation by 28% on average when compared to Model 1 b. The majority (100 % or 500 simulations) of the distribution results for Model 3c are lower than those for Model 1 b (see Figure 10-3).

- **Model 3c Phase 1 has a closer resemblance to the performance and results of the optimal exit case (see Table 10-2). This model should not be considered a reliable model for what pax would do in a real accident situation as 100% of the simulation results were lower than those of Model 1b.**

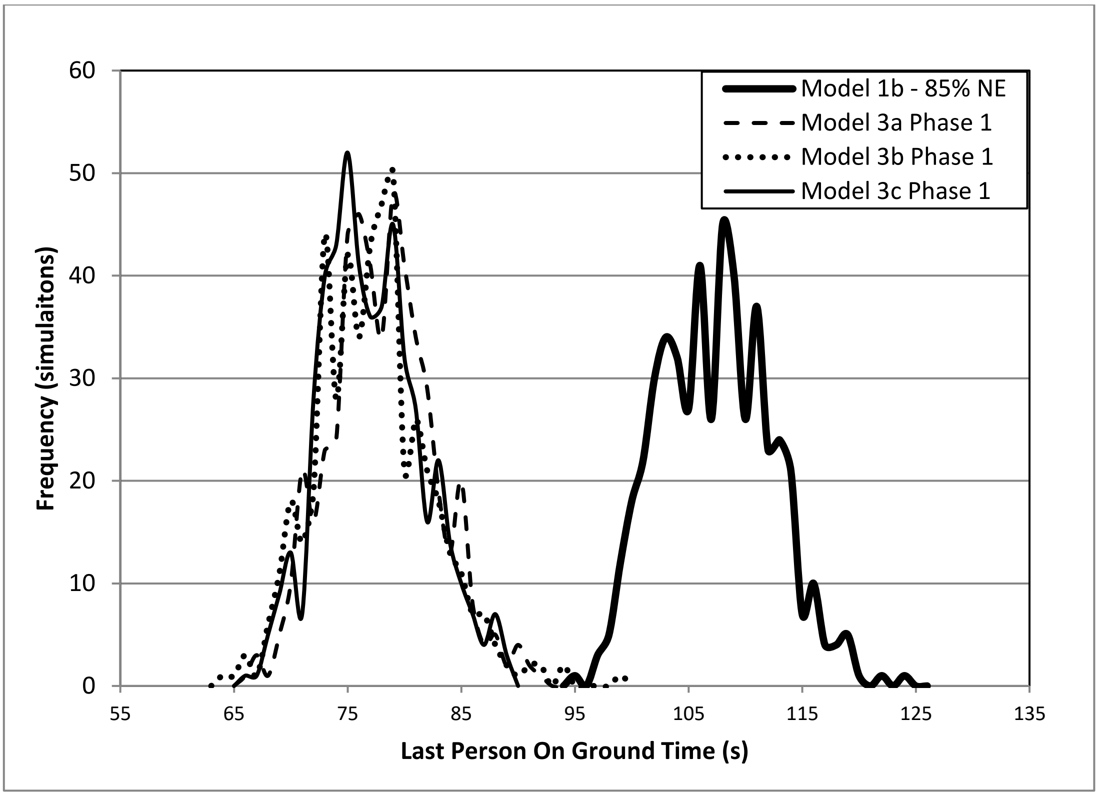


Figure 10-4: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 3a, Model 3b and Model 3c Distributions for Phase 1

The paxs in Model 4a Phase 1 (see Table 9-1) use the data gathered from questionnaires (see Chapter 8) where 23% of the pax on the aircraft have a perfect understanding of exit locations, size and flow rates. In this sophisticated model, therefor 23% of population will use Model 3a Phase 1 while 77% will use the nearest exit (Model 1 a) with no pax redirection permitted. The results for Model 4a Phase 1 (see Table 10-4) suggest that this aircraft model can produce on-ground times of between 112.2 s and 149.6 s with a mean of 129.1 s and a standard deviation of 7.0s. It should be noted that paxs travelled an average distance of 5.6 m. The average PET was 48.3.6 s, while the average CWT is 34.7 s. During this model, we find that 71.8% of the PET is wasted in congestion while the average use of the nearest exit by 89.8%. The over wing exit R2 achieves an average of 37.7 ppm which is only 1.9 % faster while the larger forward and aft exits (R1 and R3) achieve average flow rates of 30.6 ppm (see Table 10-5); only 52.9 % slower than the measured average in certification trials [105].

When comparing Model 4a during Phase 1 to Model 1 b we find that there is an increase in the mean on ground time by 19.4% while the average distance travelled by paxs is the same with an increase in the standard deviation by 0.1 m. The average PET has increased by some 20.5% while the Average CWT has increased by 27.1%. In Model 4a Phase 1, paxs travel the same distance on average to get to an available exit. Otherwise Model 4a for Phase 1 presents very few similarities to Model 1 b which suggests that although this model uses the data which has been gathered for the questionnaires, there may be some further refinements required for this model to bring it closer to Model 1b. Pax redirection may be a refinement which could alter the results. Model 4a Phase 1 has a greater resemblance to the performance and results of the 100 % Nearest Exit- Model 1a (see Table 10-2) but with more optimal use of the exits. The majority (77.2% or 386 simulations) of the distribution results for Model 4a are higher than those for Model 1 b (see Figure 10-5).

- **Model 4a Phase 1 has a closer resemblance to the performance and results of Model 1a where approximately 100% of pax use their nearest exit (see Table 10-2)**. **This Model 4a Phase 1 should not be considered a reliable model for what pax would do in a real accident situation as the majority of the simulation results were higher than those of Model 1a.**

Model 4b Phase 1 (see Table 9-1) is similar to Model 4a Phase 1 but allows pax redirection. In this model, 23% of pax will use Model 3b while 77% will continue use the nearest exit (Model 1 a). Pax redirection is only permitted for only those paxs using Model 3b. The results for Model 4b Phase 1 (see Table 10-4 and Figure 10-5) suggest that this aircraft model can produce on-ground times of between 105.8 s and 151.9 s with a mean of 125.7 s and a standard deviation of 6.6s. Paxs travelled an average of 5.7 m while the average PET and average CWT was 47.1 s and 33.5 s respectively. Approximately 71.1% of the PET is wasted in congestion while the average pax use of the nearest exit in the simulations was 89.1%. The over wing exit R2 achieves an average of 37.7 ppm which is only 1.9 % faster while the larger forward and aft exits (R1 and R3) achieve average flow rates of 31.4 ppm (see Table 10-5); only 51.7 % slower than the measured average in certification trials [105].

When comparing Model 4b Phase 1 to Model 1 b (85 % Model) we find that there is an increase in the mean on ground time by 16.5% while the average distance travelled by paxs is the same but with an increase in the standard deviation by 0.1 m. The average PET has increased by some 17.5% when comparing to the Model 1 b while the Average CWT has increased by 22.7%. Otherwise the majority of the simulation results for pax on ground times are higher than the results for Model 1 b which suggests that although this model uses the data gathered from questionnaires, modelling adjustments are needed to bring this model closer to pax using their nearest exit 85% of the time. Pax redirection appears to have slightly improved the results over the previous Model 4a (see Figure 10-5 and Table 10-4) but not enough for it be considered reliable. Over half (59.2% or 296/500 simulations) of the distribution results for Model 4b are higher than those for Model 1 b (see Figure 10-5). The introduction of redirection has improved the performance of the results by 18%.

- **Model 4b Phase 1 has a greater resemblance to the performance and results of the 100 % Neareast Exit- Model 1a (see Table 10-2 and Table 10-4) but with more optimal use of the exits.**
- **This model should not be considered reliable for what happens in real accidents as over half have higher distribution results than Model 1b.**

Paxs in Model 4c Phase 1 behave in a similar way to pax in Model 4b where the flow rates of the aisle are measured using census points as done in Model 3c Phase 1 which are located close by the exits and then provided to 23% of pax population for estimating the best path value. The rest of the pax in this model (77% of population) will use the nearest exit (Model 1 a). Pax redirection is permitted for only those paxs (23% of population) using Model 3b. The results for Model 4c Phase 1 (see Table 10-4 and Figure 10-5) suggest that this aircraft model can produce on-ground times of between 107.6 s and 148.5 s with a mean of 125.9 s and a standard deviation of 7.0s. In this model, paxs travelled an average of 5.7 m while the average PET and average CWT was 47.1 and 33.5 s respectively. During Model 4c simulations for Phase 1, 71.1% of the PET is wasted in congestion and the average use of the nearest exit by passengers in the simulations carried out was 89.2%. The Type III exit (R2) achieves an average of 37.7 ppm which is only 1.9 % faster while the larger forward and aft exits (R1 and R3) achieve average flow rates of 30.1 ppm (see Table 10-5); which is 52.6 % slower than the measured average in certification trials [105].

When comparing Model 4c to Model 1 b, the mean on ground time increases by 16.7% (see Table 10-2 and Table 10-4). The average PET has increased by some 17.5% and the Average CWT has increased by 22.7%. In Model 4c for Phase 1, paxs travel slightly further (0.1m or 1.8%) on average to get to an available exit in comparison to Model 1b. Otherwise, the majority of the simulation results for the pax on ground time are higher than the results for Model 1 b (see Figure 10-5). This suggests that even though this model uses data gathered from the questionnaires (see Chapter 8), further modelling or refinements are needed to bring it closer to pax using their nearest exit 85% of the time and for it to be considered a reliable model. Pax redirection has improved the results over Model 4a in this Phase with very good similarity to the results of Model 4b (see Figure 10-5 and Table 10-4). Model 4c Phase 1 has a closer resemblance to the performance and results of the 100 % Nearest Exit - Model 1a (see Table 10-2 and Table 10-4) but more optimal use of the exits. Over half (59.6% or 298/500 simulations) of the distribution results for Model 4b are higher than those for Model 1 b (see Figure 10-5). Pax redirection in this model has improved the performance of the results by 17.6 % when compared with Model4a in this phase.

- **Model 4c Phase 1 has a greater resemblance to the performance and results of the 100 % Neareast Exit- Model 1a (see Table 10-2 and Table 10-4) but with more optimal use of the exits which often means pax travel further.**
- **This model should not be considered reliable for what happens in real accidents as over half of the distribution results are higher than Model 1b.**

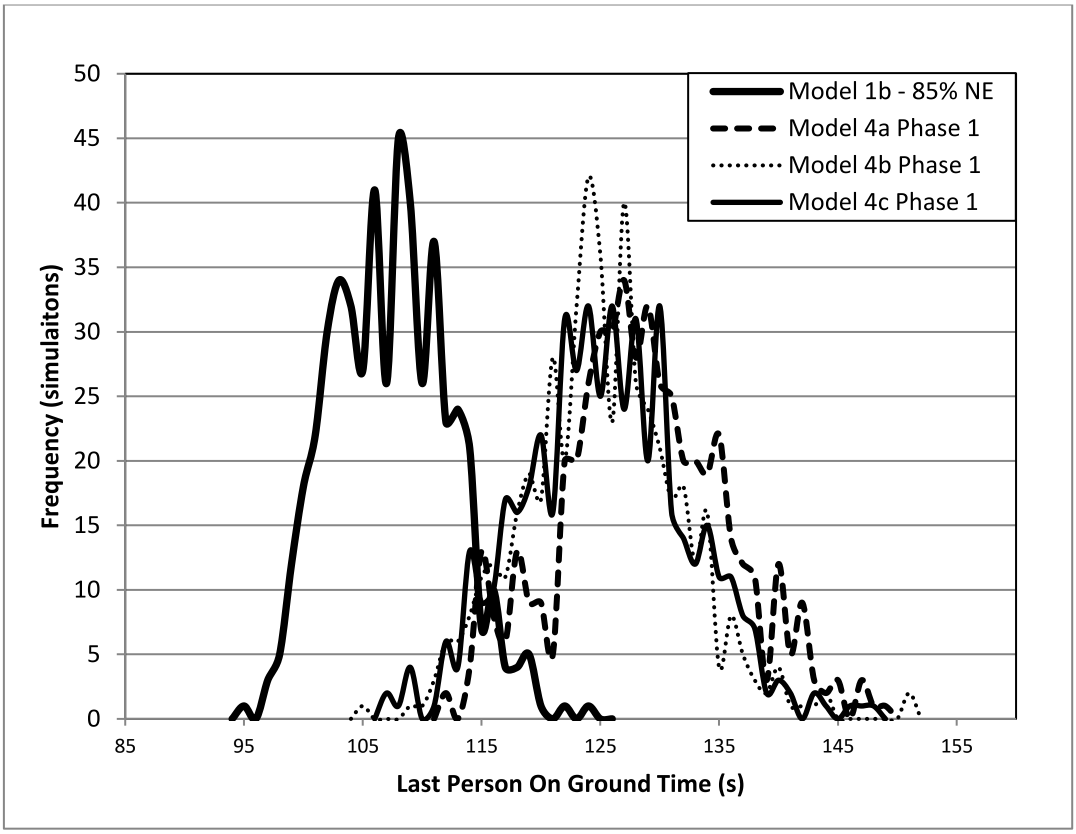


Figure 10-5: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 4a, Model 4b and Model 4c Distributions for Phase 1

The paxs in Model 5a Phase 1 (see Table 9-1) use data gathered from the results of questionnaires where 23% of the pax on the aircraft have a perfect understanding of exit locations, sizes and flow rates. In this model, 23% (approximately 34 out of 149 pax) of aircraft population will use Model 3a Phase 1 while 77% (approximately 115 out of 149 pax) will use Model 2a Phase 1. No pax redirection is permitted during this model's simulations. The results for Model 5a Phase 1 (see Table 10-4 and Figure 10-6) suggest that this aircraft model can produce on-ground times of between 88.9 s and 134.4 s with a mean of 107.2 s and a standard deviation of 7.1s. Paxs travelled an average of 6.0 m while the average PET and average CWT was 42.2 s and 28.5 s respectively. During this model's simulations, we find that 67.5% of the PET is wasted in congestion and the average use of the nearest exit by passengers in the simulations carried out was 79.1%. The Type III exit (R2) achieves an average of 37.2 ppm which is only 0.5 % faster while the larger forward and aft exits (R1 and R3) achieve average flow rates of 39.4 ppm (see Table 10-5); which is 39.4 % slower than the measured average in certification trials [105].

When comparing Model 5a Phase 1 to Model 1 b, there is a very slight decrease in the mean on ground time by 0.7%. The average distance travelled by paxs has increased by 7.1% to get to an available exit. The average PET has increased by some 5.2% when comparing to the Model 1 b while the Average CWT has increased by 4.4%. Although paxs travel further on average to get to an available exit, Model 5a Phase 1 presents a number of similarities to Model 1 b in terms of the on ground times for the evacuation (see Table 10-4 and Figure 10-6). Model 5a Phase 1 has a larger standard deviation and has a greater span between the minimum and maximum values of the on ground times (88.9 s and 134.4 s respectively) in comparison to Model 1 b. The majority (94.4 % or 472 simulations) of the distribution results for this model fall within the distribution results for Model 1 b (see Figure 10-6). The main difference between this model and Model 1b is the decreased use of the nearest exit by 6.7%. The standard deviation for the nearest exit use is greater for this model (2.5 %) than for Model 1 b (0.8 %).

- **Model5a Phase 1 has a very close resemblance to the performance of Model 1b but pax are travel 0.4m further on average to get to an available exit.**
- **Some differences still exist between the models such as very slight increases in the average PET and CWT.**
- **This model could possibly be considered a reliable model for what paxs might do in a real accident situation as nearly 94.8 % of the distribution of results corresponds with those in Model 1b.**

The paxs in Model 5b Phase 1 behave in a similar way to those pax in Model 5a but the main difference is that all paxs are able redirect during the evacuation. The results for Model 5b Phase 1 (see Table 10-4 and Figure 10-6) suggest that this aircraft model can produce on-ground times of between 76.9 s and 112.8 s with a mean of 92.3 s and a standard deviation of 5.7s. In this case it is noted that paxs travelled an average of 6.2 m. The average PET was 38.2 s and the average CWT is 24.6 s. During this model's simulation results we find that 64.4% of the PET is wasted in congestion. The average use of the nearest exit by passengers in the simulations carried out was 77.8%. The over wing exit (R2) achieves an average flow rates of 37.2 ppm which is only 0.5 % faster while the larger forward and aft exits (R1 and R3) achieve average flow rates of 50.5 ppm (see Table 10-5); which is 22.3 % slower than the measured average in certification trials [105].

When comparing Model 5b during Phase 1 to Model 1 b we find that there is a decrease in the mean on ground time by 14.5% while the average distance travelled by paxs is 0.6m (10.7 %) with an increase in the standard deviation by 0.1 m. The average PET has decreased by some 4.7% when comparing to the Model 1 b while the Average CWT has decreased by 9.9%. In Model 5b Phase 1, the majority (74.4%) of the simulation results for the pax on ground time are lower than the results for Model 1 b suggesting that there may be some further refinements required for this model to bring it closer to pax using their nearest exit 85% of the time. Pax redirection appears to have improved the overall results from the previous Model 5a but further away from Model 1b (see Figure 10-6 and Table 10-4) making it too efficient. Model 5b Phase 1 has a poor resemblance to the performance and results of the 100 % Nearest Exit- Model 1a, 85% Nearest Exit – Model 1b and the Optimal Exit (see Table 10-2 and Table 10-4). The majority (72.4 % or 472 simulations) of the distribution results for this model are lower than those for Model 1 b (see Figure 10-6).

- **Model 5b Phase 1 has a poor resemblance to the performance and results of the Model 1a, Model 1b and the Optimal Exit Scenario (see Table 10-2 and Table 10-4)**
- **This model should not be considered reliable for what happens in real accidents as the majority of the distribution results are lower (72.4) than those in Model 1b.**

In Model 5c Phase 1, 23% of the pax (approximately 34 out of 149 pax) are able to assess the path value by using flow rates which are provided to the path value algorithm using census points on the aisle. In this model, therefor 23% of Pax use Model 3c Phase 1 while 77% will use Model 2b Phase 1. Pax redirection is permitted for paxs using both of the models which are part of Model 5c Phase 1. The results for Model 5c Phase 1 (see Table 10-4 and Figure 10-6) suggest that this aircraft model can produce on-ground times of between 76.7 s and 122.8 s with a mean of 93.6 s and a standard deviation of 5.9s. Paxs travelled an average of 6.1 m while the average PET and average CWT was 38.4 s and 24.8 s respectively. In this model's results, 64.6% of the PET is wasted in congestion while the average use of the nearest exit by passengers in the simulations carried out was 78.3%. The over wing exit (R2) achieves an average flow rates of 37.2 ppm which is only 0.5 % faster while the larger forward and aft exits (R1 and R3) achieve average flow rates of 50.1 ppm (see Table 10-5); which is 22.9 % slower than the measured average in certification trials [105].

When comparing Model 5c during Phase 1 to Model 1 b, there is a decrease in the mean on ground time by 13.3% while the average distance travelled by paxs increases by 0.5m (8.9%). The average PET has decreased by some 4.2% when comparing with Model 1 b while the Average CWT has decreased by 9.2%. The majority of this model's simulation results (63.6 %) for the pax on ground time are lower than the results for Model 1 b (see Figure 10-6) which suggests that although this model uses data results from questionnaires, it seems to be too efficient for it to be considered reliable. Pax redirection has improved the results over Model 5a (see Figure 10-6 and Table 10-4) and there is a very good similarity with the results of Model 5b (see Figure 10-6 and Table 10-4).

- **Model 5c Phase 1 has a poor resemblance to the performance and results of the Model 1a, Model 1b and the Optimal Exit Scenario (see Table 10-2 and Table 10-4)**
- **This model should not be considered reliable for what happens in real accidents as the majority of the distribution results are lower (63.6%) than those in Model 1b.**

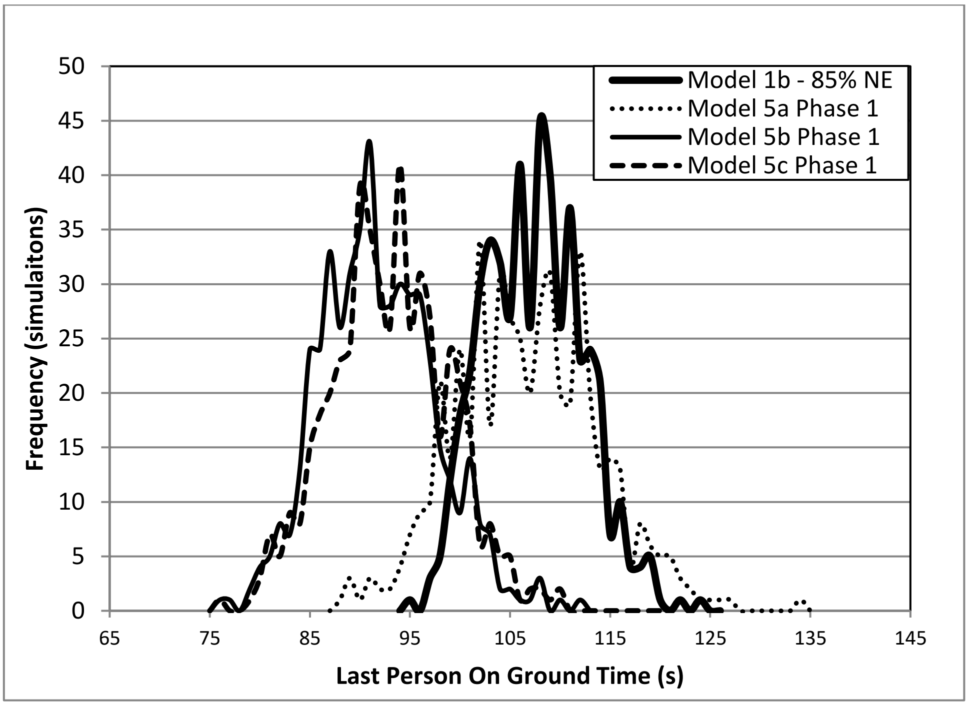


Figure 10-6: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 5a, Model 5b and Model 5c Distributions for Phase 1

10.3.3 Results and discussion of model validation for Phase2

Models 2 to 5 from Phase 1 were further refined and simulations run for Phase 2. During Phase 2, paxs still located in the seat rows will be included during the path value estimation algorithm. Phase 2 Definitions for each of the models can been found in Chapter 9 and in Table 9-1. The results for these models can be found in Table 10-6 and

Table 10-7. The results from Model 1b – 85% Nearest Exit Scenario (see Table 10-2 and Table 10-3) will be used to validate all Phase 2 models.

Table 10-6: Phase 2 Results

Model Name		Out of Aircraft time (s)	On-ground time (s)	Av.PET (s)	Av.CWT (s)	Av.DIST (m)	Av. CWT Ratio	Av. Use of Nearest Exit%
Model 2a	Min	90.0	91.4	37.1	24.0	5.6	0.6	74.5
	Mean	**111.1**	**113.1**	**44.0**	**30.6**	**5.8**	**0.6**	**82.0**
	Max	132.9	134.3	50.1	36.5	6.1	0.6	88.6
	Stdev	7.1	7.1	2.1	2.0	0.1	0.0	2.5
Model 2b	Min	78.7	80.2	34.8	21.6	5.8	0.6	73.8
	Mean	**96.1**	**98.1**	**39.3**	**25.9**	**6.0**	**0.6**	**80.2**
	Max	117.3	119.3	44.1	30.6	6.4	0.6	85.9
	Stdev	6.0	6.1	1.5	1.4	0.1	0.0	2.1
Model 3a	Min	68.4	69.9	33.7	19.9	6.0	0.5	63.8
	Mean	**80.0**	**82.0**	**36.6**	**22.9**	**6.3**	**0.6**	**69.0**
	Max	95.4	97.1	40.5	26.5	6.7	0.6	75.8
	Stdev	5.3	5.3	1.2	1.1	0.1	0.0	2.1
Model 3b	Min	66.5	67.9	33.3	19.9	6.1	0.5	67.8
	Mean	**75.7**	**77.6**	**35.7**	**22.4**	**6.3**	**0.6**	**72.1**
	Max	89.9	91.5	38.8	25.5	6.6	0.6	76.5
	Stdev	4.2	4.2	1.0	1.0	0.1	0.0	1.5
Model 3c	Min	64.7	66.7	33.0	19.9	6.1	0.5	67.8
	Mean	**75.5**	**77.5**	**35.7**	**22.4**	**6.3**	**0.6**	**72.0**
	Max	93.6	95.2	39.3	26.0	6.6	0.6	76.5
	Stdev	4.6	4.6	1.0	1.0	0.1	0.0	1.5
Model 4a	Min	112.5	114.0	43.1	29.6	5.4	0.6	84.6
	Mean	**128.8**	**130.8**	**48.6**	**35.2**	**5.6**	**0.6**	**90.7**
	Max	148.1	150.2	54.6	41.1	5.9	0.6	96.0
	Stdev	6.5	6.5	2.1	2.1	0.1	0.0	2.1
Model 4b	Min	106.5	108.9	42.3	28.8	5.5	0.6	83.9
	Mean	**125.6**	**127.5**	**47.5**	**33.9**	**5.7**	**0.6**	**89.6**
	Max	146.1	148.2	54.2	40.7	6.0	0.6	96.0

	Stdev	7.0	7.0	2.0	2.0	0.1	0.0	2.0
Model 4c	Min	106.6	108.3	41.9	28.4	5.4	0.6	83.9
	Mean	**125.3**	**127.2**	**47.5**	**34.0**	**5.7**	**0.6**	**89.7**
	Max	145.6	147.9	54.9	41.1	5.9	0.6	95.3
	Stdev	6.6	6.6	2.1	2.1	0.1	0.0	2.0
Model 5a	Min	87.3	89.7	37.0	23.3	5.7	0.6	70.5
	Mean	**105.3**	**107.2**	**42.2**	**28.5**	**6.0**	**0.6**	**79.1**
	Max	132.5	135.0	49.4	35.5	6.2	0.6	86.6
	Stdev	7.1	7.1	2.0	1.9	0.1	0.0	2.5
Model 5b	Min	76.7	78.4	34.8	21.6	5.9	0.5	71.8
	Mean	**91.0**	**93.0**	**38.3**	**24.8**	**6.1**	**0.6**	**78.1**
	Max	107.6	108.9	45.0	30.8	6.6	0.6	83.9
	Stdev	5.3	5.3	1.3	1.3	0.1	0.0	1.9
Model 5c	Min	74.9	76.4	34.9	21.5	5.9	0.5	72.5
	Mean	**91.3**	**93.3**	**38.4**	**24.9**	**6.1**	**0.6**	**78.2**
	Max	106.7	108.6	43.1	29.2	6.4	0.6	85.2
	Stdev	5.7	5.7	1.4	1.3	0.1	0.0	2.0

Table 10-7: Achieved Exit flow rates (persons per minute) and time for last pax to use each exit for 149 pax aircraft for Phase 2 Models

Model Name	Door	Type C R1 Flow Rate (ppm)	Type III R2 Flow Rate (ppm)	Type C R3 Flow Rate (ppm)	Type C R1 Out of Aircraft Time (s)	Type III R2 Out of Aircraft Time (s)	Type C R3 Out of Aircraft Time (s)
Model 2a	Min	16.8	30.1	25.1	36.2	90.0	49.7
	Mean	**33.5**	**36.8**	**40.3**	**79.4**	**111.1**	**84.5**
	Max	67.5	43.5	68.5	119.2	132.9	119.0
Model 2b	Min	25.0	30.9	29.4	39.7	78.7	52.2
	Mean	**44.5**	**37.2**	**52.3**	**66.0**	**96.1**	**71.6**
	Max	68.0	42.8	69.2	100.3	117.3	96.3
Model 3a	Min	31.2	29.4	41.6	44.3	65.1	56.7
	Mean	**54.5**	**37.0**	**59.2**	**59.6**	**79.4**	**70.7**
	Max	75.4	45.0	73.4	92.4	95.4	90.7
Model 3b	Min	38.0	28.4	48.4	44.3	64.6	56.1
	Mean	**60.4**	**37.2**	**63.6**	**55.3**	**75.5**	**66.7**
	Max	74.7	43.4	73.5	79.9	89.9	82.3
Model 3c	Min	35.6	29.4	50.5	42.7	63.7	56.6
	Mean	**60.2**	**37.2**	**63.9**	**55.7**	**75.4**	**66.5**
	Max	74.8	44.8	74.1	83.8	93.6	81.7
Model 4a	Min	13.4	32.7	19.6	30.9	111.1	42.7
	Mean	**30.3**	**37.7**	**30.8**	**79.5**	**128.7**	**98.0**
	Max	78.3	43.3	71.1	138.0	148.1	138.3
Model 4b	Min	15.0	32.4	20.2	32.1	106.5	41.3
	Mean	**29.2**	**37.5**	**33.5**	**82.9**	**125.5**	**93.1**
	Max	74.0	43.4	72.4	132.9	146.1	137.1
Model	Min	13.2	32.2	19.5	29.5	106.6	43.2

4c	**Mean**	**28.5**	**37.7**	**33.7**	**83.6**	**125.2**	**92.5**
	Max	77.8	42.8	70.6	136.1	145.6	137.4
Model 5a	Min	20.7	30.8	26.2	39.7	87.3	46.3
	Mean	**37.1**	**36.7**	**41.3**	**75.3**	**105.2**	**85.6**
	Max	69.0	43.5	71.6	115.8	132.5	125.1
Model 5b	Min	25.1	30.7	37.1	41.7	76.7	53.2
	Mean	**46.7**	**37.2**	**52.9**	**64.8**	**91.0**	**73.0**
	Max	69.4	43.2	68.9	99.3	107.6	97.8
Model 5c	Min	27.0	30.6	32.6	40.3	74.9	51.6
	Mean	**47.6**	**37.2**	**52.7**	**63.8**	**91.3**	**73.0**
	Max	71.4	42.7	68.2	97.5	106.7	96.6

The results for Model 2a Phase 2 (see Table 10-6) suggest that this aircraft model can produce on-ground times of between 91.4s and 134.3 s with a mean of 113.1 s and a standard deviation of 7.1s. Paxs travelled an average of 5.8 m, the average PET was 44.0 s, while the average CWT is 30.6 s. During this model's simulations for, we find that 69.5% of the PET is wasted in congestion. The average use of the nearest exit by passengers in the simulations carried out was 82%. The R2 exit achieves an average flow rates of 36.8 ppm which is only 0.5 % slower while the larger forward and aft exits (R1 and R3) achieve average flow rates of 36.9 ppm (see Table 10-5); which is 43.2 % slower than the measured average in certification trials [105].

When comparing Model 2a Phase 2 to Model 1b (85 % Model) we find that there is an increase in the mean on ground time by 4.8% while the average distance travelled by paxs is increased by 3.6%. The average PET has increased by some 9.7% when comparing to the Model 1b while the Average CWT has slightly increased by 12.1%. Model 2a Phase 2 has a larger standard deviation with a greater span between the minimum and maximum values of the on ground times (91.4 s and 134.3 s respectively) in comparison to Model 1 b (see Table 10-2). The mean on ground time for Model 2a Phase 2 compared to Model 2a Phase 1 has increased on average by 5.9 % possible due to the slight decrease in the average use of the nearest exit by 0.7%. Therefore the inclusion of paxs still located in the seat rows for the path value calculations has had some effect over the simulation results for this model. The majority (94.8 % or 474 simulations) of the distribution results for Model 2a Phase 2 fall between the distribution results for Model 1 b (see Figure 10-7) even though the mean on ground time has increased by 5.2 s. Model 2a for Phase 2 presents a number of similarities in terms of results to Model 1b suggesting that this model could possibly be considered reliable.

- **Model2a Phase 2 has quite a close resemblance to the performance of Model 1b but differences exist such as increases in the average on ground time, PET and CWT.**
- **Although an equal majority of both Model 2a Phases 1 and 2 (94.8 % or 474 simulations) fell between the distribution results for Model 1b, the mean ground time for Model 2a Phase 1 was closer to Model 1b than that of its Phase 2 counterpart.**
- **Model 2a Phase 2 should be considered quite reliable but less reliable than the Model 2a Phase 1.**

The results for Model 2b Phase 2 (see Table 10-6 and Figure 10-7) suggest that this aircraft model can produce on-ground times of between 80.2 s and 119.3 s with a mean of 98.1 s and a standard deviation of 6.1s. Paxs travelled an average of 6.0 m while the average PET was 39.3 s, and the average CWT is 25.9 s. During Model 2b simulations for Phase 2, we find that 65.9% of the PET is wasted in congestion while the average use of the nearest exit by pax was 80.2%. The R2 exit achieves an average flow rates of 37.2 ppm which is only 0.5 % faster while the larger forward and aft exits (R1 and R3) achieve average flow rates of 48.4 ppm (see Table 10-5); which is 25.5 % slower than the measured average in certification trials.

When comparing the results of Model 2b Phase 2 to Model 1 b (see Table 10-6 and Table 10-2) we find that there is a reduction in the mean on ground time by 9.1% while the average distance travelled by paxs has increased by 7.1%. The average PET has been slightly decreased by some 2.0% when compared to the Model 1 b while the Average CWT has decreased by 5.1%. Paxs travel further on average (0.4 m) to get to an available exit which improves overall efficiency of the evacuation. Model 2a for Phase 2 presents some similarities as well as a number of differences to Model 1b suggesting that what is constructed in this model may not be close to the way paxs behave in real emergencies. Both Model 2b Phases 1(65.6 % or 328) and 2 (63 % or 315) simulations fell between the distribution results for Model 1b, and the mean ground time for both phases of Model 2b was almost identical (see Table 10-4 and Table 10-6).

- **Model2b Phase 2 shows some resemblance to the performance and results of the Model 1b - but with a lower average use of the nearest exits making the overall evacuation too efficient.**
- **The Model 2b could possibly be considered a reliable model as two thirds of its distribution of results corresponds with those of Model 1b but it is less reliable than Model 2a Phase 2.**

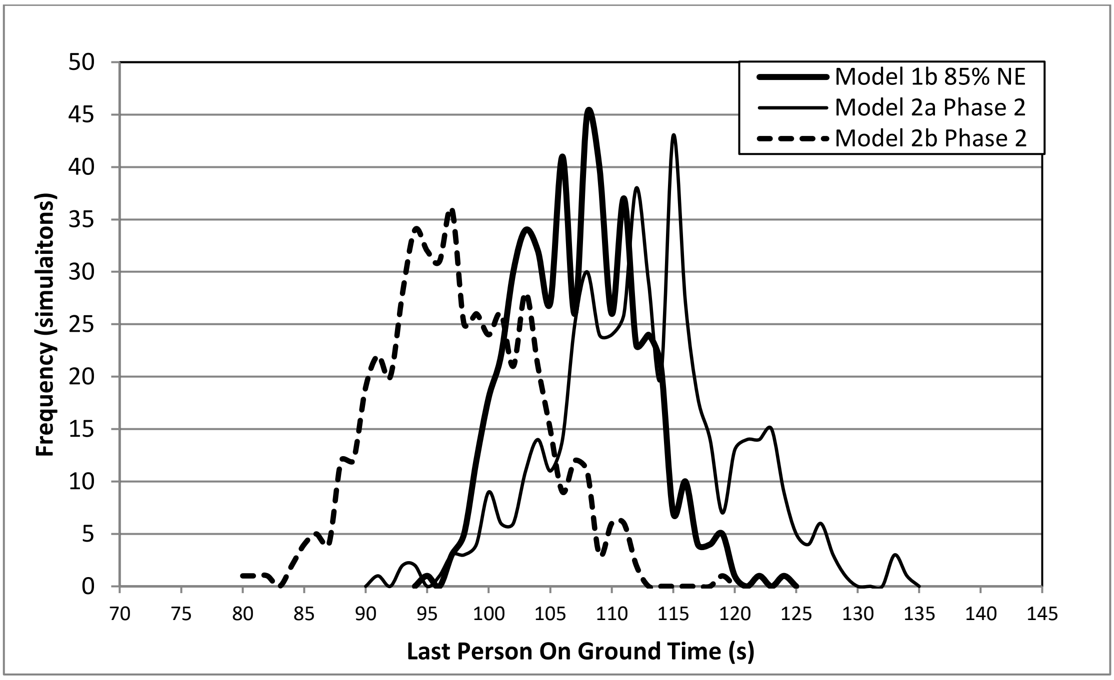


Figure 10-7: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 2a and Model 2b Distributions for Phase 2

The results for Model 3a Phase 2 (see Table 10-6 and Figure 10-8) suggest that this aircraft model (see Table 9-2) can produce on-ground times of between 69.9 s and 97.1 s with a mean of 82.6 s and a standard deviation of 5.3s. It is noted that paxs travelled an average of 6.3 m while the average PET was 36.6 s and the average CWT is 22.9 s. During Model 3b Phase 2 simulations, we find that 62.6% of the PET is wasted in congestion and the average use of the nearest exit by passengers in the simulations carried out was 69%. The R2 exit achieves average flow rates of 37 ppm which is expected for Type III exit, while the larger forward and aft exits (R1 and R3) achieve average flow rates of 56.9 ppm (see Table 10-5); which is 12.5 % slower than the measured average in certification trials.

When comparing Model 3b Phase 2 to Model 1 b (85 % Model), there is a reduction in the mean on ground time by 24% while the average distance travelled by paxs is increased by 12.5%. The average PET has decreased by some 8.7% when comparing to the Model 1 b while the Average CWT has decreased by 16.1%. For this Phase 2 model, paxs travel further on average (0.7 m) to get to an available exit improving the efficiency of the evacuation by 24% when compared to Model 1 b. This model presents hardly any similarities to Model 1 b. Both Model 3a Phases 1 (0%) and 2 (0.8% or 4) simulations fell between the distribution results for Model 1b, and the mean ground time for Model 3a Phase 2 was higher than Phase 1 by 3.4 s (see Table 10-4 and Table 10-6).

- **Model 3 a Phase 2 doesn't appear to be a reliable model as its correspondence with the results of Model 1b is poor with the majority 99.2 % being lower.**
- **Introducing the Phase 2 refinements to this model has had some impact in terms of reducing the mean on ground time.**

The results for Model 3b Phase 2 (see Table 9-2 and Table 10-4) suggest that this aircraft model can produce on-ground times of between 67.9 s and 91.5 s with a mean of 77.6 s and a standard deviation of 4.2s. In this case it is noted that paxs travelled an average of 6.3 m. The average PET was 35.7 s, while the average CWT is 22.4 s. During this model's simulations, 64.7% of the PET is wasted in congestion. The average use of the nearest exit by passengers in the simulations carried out was 72.1% which is identical to Model 3b Phase 1. The R2 exit achieves average flow rates of 37.2 ppm which is 0.5% faster, while the larger forward and aft exits (R1 and R3) achieve average flow rates of 62ppm (see Table 10-5); which is only 4.6 % slower than the measured average in certification trials [105]. Bringing redirection into this model has also improved the flow rate of the forward and aft exits (R1 and R3) between this model and Model 3a by approximately 9%.

When comparing Model 3b Phase 2 to Model 1 b (85 % Model), there is a large reduction in the mean on ground time by 28.1% while the average distance travelled by paxs is increased by 12.5%. The average PET has decreased by some 11% in comparison to

Model 1 b while the Average CWT has decreased by 17.9%. This model presents very few similarities to Model 1 b and including Pax redirection as part of the path value estimation has made 5.4% difference to the on ground times between this model and Model 3a Phase 2. Introducing the paxs ahead still seated, into the path value estimation has had very little impact (0.2% decrease) in the overall ground times between phases 1 and 2 for Model 3b. All simulations for Model 3b Phase 2 were lower than results for Model 1b, and the mean ground time for both phases of Model 3b was almost identical (see Table 10-4 and Table 10-6).

- **Model 3b Phase 2 has a greater resemblance to the performance and results of the optimal exit case (see Table 10-2) which is the scenario most similar to that of the 90 s certification trial for the narrow bodied aircraft.**
- **Model 3b Phase 2 should not be considered a reliable model for what pax would do in a real accident situation.**
- **The introduction of Phase 2 for Model 3b has had almost no impact.**

The results for Model 3c Phase 2 (see Table 9-2, Table 10-4 and Figure 10-8) suggest that this aircraft model can produce on-ground times of between 66.7 s and 95.2 s with a mean of 77.5 s and a standard deviation of 4.6s. In this case it is noted that paxs travelled an average of 6.3 m. The average PET was 35.7 s, while the average CWT is 22.4 s. which were identical to those in the Phase 1. During Model 3c Phase 2, 62.8% of the PET is wasted in congestion and the average use of the nearest exit by paxs in simulations for this Phase 2 model was 72 % which is practically the same as for Phase 1 (72.1%). The R2 exit achieves average flow rates of 37.2 ppm which is 0.5% faster, while the larger forward and aft exits (R1 and R3) achieve average flow rates of 62.1 ppm (see Table 10-5); which is 4.5 % slower than the measured average in certification trials and almost identical to what was achieved for this model in Phase 1. Bringing redirection into this model has also improved the flow rate of the forward and aft exits (R1 and R3) between this model and Model 3a by 9.1%.

When comparing Model 3c during Phase 2 to Model 1 b, there is a reduction in the mean on ground time by 28.2% while the average distance travelled by paxs is increased by 12.5%. The average PET has decreased by some 11% when comparing to the Model 1 b while the Average CWT has decreased by 18%. This model presents very few similarities to Model 1 b as did Model 3c Phase 1. Pax redirection within this phase does make a difference in the performance between Model 3c and Model 3a but the redirection causes the evacuation to become too speedy and therefor closer to the results of the optimal scenario (Model 1c) but with a larger standard deviation (see Table 10-2 and Table 10-6). Model 3c Phase 2 has a higher maximum on ground time than Model 3b Phase 2 and hence a higher standard deviation of 4.6 s. All simulations for Model 3c Phase 2 were lower than results for Model 1b, and the mean ground time for both phases of Model 3b was almost identical (see Table 10-4 and Table 10-6).

- **Model 3c Phase 2 has a greater resemblance to the performance and results of the optimal exit case which is the scenario most similar to that of the 90 s certification trial for the narrow bodied aircraft.**
- **Model 3c Phase 2 should not be considered a reliable model for what pax would do in a real accident situation.**

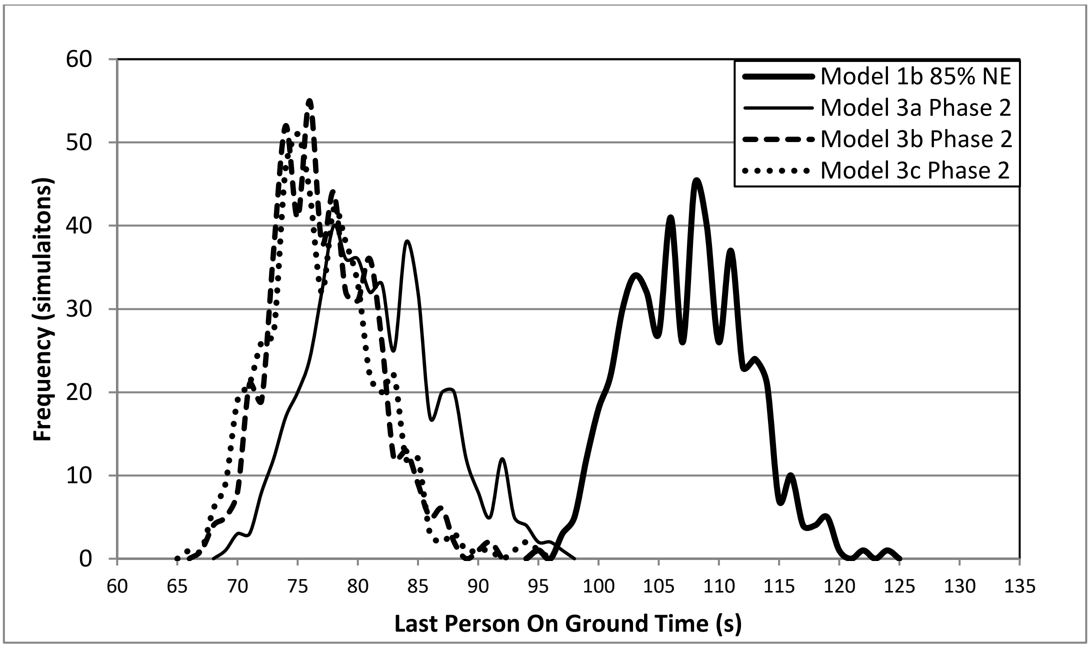


Figure 10-8: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 3a, Model 3b and Model 3c Distributions for Phase 2

The results for Model 4a Phase 2 (see Table 9-2, Table 10-4 and Figure 10-9) suggest that this aircraft model can produce on-ground times of between 114 s and 150.2 s with a mean of 130.8 s and a standard deviation of 6.5 s. In this case it is noted that paxs travelled an average of 5.6 m. The average PET was 48.6 s, while the average CWT is 35.2 s. These values are very close to those in the same model but in Phase 1. During Model 4a Phase 2 simulations, we find that 71.4% of the PET is wasted in congestion which is almost the same as for Model 4a Phase 1 (71.2 %). The average use of the nearest exit by passengers in the simulations carried out was 90.7% which is only 0.9% lower than the same model in Phase 1. The R2 exit achieves average flow rates of 37.7 ppm which is 1.4% faster, while the larger forward and aft exits (R1 and R3) achieve average flow rates of 30.6 ppm (see Table 10-5); which is 52.9 % slower than the measured average in certification trials. These flow rates achieved are very similar to what was achieved for this model in Phase 1.

When comparing Model 4a Phase 2 to Model 1 b, there is an increase in the mean on ground time by 21.2%, while the average distance travelled is the same but with an increase in the standard deviation by 0.1 m. The average PET has increased by some 21.2% when comparing to the Model 1 b while the Average CWT has increased by 28.9%. In Model 4a Phase 2, paxs travel the same distance on average to get to an available exit as in Model 1b. Model 4a Phase 2 presents very few similarities to Model 1 b and more closely resembles Model 1a suggesting that this is not a reliable model. The majority (84%) of simulations for Model 3c Phase 2 were higher than results for Model 1b, and the mean ground time for both phases of Model 3b was almost the same (see Table 10-4 and Table 10-6).

- **Model 4a Phase 2 has a greater resemblance to the performance and results of the 100 % Nearest Exit- Model 1a but with more optimal use of the exits.**
- **This model should not be considered a reliable model for what pax would do in a real accident situation as the majority of the results were higher than those for Model 1b.**

The results for Model 4b Phase 2 (see Table 9-2, Table 10-4 and Figure 10-5) suggest that this aircraft model can produce on-ground times of between 108.9 s and 148.2 s with a mean of 127.5 s and a standard deviation of 7.0s. In this case paxs travelled an average of 5.7 m which is identical to the distance travelled on average in Phase 1 for this model. Introduction of redirection into this model made the pax travel 0.1m further on average than in Model 4a Phase 2. The average PET was 47.5 s, while the average CWT is 33.9 s. which is almost the same as for the same model in Phase 1. During Model 4b model simulations for Phase 2, 71.4% of the PET is wasted in congestion which is only 0.3% higher than the same model in Phase 1. The average use of the nearest exit by paxs in the simulations for Model 4a Phase 2 was 89.6 %; only 0.4% higher than in Phase 1. Including paxs still located in seat rows ahead into the path value calculation appears to have had very little effect on the overall results. The R2 exit achieves average flow rates of 37.5 ppm which is approximately 1.4% faster, while the larger forward and aft exits (R1 and R3) achieve average flow rates of 31.4 ppm (see Table 10-5); which is 51.7 % slower than the measured average in certification trials. The flow rates achieved for this model are very similar to what was achieved for this model in Phase 1.

When comparing Model 4b Phase 2 to Model 1 b, there is an increase in the mean on ground time by 18.2% while the average distance travelled by paxs to an available exit has increased by 0.1 m. The use of the nearest available exit (89.6%) has increased by 4.4 %, the average PET and Average CWT have increased by some 18.5% and 24.2% respectively when compared to Model 1b. The majority of the simulation results (67.8 %) for Model 4b Phase 2 on ground times are higher than the results for Model 1 b suggesting that this may not be a reliable model. Pax redirection appears to have slightly improved the results in comparison to Model 4a (see Figure 10-9 and Table 10-4) but introducing pax allocated in seat rows ahead into the path value calculation for Phase 2 has made almost no difference to the average on ground times for Model 4b. Only around one third (32.2 % or 161 simulations) of the distribution results for Model 4b Phase 2 fall within the distribution results for Model 1 b (see Figure 10-9).

- **Model 4b Phase 2 has a greater resemblance to the performance and results of Model 1a but with more optimal use of exits which are often further away.**
- **This model should not be considered a reliable model for what paxs would do in a real accident situation**

The results for Model 4c Phase 2 (see Table 9-2, Table 10-4 and Figure 10-9) suggest that this aircraft model can produce on-ground times of between 108.3 s and 147.9 s with a mean of 127.2 s and a standard deviation of 6.6 s. During this model's simulations, paxs travelled an average of 5.7 m which is identical to the average distance travelled in Phase 1. The average PET was 47.5 s, while the average CWT is 34.0 s which is still very close to the values achieved previously in Phase 1. During this model's simulations, 71.6% of the PET is wasted in congestion while in Phase 1 the pax wasted 71.1%. The average use of the nearest exit by passengers in the simulations carried out was 89.7% while in Phase 1 it was 89.2%. The R2 exit achieves average flow rates of 37.7 ppm which is approximately 1.9% faster, while the larger forward and aft exits achieve average flow rates of 31.1 ppm (see Table 10-5); which is 52.2 % slower than the measured average in certification trials. The flow rates achieved for this model are very similar to what was achieved for this model in Phase 1.

When comparing Model 4c during Phase 1 to Model 1 b (85 % Model), there is an increase in the mean on ground time by 17.9 % while the average distance travelled by paxs increased by 0.1 m (1.8%). The average use of the nearest exit has increased by 4.6%, the average PET has increased by some 18.5% when comparing to the Model 1b while the Average CWT has increased by 24.5%. Otherwise in Model 4c Phase 2, the majority of the simulation results (66.6%) for the pax on ground time are higher than the results for Model 1 b (see Figure 10-9) suggesting that although this model uses the data gathered for the questionnaires, this may not be a reliable model. There are very close similarities with the results of Model 4b (see Figure 10-9 and Table 10-4) and close resemblance to the performance and results of the 100 % Nearest Exit- Model 1a (see Table 10-2 and Table 10-4). Pax redirection appears to have slightly improved the overall results in comparison to Model 4a Phase 2 but introducing pax allocated in seat rows ahead into the path value calculation for has slightly increased the average on ground times by 1% for Model 4c which makes it worse than its counterpart model in Phase 1. Only around one third (33.4 % or 167 simulations) of the distribution results for Model 4c Phase 2 fall within the distribution results for Model 1 b (see Figure 10-9). Approximately two thirds of the results for this model are higher than the results of Model 1b.

- **Model 4c Phase 2 has a greater resemblance to the performance and results of the 100 % Nearest Exit - Model 1a.**
- **This model should not be considered a reliable model for what paxs would do in a real accident situation as only one third of its distribution results correspond with those of the 85 % Nearest Exit Scenario Model 1b.**

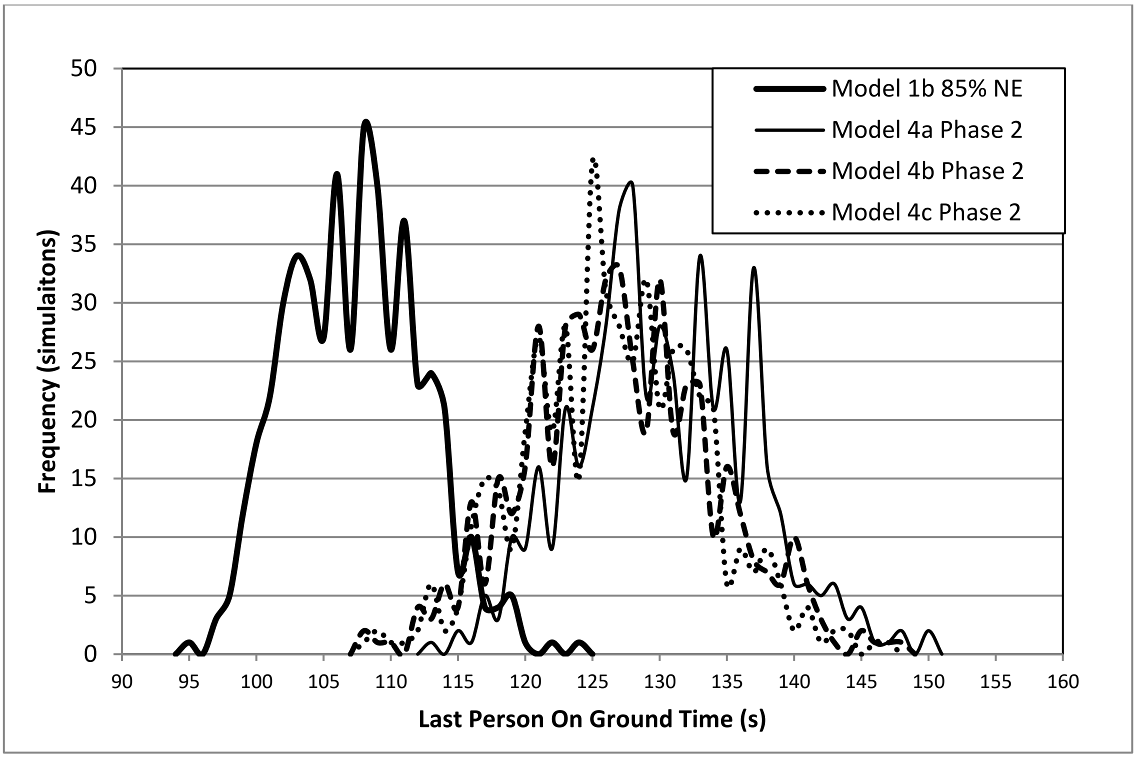


Figure 10-9: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 4a, Model 4b and Model 4c Distributions for Phase 2

The results for Model 5a Phase 2 (see Table 9-2, Table 10-4 and Figure 10-10) suggest that this aircraft model can produce on-ground times of between 89.7 s and 135 s with a mean of 107.2 s and a standard deviation of 7.1s. These model results are very close to those achieved in Phase 1 with the same average on ground time. Paxs travelled an average of 6.0 m which is the same as in Phase 1 with the same standard deviation. The average PET was 42.2 s, while the average CWT is 28.5 s with 67.5 % of PET wasted in congestion which is identical to the results of Phase 1 for this model (see Table 10-4 and Table 10-6). The average pax use of the nearest exit in model 5a Phase 2 results was 79.1% which remains unchanged since Phase 1 results. The R2 exit achieves average flow rates of 36.7 ppm which is approximately 0.8% faster, while the forward and aft exits (R1 and R3) achieve average flow rates of 39.2 ppm (see Table 10-5); which is 39.7 % slower than the measured average in certification trials. The flow rates achieved for this model are almost the same as in Phase 1. Including the pax still in seat rows ahead in to the path evaluation algorithm has made practically no difference to results for this model.

When comparing Model 5a Phase 2 to Model 1 b, there has been a slight decrease in the mean on ground time by 0.7%, while the average distance travelled by paxs to an available exit has increased by 7.1%. The average PET has increased by some 5.2% while the Average CWT has increased by 4.4%. Although paxs travel further on average, this model still presents a number of similarities to Model 1 b in terms of the on ground time for the evacuation (see Table 10-2, Table 10-6 and Figure 10-10). It also has a larger standard deviation (7.1 s) and has a greater span between the minimum and maximum values of the on ground times (89.7 s and 135 s respectively) in comparison to Model 1 b which only has a standard deviation of 4.9s. The majority (94.6 % or 473 simulations) of the distribution results for Model 5a Phase 2 fall within the distribution results for Model 1 b (see Figure 10-10). The main difference between this model and Model 1b is the decreased use of the nearest exit by 6.7%. The standard deviation for the nearest exit use is greater for this model (2.5 %) than for Model 1 b (0.8 %).

- **Model 5a Phase 2 has a very close resemblance to the performance and results of the 85 % Neareast Exit - Model 1b but more optimal use of the available exits means that the pax are travelling further to evacuate.**
- **There are still some differences between the models such as slight increases in the average PET and CWT. This model could possibly be considered a reliable model for what paxs might do in a real accident situation as nearly 95% of its distribution of results correspond with those of the 85 % Nearest Exit Scenario Model 1b.**

The results for Model 5b Phase 2 (see Table 9-2, Table 10-6 and Figure 10-10) suggest that this aircraft model can produce on-ground times of between 78.4 s and 108.9 s with a mean of 93 s and a standard deviation of 5.3s. Paxs travelled an average of 6.1 m which is 0.1 m less on average than in Phase 1. The average PET was 38.3 s, while the average CWT is 24.8 s. Pax wasted 64.8% of PET in congestion which is only 0.4% higher than in Phase 1. The average use of the nearest exit by pax in the simulations carried out was 78.1% was only 0.3% higher than Phase 1 indicating that including new Phase 2 features has had very little effect on the performance of Model 5b. Introducing redirection into this model has improved the overall performance with 13.3% decrease in the average on ground time and 4% decrease in the average PET wasted in congestion. Redirection has also improved the flow rates of the R1 and R3 exits with an average increase of 27% when compared to

Model 5a in this phase while the flow rate of the middle exit has slightly increased by 0.5ppm (1.4%).

When comparing Model 5b Phase 2 to Model 1 b (85 % Model) the mean on ground time decreases by 13.8% while the average distance travelled by paxs is 6.1 m which is an increase of 0.5m (9.8 %). The average PET has decreased by some 4.5% while the Average CWT has decreased by 9.2%. The majority (67 %) of the simulation results for the pax on ground time with this model are lower than the results for Model 1 b which suggests that although this version of Model 5b uses data gathered from the questionnaires, including pax redirection has made this model too efficient and less reliable than Model 5a Phase 2 where 95% of the results fell within the distribution for Model 1b. Pax redirection does appear to have improved the overall results from the previous Model 5a but further away from Model 1b (see Figure 10-10, Table 10-2 Table 10-6). Model 5b Phase 2 has a poor resemblance to the performance and results of the Model 1 a, Model 1 b and the Optimal Exit Model (see Table 10-2 and Table 10-6).

- **Model 5b Phase 2 does not have a close resemblance to the performance and results of the 85 % Nearest Exit - Model 1b and should not be considered a reliable model for what paxs might do in a real accident situation as only 33% of its distribution of results correspond with those in the 85 % Nearest Exit Scenario Model 1b.**
- **The introduction of pax redirection into this Phase 2 Model has made these simulations too efficient and therefore not comparable with Model 1b.**

The results for Model 5c Phase 2 (see Table 9-2, Table 10-6 and Figure 10-10) suggest that this aircraft model can produce on-ground times of between 76.4 s and 108.6 s with a mean of 93.3 s and a standard deviation of 5.7s. These simulation results for Model 5c have barely changed with introduction of the Phase 2 features however there was a reduction in the standard deviation for the on ground time by 0.2 s (3.4%). In this model it is noted that paxs travelled an average distance of 6.1 m, the average PET was 38.4 s and the average CWT is 24.9 s which correspond closely with this model in Phase 1 and with Model 5b in Phase 2. During this model's simulations for Phase 2, we find that 64.8% of the PET is wasted in congestion which is on a 0.2% increase in congestion since Phase 1 compounding the fact that including pax ahead in seats into the path value estimation barely has any impact on the overall distribution of results. The average use of the nearest exit by pax was 78.2% which is almost identical to this model in Phase 1.

When comparing Model 5c Phase 2 to Model 1 b, there is a decrease in the mean on ground time by 13.5% while the average distance travelled by paxs increases by 0.5m (8.9%). The average PET has decreased by some 4.2% while the Average CWT has decreased by 8.8%. This model also has a lower PET wasted in congestion (64.8 %) than that of Model 1b (68.1 %). The majority of this model's simulation results (67.2 %) for the pax on ground time are lower than the results for Model 1 b (see Figure 10-10) suggesting that as with Model 5b Phase 2, introducing the redirection feature has made this model too efficient and far removed from the results of Model 1b. Model 5c Phase 2 has a poor resemblance to the performance and results of the Model 1 a, Model 1 b and the Optimal Exit Model (see Table 10-2 and Table 10-6).

- **Model 5c Phase 2 does not have a close resemblance to the performance and results of the 85 % Nearest Exit - Model 1b and should not be considered a reliable model for what paxs might do in a real accident situation as only 32.8% of its distribution of results correspond with those in the 85 % Nearest Exit Scenario Model 1b.**
- **The introduction of redirection into this Phase 2 Model has made these simulations too efficient and therefore not comparable with Model 1b.**

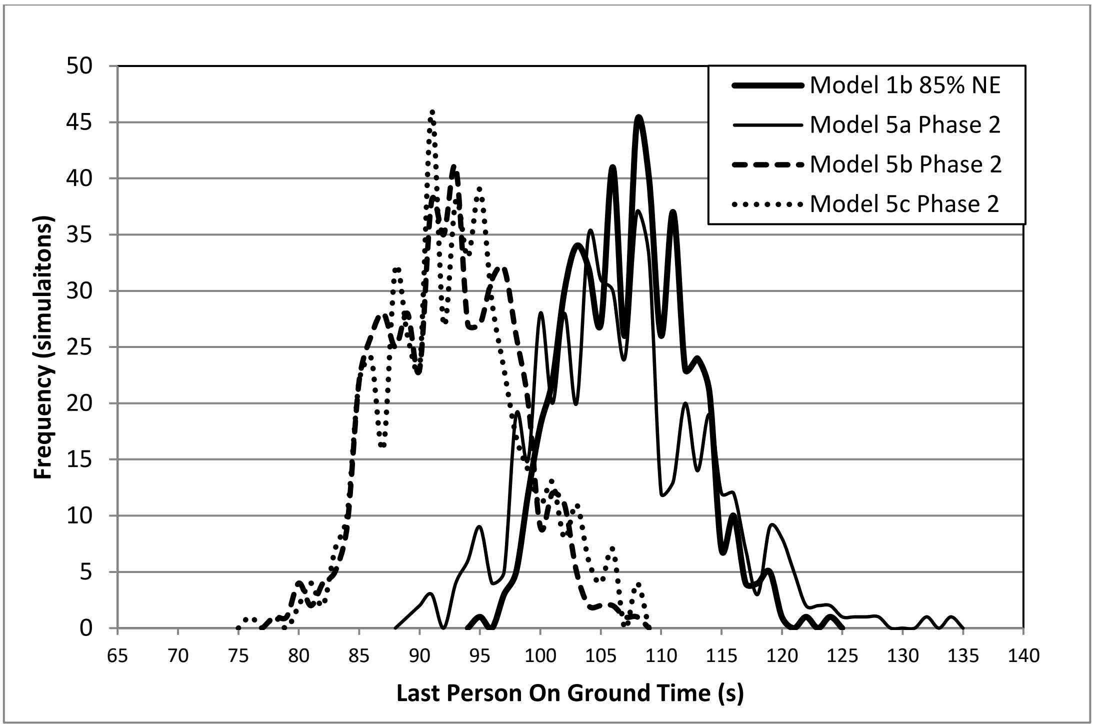


Figure 10-10: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 5a, Model 5b and Model 5c Distributions for Phase 2

10.4 CONCLUDING REMARKS

During the verification and validation of the path evaluation model, a total of 12,500 simulations have been run and analysed. Three base cases were first established which were namely Model 1a (100% Nearest Exit Scenario), Model 1b (85 % Nearest Exit Scenario) and the Optimal Exit Model. Firstly Model 1a was a used as starting point but secondly; Model 1b was used for comparison with the newly developed models as previous analysis using the AASK database [2] has suggested that 85% of pax who reported exit usage will use their nearest exit during an emergency. Thirdly the Optimal Exit Scenario was simulated and used for comparison. The Optimal Exit Scenario is closest to the way that pax will be behave in a 90 s certification trial where they will be directed by crew to go to their most optimal exit. In an Optimal evacuation scenario, the exits should stop functioning within 10 s of each other.

It is difficult to determine which of these base case scenarios is closest to a real accident however the data suggests [2] that the simulation of Model 1b (85 % Nearest Exit Scenario) is the best comparator that currently exists. Although construction of 85% of pax using their nearest exit in airExodus is fairly simple, the populations generated and used are recommended by FAR requirements for the certification testing [225] where the relevant number of required pax are set according to the specified mix in terms of age and gender as set out in FAR [2]. These population requirements for certification testing only take pax populations between the ages of 18-60 which excludes children and pensioners who may make a dramatic difference to the performance of an evacuation. Validating any aircraft evacuation model which is considered to be representative of a possible real accident scenario should commence with caution when validating against a pax population which complies with certification testing.

When summarising over the results of the simulations for the base case Model 1a (100% Nearest Exit Scenario) achieved average on ground times which varied between 126.1s to 158.3 s with a mean of **141.5 s**, Model 1 b (85% Nearest Exit Scenario) achieved lower on ground times which varied between 95.6s to and 124.2 s with a mean of **107.9 s.** The Optimal Exit case Model which was the scenario most similar to the certification trial had on ground times which ranged from 59.5s to 72.9 s with a mean of **65.8 s**. It should be noted the average time for the certification of the B737-300 series aircraft fell close to the middle of this range [105] for the Optimal Exit scenario results. The flow rates achieved for each of these scenarios were representative with what was measured in the certification trial for the type of exits used on this aircraft geometry. During the simulation results for the base cases, pax wasted 75.1% of PET in congestion in Model 1a, 68.1% was wasted in Model 1 b and 61.9 % in the Optimal Exit Model. Although it was difficult to accurately model the use of the nearest exit to exactly 100% and 85% some close values were achieved (see Table 10-2), when optimising the pax use of the exits for the Optimal Exit Model an average of 67.5 % nearest exit was achieved during the simulations.

During the development of this best path evaluation model, a total of 22 models were developed, simulated and validated. There were 2 separate phases (Phase 1 and 2) of the models and each phase consisted of 11 models (Models 2a, 2b, 3a, 3b, 3c, 4a, 4b, 4c, 5a, 5b and 5c). The only main difference of Phase 2 models was that pax still seated in the seat rows ahead would be taken into consideration as part of the algorithm for determining the best path value.

When considering the results of the models in both phases, each developed model was compared to Model 1b. Part a of the models (Model 2a, 3a, 4a and 5a) would have no pax redirection included while Model's b and c would include pax redirection as part of the algorithm. In each of the model's simulation results, good flow rates were achieved for the smaller emergency Type III exits which corresponded well with what was achieved in the measured certification trials for this type of aircraft. The larger forward and aft Type C exit flow rates were much lower on average than in practically all model simulation cases except in Model 3a, b and c where flow rates achieved were only slightly lower but very close to those in the measured certification trial. In nearly all model cases when comparing the flow rates of the larger forward and aft exits (R1 and R3), it should be noted that the average flow rates marginally decreased by introducing the new features of Phase 2 into the model simulations. Introducing redirection into the models, increased the average flow rates of the Type C forward and aft exits by approximately 15% for Model 2, 4 and 5 for Phase 1 but it slightly decreased on average when introduced into Model 3 by 0.5%. Introducing redirection for Phase 2 into the simulated models increased the flow rates of the Type C exits for all models by approximately 17%. Introducing redirection however made these model results too efficient and further from the model used for validation.

The main hypothesis of this work is that ***pax often use slower and smaller exits during an emergency evacuation because they poor knowledge of exit flow rates***. Evidence from the AASK database tells us that approximately 85% of pax will use their nearest exit [2] irrespective of the size and flow rates. A number of cases in both Phases 1 and 2 have been compared in the previous sections to Model 1b which is most representative of the 85% nearest case which had a mean on ground time of **107.9 s**. It was concluded that the results of Model 2a and Model 5a in both phases 1 and 2 (see Figure 10-11 and Figure 10-12) were the most similar to Model 1b even though the pax are behaving in totally different ways. These model distributions fitted more closely than any of the other models.

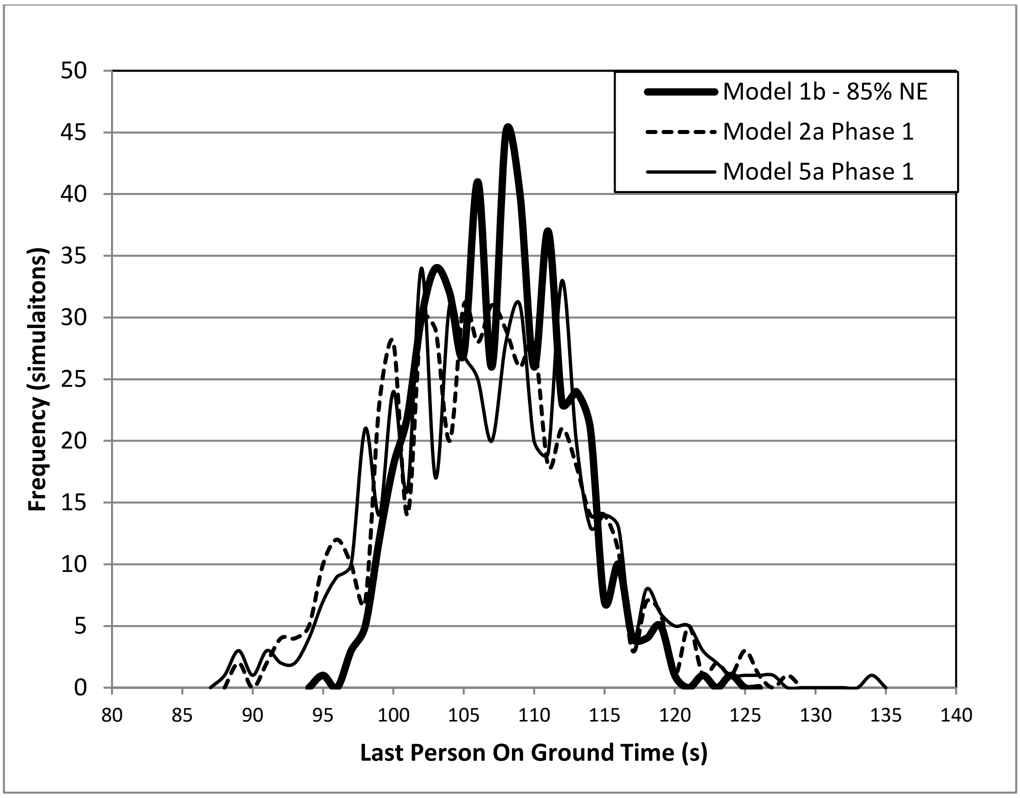


Figure 10-11: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 2a and Model 5a Distributions for Phase 1

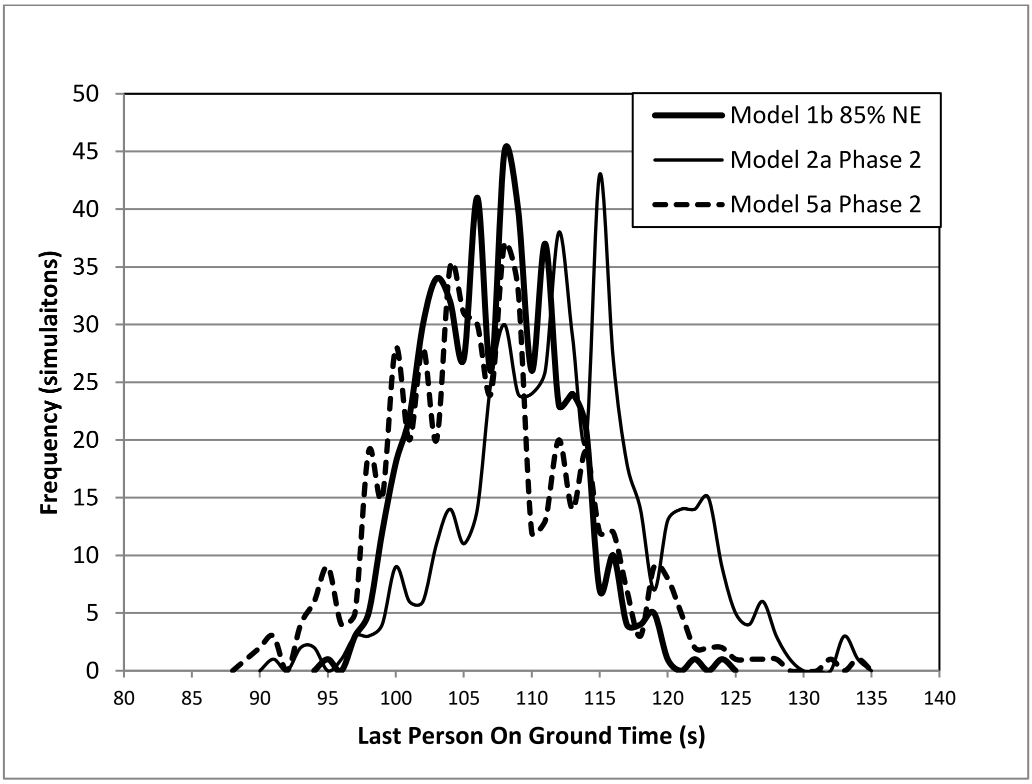


Figure 10-12: Frequency Distribution for Last Pax On Ground Times for 149 pax aircraft with Model 1b, Model 2a and Model 5a Distributions for Phase 2

Firstly in Model 1b, 85 % of pax are travelling or sent to their nearest exit and do not use any form of algorithm to make personal choices. In Model 2a pax for Phase 1, pax are making individual and personal choices during the simulation and each pax uses an algorithm to estimate their best path to a swift evacuation. During this model, all pax have poor knowledge of exit sizes and flow rates but are able to estimate their best path to evacuation using a uniform flow rate value for all available exits. During this model for phase 1 when the pax makes their personal estimation they are not taking pax still seated in the seats rows ahead into consideration. Model 2 a Phase 1 had a mean on ground time of **106.8 s** which is very close to the mean on ground time for the 85% case with decrease of only **1.1s.** In this model pax are not distinguishing between different exits types or flow rates but at the same time is echoing the average results of the Model 1b result for the 85% nearest exit case. If we later introduce the additional algorithm features of Phase 2 which includes the pax still located in seat rows ahead into the best path evaluation, the average results become slightly worse with an average on ground time of **113.1 s** which is **5.2 s** higher than in Model 1b and **6.3 s** higher than in Model 2a in Phase1. Introducing Phase 2 features in Model 2a has reduced the average flow rates of the forward and aft Type C exits (R1 and R3) with a much larger variation between the min and max values. The average flow rates of the over wing exit on the other hand remains practically unchanged during Phase 2. Introducing redirection into Model 2 has reduced the ground time dramatically in both Phases 1 and 2. When considering redirection in the results Model 2a during Phase 1, there is a decrease in the pax's nearest exit usage by only 2.8 % but this reduced the average on ground time by 8.2%.

Phase 2 brings additional features into the algorithm but at the same time brings more possibility of pax making a bad path evaluation choice. During the algorithm for Phase 2, as only 50% of the pax ahead in the seat rows are expected to get into the aisle first, this 50% value may be too high or too low and hence encouraging or discouraging the pax to make the right choice. With this uncertainty of the correct % value, the Phase 2 version of this model is currently less reliable than in Phase 1 where only the pax in the aisle are considered during the algorithm.

When comparing the similarity of results of Model 5 (a,b and c) Phase 1 to the 85% nearest exit case (Model 1b), it is noted that pax are again making and personal choices as they did in Model 2 and its variations. Each pax continues to use an algorithm to estimate their best path to a swift evacuation. When considering Model 5a, not all pax are using the same algorithm with 23% of pax using a combination of Model 3a while the remaining 77% use Model 2a. In Model 3a all pax are assumed to have perfect knowledge of exit sizes and flow rates. In the survey carried out in Chapter 8, the results showed that 23% of participants had perfect knowledge of exit size, location and flow rate while the rest were unaware of the differences between the exits. In Model 5 a, the remaining 77% use Model 2a where pax assume that all exits are the same size and have the same flow rate. Even with the changes of pax behaviour in Model 5a Phase 1, the average results for the on ground time (**107.2 s**) was remarkably similar to those of Model 1b (85% Nearest Exit Scenario). When comparing the results of this model to the same model in Phase 2, the average ground time was identical at 102.2 s with the same standard deviation rate. Introducing redirection into Model 5 has reduced the ground time substantially in both Phases 1 and 2. When including redirection into the Model 5 during Phase 1, there is a decrease in the paxs nearest exit usage by only 1.3 % but this induces an 18.9% reduction to the average on ground time.

The introduction of the new behaviour of Phase 2 for Model 5a has had very little impact on the overall results with the difference between the average flow rates for the over wing, forward and aft exits being almost negligible. The main difference between the 2 separate phases is an unusually low minimum flow rate (16.4ppm) achieved for the R1 exit in Phase 1, while in Phase 2, the minimum flow rate of R3 increases to 20.7ppm. These are very low flow rates for Type C exits to achieve and can be explained due to the fact that during these simulations, R1 and R3 exits do not have a constant flow of passengers as does the over wing exit. It has also been noted that there were often large gaps in the flow of pax to the forward and aft (R1 and R3) which made the average flow rate value appear much lower than expected for this type of exit.

If we consider the minimum flow rate of the Type C exits (R1 and R2) for all of the models in Phase1 and 2 it should be noted that in every case they are much lower than those achieved in the base cases where an average minimum of 55.9% was achieved. On the other hand, in nearly every case for the models of Phase 1 and 2, the maximum flow rates of R1 and R3 are quite consistent with the average maximum (75.9 ppm) which is being achieved in the base cases(Model 1a, model 1b and the Optimal Exit Model). To achieve such low flow rates for these larger exits, there would need to be a combination of a small number of pax using these exits together with gaps between groups or individual pax would need to be large.

The unusual minimum flow rate of 16.8 ppm was achieved for the Type C exit (R1) in Model 2a Phase2 was concerning but can be explained quite simply. The individual simulation file with this low flow rate was checked and it revealed the following. The flow time for that particular exit R1 was **110.5 s** while the total number of paxs using the exit was only 32. The first pax left the aircraft at **8.5s** while the last left at **119 s**. The majority of pax (26) had left by **33.3s** but in the following **85.7 s** only a further 6 pax left through the same exit (R1) which considerably slowed down the flow rate. If we calculated the flow rate using the first 26 pax who evacuated in a total time of **24.9 s** then a more likely flow rate of **57.5** ppm could possibly be deduced. This newly calculated flow rate corresponds well with those in Model 1b for the 85% Nearest Exit Scenario. By the last 6 pax re-estimating the path value while they were still located in the seat rows and blocked by the aisle queue, they have in fact minimised the overall ground time. The average distance travelled by the aircraft population during the simulation was 5.8m while the average distance travelled by the last 6 pax leaving through the R1 exit (Type C) was 8.5m which is an increase of 46.6%. The lower flow rate achieved by the larger exits at the front and aft can be explained in terms of paxs making individual choices for themselves and not for the aircraft as a whole. If a pax is still located in a seat row then they could re-asses to use an exit which is further away which may in turn reduce their individual PET. This could occur at any time or quite late in the evacuation, causing possible large gaps between the flows of the pax for that particular exit which would cause the unusually low flow rates. The unusually low flow rates in other model results for Phase 1 and 2 could be explained using the same theory.

During the path evaluation algorithm for Model 3a for Phase 1, pax were provided with the correct flow rates but were not permitted to redirect. In the results, the on ground times varied from **66.9s** to **95.6 s** with a mean of **78.6 s**. This was a **26 %** improvement over Model 2 a Phase 1 where the mean on ground time was significantly higher with **106.5 s.** A lower mean on ground time was anticipated for this unrealistic model as pax had been given full and accurate knowledge of the sizes and flow rates of the available exits. This model's results are more closely related to the results of the Optimal Model Exit scenario but the mean on ground time was still **19.5%** higher while pax travelled **0.2m** less on average. The mean on ground time for the optimal scenario is lower due to the fact that there is normally crew intervention with pax directed to the most optimal exit. In the measured certification trial and the Optimal Model Exit scenario, the aircraft is evacuated to benefit performance of the aircraft as a whole, while in Model 3a pax using the algorithm are only interested in reducing their own PET which may not be optimal for the whole aircraft performance.

Introducing redirection (Model 3b and 3c) made very little difference to the overall results when compared to Model 3a as pax were already making the best decisions based on full knowledge of exit flow rates. The pax in these models travelled the same average distance to an available exit suggesting that very little redirection was necessary. The average use of the nearest exit during Phase 1 has only marginally improved (0.1%). since permitting redirection.

The mean flow rates of the exits for the models 3a, 3b and 3c have improved since Model 2a which is to be expected as the pax have been provided with correct knowledge of flow rates and are therefore making better personal choices. The mean flow rates for Phase 1 are still 4.2% lower than those in measured trials for this type of aircraft which is to be expected as pax using the algorithms during these models are optimising their own PET rather than the ground time of the aircraft as a whole. Introducing the features of Phase 2 made almost no difference to Model’s 3b and 3c with just a slight increase to the mean on ground time for 3a. Model 3 (a,b and c) have shorter overall evacuation times than other developed models in this study, as paxs are making valid decisions and achieving lower PETs. Including pax located in seat rows ahead into the algorithm may not have such a large impact as it would do where there is more congestion encountered in the aisle and seat rows. The arbitrary value of 50% of pax still located in the seat rows ahead who may get into the aisle first may not be an accurate parameter, as previously stated for Model 2a so should be considered with caution in terms of validity. Models 3a, 3b and 3c for both Phases 1 and 2 should not be considered reliable for how pax would behave in a real accident or in a certification trial of an aircraft. The results of Model 3 and its variations indicates that if all paxs were provided with exits sizes and flow rates then the evacuation times may dramatically improve during an emergency.

When considering the results of Model 4 (a, b and c) for Phases 1 and 2 it is clear to see that this model has the longest average evacuation times. Model 4 a and it's variations resemble some of the results of base case (Model 1a) where 100 % of pax using use their nearest exit irrespective of size and flow rate. It is not surprising that the results are similar as Model 4 is constructed with a combination of 23% of pax using a version of Model 3, while 77% use Model 1a. The results for the on ground times in Model 4 a Phase 1 varied from 114s to 150.2 s with a mean of 130.8 s which is 7.6% lower than the mean on ground time achieved in the 100% nearest exits simulations (Model 1a) which was anticipated as less pax were using their nearest exit. In the results presented for Model 4 a Phase 1, 23% of pax were given knowledge of the exit sizes and flow rates so could have optimised their exit choices but the average results tell us that only 10.2% of pax on the aircraft did not use their nearest exit. As the congestion builds during the evacuation up it may have been better for the pax with exit knowledge to wait in a queue than to attempt go contra flow to a faster exit. Introducing redirection into Model 4 for the 23% of pax who had exit knowledge made very little impact which is understandable as only 10.2% of pax in Model 4a didn't use their nearest exit on average. In Model 4b where redirection was permitted, 10.9% on average used a more optimal exit meaning that redirection has only improved exit usage by 0.7% for this model. When Phase 2 features were introduced into Model 4, the average results slightly worsened which were not expected to be dramatic as only 23% of pax would have been initially affected by the additional behaviour of Phase 2. The nearest exit usage of Model 4a Phase 2 slightly increased to 90.7% indicating that approximately 60% of the pax with exit knowledge opted to use their nearest exit irrespective of size or flow rate. If should be noted that in some cases the nearest exit may have also been the larger and faster exit.

It should be concluded therefor than the most reliable to model which could be considered as being closest to the way that pax behave during an emergency should be that of either Model 2a Phase 1 or Model 5a Phase 1. Phase 2 should not be considered reliable as further testing is needed to validate the use of an arbitrary value used in the algorithm which assumed the percentage of paxs still located ahead in the seat rows that might get into the aisle first. To substantiate which is the most reliable model between Model 2a Phase 1 or Model 5a Phase 1, we can first conclude that Model2 a is slightly less reliable as 100% of pax assume that there is no difference between the sizes of exits and flow rates while the evidence from the AASK database indicates that only 85% of pax will use their nearest exit. Further data gathered in the questionnaires during a conducted survey suggests that 23% of pax have knowledge of exit sizes and flow rates. This survey data was introduced to Model 5a Phase 1 and its simulation results (94.4%) corresponded closely with those of the simulated Model 1b constructed to simply direct 85% of the pax to their nearest exit.

11 CONCLUSIONS

11.1 INTRODUCTION

In this chapter a summary and final discussion will be given with regards to the research questions posed in Chapter 1. The most important results and findings of this thesis can be found within Chapters 5 and 10. As well as revisiting the research questions this chapter will also discuss future work which is still required in in evacuation modelling.

11.2 THE MAIN FINDINGS

11.2.1 Research Question 1

The 90s certification test is currently used as a benchmark or kite mark of the ultimate safety of passengers and yet this test only provides a single data point. This benchmark must serve as an indicator of safety and should be as representative of reality and as challenging as possible. The first question posed in this thesis was:

(1) Is the current 90s certification test a suitable and challenging benchmark for the safety of passengers travelling on aircraft?

The hypothesis during this thesis was that the 90s certification test is not a suitable benchmark for the safety of paxs. The current test configuration of using half of the available exits usually down one side is not relevant with real accidents currently stored in the AASK database [2].

The main findings of this thesis for Research Question 1 are:

- **The current 90s certification test is not robust enough to ensure pax safety and could be putting lives at risk on both three exit zones and four exit zone aircraft**.
- T**he 90s certification test (base case) produces the fastest on ground times when compared with the top five most likely available exit scenarios to occur during real accidents on a narrow bodied aircraft suggesting that this test is too easy and doesn't test for what happens during real accidents**.

- **Only two Scenarios out of the five most likely exit availability scenarios for a narrow bodied aircraft actually pass the 90s certification criteria.**
- **The two most frequently occurring exit configurations fail to meet the certification criterion on a narrow bodied three exit zone aircraft.**
- **Only two scenarios out of the five most likely exit availability scenarios for a wide bodied 4 exit zone aircraft actually pass the 90s certification criteria.**
- **The base case simulation results for the wide bodied aircraft was more efficient than four out of five of the most likely exit availability scenarios.**
- **The worst performing exit configuration for the four exit zone aircraft fails to meet the certification criteria and is also the most likely exit configuration according to past accident data analysed.**

Within Chapter 5 the influence of exit availability was examined for a both a narrow bodied and wide bodied aircraft which had previously passed the certification requirements. Whilst maintaining the certification requirements of providing 50% of the exits, a total of twelve different exit configurations were examined (six for each aircraft configuration). Each aircraft configuration included the standard certification configuration (one exit from each exit pair) and five other exit configurations based on commonly occurring exit combinations found in accidents based on data derived from the AASK V4.0 database.

Within AASK V4.0, 42 accidents did meet the criteria with 31 accidents involving aircraft with three exit zones and 11 accidents involving aircraft with four exit zones. Due to this available data the narrow bodied aircraft with three exit zones and the wide bodied aircraft with four exit zones were chosen to test this hypothesis and to answer this first research question.

In contrast to the evacuation certification requirements, the AASK V4.0 study [2]suggests that a third (33%) of the emergency evacuations examined involve aircraft in which less than 50% of the exits are available (see

Table 5-1). It has also been noted during this study that smaller aircraft were more likely to have less than 50% of exits available than larger aircraft and over half of the accidents analysed (55%), involved a cabin section where no exit was available.

Summary of Results for 3 Exit Zone Aircraft

A list of more realistic exit combinations for aircraft with three exit pairs [2] – while maintaining the certification required 50% availability condition was discussed presented and discussed in Chapter 5.

The five more realistic scenarios formed the sub questions (1b – 1f) relating to research question (1) during Chapter 1. Each of these scenarios (i) to (v) for the 3 exit zone aircraft was tested and analysed using the airExodus evacuation software during Chapter 5. A total of 1000 simulations using 10 different populations (i.e. each population was run 100 times) were run and outputs saved for each case. Simulations producing suboptimal results (simulations in which the exits failed to complete passenger flow within ten seconds of each other) were discarded and later re-run until optimal results were produced. Each of these cases was compared against the configuration most often used during a 90s certification trial which included a **single forward exit**, a **single over wing exit** and a **single aft exit**.

A base case, the configuration most often used during a 90s certification trial formed sub question (1a) in Chapter 1 was run under strict evacuation certification conditions producing a mean on-ground time of 71.2 s and a 95th percentile time of 73.8 s (See Chapter 5). The finding here suggested that **simulations carried out for the configuration of available exits used most often within a real certification trial for this three exit zone aircraft indicates that it would comfortably pass the test and indicate a benchmark of false safety.**

The descriptions and simulation results for Scenarios (1) to (5) for the narrow bodied aircraft can be found in Chapter 5. The results produced from the simulation results for the top five ranked

The results for **Scenario (1)**; the most likely situation to occur according to real accident data stored in AASK for three exit zone aircraft, can produce a mean on-ground time of **87.7s** and a 95th percentile time of 92.4s. In this case it should be noted that the mean on-ground time has increased by 23% when compared to the case used most often in trials. **Using the 95th percentile pass/fail criterion, the aircraft with available exits configured as indicated in Scenario (1) just fails the evacuation certification trial.**

Scenario (2); the second most likely situation to occur for three exit zone aircraft, can produce a mean on-ground time of **98.1s** and a 95th percentile time of 105.4s. In this case it should be noted that the mean on-ground time has increased by 38% when compared to the case used most often in trials. **Scenario (2) fails the evacuation certification trial using the 95th percentile pass/fail criterion.**

Scenario (3); the third most likely situation to occur can produce a mean on-ground time of **77.7s** and a 95th percentile time of 81.4s. In this case the mean on-ground time has increased by 9% when compared to the base case. **Scenario (3) comfortably passes the evacuation certification using the 95th percentile pass/fail criterion.**

Scenario (4); the fourth most likely scenario to occur according to real accident data suggests that this available exit configuration can produce a mean on-ground times results of **76.5s** and a 95th percentile time of 80.5s. Here, the mean on-ground time has increased by 7% when compared to the case used most often in trials. **Scenario (4) comfortably passes using the 95th percentile pass/fail criterion. It should be noted that the results of Scenario (4) were very similar to those of Scenario (3).**

Scenario (5); can produce a mean on-ground time of **91.1s** and a 95th percentile time of 97.8s. In this case the mean on-ground time has increased by 28% when compared to the base case. **Using the 95th percentile pass/fail criterion, Scenario (3) would fail the evacuation certification.**

After the simulations were run for the narrow bodied aircraft, the sub questions (1g-1i) could then be answered. Sub question (1g) asks:

"***Will the simulation results of (1a) produce the most efficient results than the more relevant combination of available exit locations described in (1b- 1f) based on analysis carried out on past accidents?***"

Sub question (1a) refers to the simulation results of the **base case** while sub questions (1g-1i) refer to simulations results for **Scenarios 1-5** for the 3 exit zone aircraft**.** From the results produced the answer to sub question (1g) is "**yes**". The distribution of the results for the base case were lower and more efficient than the results for all five scenarios (See Chapter 5) which are placed 1 to 5 in the ranking for most likely exit availability to occur during an accident on a 3 exit zone narrow bodied aircraft.

Sub question (1h) asks:

*"**Where will the simulation results of (1a – the base case) rank in terms of evacuation efficiency when compared to the results of the more relevant combination of available exit locations described in (1b – 1f)?**"*

From the results produced the answer to sub question (1h) is "**1st**". The distribution of the results for the base case were lower and more efficient than the results for all five Scenarios (See Chapter 5) placed 1 to 5 in the ranking for most likely exit availability to occur during an accident on a 3 exit zone narrow bodied aircraft. **This suggests that the test is not robust enough and is the least challenging test that could be performed.**

Sub question (1i) asks:

*"**Will any of the simulation results of the more relevant combination of available exit locations described in (1b – 1g) satisfy the 90 s certification criteria?**"*

From the results produced the answer to sub question (1i) is "**yes**". Two cases (Scenarios 3 and 4) both satisfy the 90s certification requirements with the distribution of both sets of results falling lower than 90s in all simulations (See Chapter 5). Although these two scenarios both pass the test, the results are still lower on average by 8% when compared to the base case.

From these results produced, **the hypothesis that the 90s certification test is not relevant or robust enough has been proved in terms of the three exit zone narrow bodied aircraft.** Chapter 5 also found a further set of interesting results relating to this aircraft which suggested that **the two most frequently occurring exit configurations i.e. Scenarios 1 and 2, fail to meet the certification criterion**. **Two scenarios with similar exit configurations i.e. Scenario 2 (two forward and one over-wing exit) and Scenario 5 (two aft and one over-wing exit) and hence similar exit capacities produced very different on-ground times.**

Summary of Results for 4 Exit Zone Aircraft

A list of more realistic exit combinations for aircraft with four exit pairs was also tested– while maintaining the certification required 50% availability condition – has been suggested in literature with a decreasing order of likelihood [2].

The five scenarios for the 4 exit zone aircraft with 440 pax and 11 cabin crew are listed as (i) to (v) [2]. Each of these scenarios for the 4 exit zone aircraft was tested using the same method as with the aircraft with 3 exit zones (See Chapter 5). Simulations were set up and run in the same way as with the 3 exit zone narrow bodied aircraft. Each of these cases was then compared against the configuration most often used during a 90s certification trial which included a 4 Type A exits (two of these included Cantors) on the left side of the aircraft **single forward exit**, a **single mid forward exit**, a **single mid aft exit** and a **single aft exit**.

A base case (the configuration most often used during a 90s certification trial) was also run under strict evacuation certification conditions the configuration most often used during a 90s certification trial producing a mean on ground time of 76.9 s and a 95th percentile time of 80.0s. The time achieved by this wide bodied aircraft with 4 exit zones in the actual certification trial falls on the predicted curve and is between the minimum and mean predicted times. **The simulations carried out for this four exit zone base case suggests that it would comfortably pass the test and indicate a benchmark of false safety as with the three exit zone aircraft.**

The description and results for Scenario (i) to (v) for the wide bodied four exit zone aircraft can be found in Chapter 5. The results for **Scenario (i)**; the most likely situation to occur according to real accident data stored in AASK for four exit zone aircraft, the mean on-ground time has increased by 79% to 137.9s when compared to the base case. Using the 95 percentile pass/fail criterion this available exit configuration **fails** the evacuation certification trial.

Scenario (ii); the second most likely situation to occur according to real accident data stored in AASK for this aircraft type, the mean on ground time has increased by 10% to 84.5s. Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in **Scenario (ii)** barely **passes** the evacuation certification trial.

The results for **Scenario (iii)**; the third most likely situation achieves a mean on ground time of **77.7s** which is an decrease of 2.5% when compared to the case used most often in trials. Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in **Scenario (iii)** comfortably **passes** the evacuation certification trial.

Scenario (iv); the fourth most likely situation achieves a mean on ground time of **95.1s** which is an increase of 24% when compared to the case used most often in trials. Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in **Scenario (iv); fails** the evacuation certification trial.

Scenario (v) and fifth most likely scenario; achieves a mean on ground time of **105.3s** which is an increase of 37% when compared to the case used most often in trials. Using the 95 percentile pass/fail criterion, the aircraft with available exits configured as indicated in **Scenario (iv)** convincingly **fails** the evacuation certification trial.

Therefore considering the evacuation of the five most likely scenarios for the 4 exit zone aircraft, **only 2 scenarios are likely to pass (Scenario (ii) and (iii)). Three scenarios fail which are namely Scenario (i), (iv) and (v) when based on a 95th percentile pass/fail**

criterion. What is more worrying is that the most likely scenario to occur according to the AASK database V4.0 fails seriously with a mean on ground time of 137.9s which occurs more than likely due to the very long overall distance that the paxs in Scenario (i) are having to travel.

The distribution of the results for the base case were lower and more efficient than nearly all of the results for all Scenarios apart from Scenario (iii) which are placed 1 to 5 in the ranking for most likely exit availability to occur during an accident on a 4 exit zone wide bodied aircraft. Scenario (iii) however had a mean on ground time which was only 2.5% lower than the base case. Scenarios (i, ii, iv and v) had mean on ground times which were higher than the base case with all four of these Scenarios failing the certification trial.

From the results produced the base case scenario for the four exit zone aircraft will rank "**2nd**" in terms of evacuation efficiency. The distribution of the results for the base case was more efficient than the results for four Scenarios placed at 1, 2, 4 and 5 in the ranking for most likely exit availability to occur during an accident on a four exit zone wide bodied aircraft. This suggests that the test is not robust enough and is nearly the least challenging test that could be performed.

Two cases (Scenarios (ii) and (iii)) both satisfy the 90s certification requirements with the distribution of both sets of results falling lower than 90s if the 95th percentile pass/fail criterion is used. Although these two scenarios both pass the test, Scenario (iii) still ranks below the base case in terms of evacuation efficiency.

From these results produced, **the hypothesis that the 90s certification test is not relevant or robust enough has been proved in terms of the four exit zone wide bodied aircraft**. Chapter 5 also found a further set of interesting results relating to this aircraft which suggested that **the worst performing exit configuration which also fails to meet the certification criterion is the most likely exit configuration according to past accident data analysed.**

11.2.2 Research Question 2

Analysis of the AASK database [2] has shown that 85% of paxs used their nearest exit while evacuating during aircraft emergencies with the rest of those questioned giving valid reasons as to why they did not (i.e. exit was blocked). This analysis carried out [2] led the way to, a second research question which is:

> ***"How do passengers evaluate the best path or route for evacuation on board a narrow bodied single aisle aircraft used for domestic flights****?"*

The hypothesis was that most paxs are unaware of the size, location and flow rates of exits on board an aircraft with frequency of flight having very little significance. This in turn can greatly reduce the effectiveness of the overall evacuation of the aircraft and cause unnecessary injury, incapacitation or even fatality to paxs. Chapter's 7,8,9 and 10 are dedicated to answering this second research question so it could be said that this was the most important topic of this thesis. In a studies carried out using the AASK database [2, 3], the analysis showed that 85% of pax questioned made use of their nearest exit with the others giving valid reason as to why not. The criteria for success in proving this hypothesis was to demonstrate that any data gathered and then implemented into a computer model, would closely represent what is happening in real accidents. This would be done by achieving similar mean evacuation results from the new models where paxs are making their own individual decisions compared to evacuation simulations where 85% of the pax use their nearest exit. This new data also needed validation against measured certification trial data [105] and simulations of base cases such as the 100% and 85% nearest exit scenarios as well as the Optimal Scenario which is most similar to the 90 s certification test scenario.

To answer this research question fully a number of sub questions would first have to be answered which were namely 2a – 2j as listed in Chapter 1. Before the sub questions 2a – 2h could be answered, a survey of 459 passengers was carried out (See Chapter 7) and the data analysed (See Chapter 8). Within in the data, four sub-populations were formed which were:

- ***Sub-population who has flown within the past 12 months*** (367 participants) – (recent flyers)

- ***Sub-population who have not flown within the past 12 months*** (92 participants)- (not flown recently)
- ***Sub-population of frequent flyers*** who had flown within the past 12 months (194 participants) - (recent frequent flyers)
- ***Sub-population of infrequent flyers*** who had flown within the past 12 months (173 participants) - (recent infrequent flyers)

From analysis carried out and discussed in Chapter 8, 75% (344) could correctly identify the location of the three exit pairs ***indicating that a quarter of the participants (25% or 115) did not know that the aircraft had three exit pairs and where they were located.*** Comparison was made between the sub-population who had flown within the past 12 months (367 participants) with those who have not flown within the past 12 months (92 participants). The correct knowledge of the number and location of the exits was almost identical, with the proportion of those having flown in the past 12 months only being some 3% larger than the proportion of those who had not flown in the past 12 months. ***Simply having flown recently does not convey good knowledge of the aircraft layout.***

Comparison was also made between the sub-population of "***frequent flyers*****"** who had flown within the past 12 months (194 participants) with "***infrequent flyers***" who have flown within the past 12 months (173 participants). Of those "**frequent flyers"**, 82% could correct locate 3 exit pairs while this was reduced to 68% for "***infrequent flyers***". The difference between these two sub groups was not statistically significant however and therefore indicating again that ***having flown recently does not imply that people will have a good knowledge of the aircraft exit layout and configuration.***

Only 37% of the entire sample knew that the exits were of different sizes. For those who had recently flown 40% knew that the exits were different sizes reducing to 30% for those that had not recently flown. Only 45% (91) of the "***recent frequent flyers*****"** realised that the exits were not the same size, while only 31% (54) of the "***recent infrequent flyers*** knew" suggesting that over half the population of "***recent frequent flyers"*** do not know that the exits are of different sizes.

Only 22% of the entire sample could identify the number, the location and relative size of the exits on a narrow bodied domestic aircraft increasing to 23% for pax who had recently flown and reducing then to 16% for those who had not recently flown. Only 27% (53) of the "***recent frequent flyers***" could identify the three key configurational facts relating to; the number of exits, the location of the exits and that the central exits were smaller in size. This compared to only 18% (31) for the "***recent infrequent flyers***". This now implies that "***recent frequent flyers***" have better configurational knowledge of the aircraft than "***recent infrequent flyers***" with the difference being statistically significant**.** While being a "***recent frequent flyer***" conveys better knowledge of the aircraft exit configuration and layout, ***the result that only a little more than a quarter of the recent frequent flier sub-population - 27% (53) - could correctly identify the number of exits, locate their position and identify their relative size is concerning.***

Of the entire sample, 75% can correctly identify that it would take longer to pass through the larger exit than the smaller emergency over wing exit. There was practically no difference in percentage between the sub groups for the correct identification of the flow rates between the larger and smaller exits. Three quarters of the entire population (75% or 340 participants) understood that the smaller exit meant a slower egress time through the exit. ***However, a quarter of the entire population (26% or 119 participants) thought that the smaller exit would allow them to pass through in approximately the same amount of time or quicker than the larger exit. This result appears to be independent of flyer experience.***

If during an emergency situation the passenger was alone on the aircraft and situated in the aisle at an equal distance between a large exit and the smaller ROW exit, ***on average almost two fifths (38%) of the entire population elect to use the centrally located smaller over wing exit rather than the larger forward/rear (Type-C) exits.*** When we consider the sub-population with the most flying experience, the "***recent frequent flyer***" group, the percentage electing to use the over wing exit decreases slightly to one third (33% or 129). However, this difference is not statistically significantly different (See Chapter 8) supporting the null hypothesis that flyer experience does not make a difference in exit choice.

If during an emergency situation where the pax was not alone on the aircraft and situated in the aisle at an equal distance between the large FR exit and the smaller ROW exit it is substantiated that ***even with a queue at each exit, on average, almost two fifths (39%) of the entire population again elect to use the centrally located smaller over wing exit. These results demonstrate that a significant proportion – two fifths - of the general population do not correctly perceive that it will take them longer to exit via the smaller over wing exit.***

Before the results of the survey carried out in Chapter 8 were validated, a simple model algorithm was designed and then implemented into airExodus (See Chapter 9). A number of variations of this simple model were developed which included the data gathered from the survey results. Each of these models was simulated with the results outputted and later analysed. The analysis of each of model's results were then compared to the results of an aircraft evacuation simulation where 85% of pax were sent to their nearest exit as is reported to happen in real accidents according to literature [2,3].

Two separate phases (Phase 1 and 2) of the simple model and its variations were developed with the descriptions of each model listed in Table 9-1 and Table 9-2. A total of 22 separate models were developed and tested with the results of each model being presented in Chapter 10. During the development discussion, a set of base cases was constructed and used for comparison, namely 100% and 85% nearest exit scenarios and were referred to as Model 1a and Model 1b (See Table 10-2). A further base case was constructed and used for comparison was the Optimal Exit Scenario.

The new simple model algorithm allowed individual paxs to think as agent who would evacuate in a way which was best for them rather than using a system of potential map values which literally draws the passengers to the exit. Within this new simple model algorithm the pax could evaluate the most efficient path route based on their location and the number of passengers who may get or already be ahead of them. Not all of the data from the survey was used during the validation and this may be used in further work. The data chosen to be validated within the model was gathered from the sub group "***recent frequent flyers***" including 194 participants where 27% were able to correctly identify the number, location and size of the exits on the aircraft. This number was reanalysed and reduced further to 23% of paxs in this sub group being also able to identify the correct flow rates. The original intention of this survey was to carry out questionnaires on paxs who had only just disembarked an aircraft but this became difficult due to recent security restrictions at airports. The "***recent frequent flyers***" sub group was chosen as this group most closely represented the original intention of the survey.

In Model (4 and 5) for both Phases, 23% of the paxs were given knowledge of the number, location size and flow rates of the exits while the rest of the paxs were doing something else. It is the results of Model 4 and 5 simulations which were compared against the case constructed to represent the 85% Nearest Exit Case (Model 1b).

The results for all models developed during this thesis can be found in Chapter 10. The main results for Models 2-5 and there variations in both Phases 1 and 2 can be found in Table 10-4 and Table 10-6. Model 2-5 and their variations were then compared against the results of Model 1b (85% Nearest Exit Scenario). The distribution results for Model 1b were on-ground times which ranged from **95.6s** to a **124.2s** with a mean of **107.9s**. Paxs in this model travelled an average distance of 5.6m. During the construction of this model the average use of the nearest exit was **85.8%** which is just slightly higher than in what is reported in the analysis of real accident case within the AASK database [2, 3].

In the Phase 1 developed models, only two resembled the results of Model 1b which were namely Model 2a and Model 5a. In both of these models redirection was not switched on and paxs still located within the seat rows ahead of the decision making pax were not included in the algorithm. The on ground times for Model 2a where all pax were provided with information that all exits were the same size and had the same flow rate, ranged from **89.1s** to **128.1s** with a mean of **106.7s** with pax travelling 5.8m on average. The average use of the nearest exit in this case was **82.6%** which is only **2.4%** difference from the results presented in [2]. Model 2a did not include any data from results of the survey carried out during Chapter 8.

In Model 5a, 23% of pax have full, configurational knowledge of the aircraft, while the remaining 77% use a standard flow rate for all exits on board as was done in Model 2a, the on ground times range from **88.9s** to **134.4s** with a mean of **107.2s**. Paxs travel an average distance of **6.0m** while the average use of the nearest exit is **79.1%** which is nearly **6%** lower than what was found to be the case in the analysis of accidents within AASK.

When paxs still located in the seat rows ahead were introduced into Phase 2 of the models the mean value of Model 2a increased by **6.4s.** Model 5a which has the closest mean value in Phase 2 was virtually unchanged with the same mean value of **107.2s.** Introducing the new complexities have made a difference to the results of Model 2a where all pax were using a standard flow rate irrespective of the exit size while there has been practically no effect to Model 5a.

From the results of the Model 5a developed in both Phases 1 and 2 with the use of the new data gathered from survey result, there is an indication that the results output and analysed are similar to results when approximately 85% of passengers are simulated to use their nearest exit. There are still some differences between the results as further work is required on this model. There is also a chance that 85% is not the exact value as reported within the AASK analysis of real accidents [2] due to the some limitations in the AASK data recorded with this value being slightly higher or lower than 85%.

Model 2a for Phase 1 does not use any data gathered from the survey results but was an assumed case but these results are also very similar to what is happening during the pax's 85% use of the nearest exit.

***The work in this thesis has found a method to evaluate the best path or route for evacuation on board a narrow bodied single aisle aircraft with the results of the model matching up closely to what is happening during emergency evacuations reported in the AASK database where 85% of passengers reportedly use their nearest exit*?**

11.2.3 Research Question 3

The results of the survey data produced in Chapter 8 demonstrated very poor knowledge of the overall exit configuration even by those who fly frequently. This made the way to a third research question:

> ***"If paxs on board a narrow, bodied, single, aisle aircraft were provided with detailed and full information about the location, size and flow rates of the exits on board, would this improve the evacuation time of the aircraft and hence save lives?"***

To test this hypothesis, an assumed hypothetical model was constructed where pax were given full knowledge of the exit location, size and flow rate.

It should be recalled that a significant number of the population were not aware of the differences between the exits and the implications it may have on exit performance. To test whether or not the participants would change their answers if they were presented with detailed information concerning the size and flow rate these questions were repeated progressively during the survey providing the participants with more information concerning the exit configurations.

When the entire sample of participants was informed that the forward and rear exits are larger than the over wing exit, the proportion electing to use the larger forward exit increases to from 68% to 88% (402), and further increases to 90% (415) when there is a queue at each exit (see Table 8-2). When the entire population sample was informed that the larger exit was also faster than the smaller over wing exit, the proportion now electing to use the larger forward exit increases to 91% (420) and further increases to 93% (427) when there is a queue present at each exit. When compared with the case where the participants are given no additional configuration information, the proportion of participants selecting the larger exit is statistically significantly different demonstrating a very strong departure from the null hypothesis that providing additional exit configuration and performance information does not result in better exit selection (See Chapter 8). When providing full information to the paxs regarding the size and flow rate of the exits, the gap between the entire sample and the recent frequent fliers results is now very small. ***These results have shown that the participants are capable of making better choices if they are provided with appropriate configurational and exit performance information.***

These findings were evaluated with the use of the previously developed simple model algorithm developed and described in Chapter 9. Model 3 and its variations for both Phases 1 and 2 was developed providing paxs with full configurational knowledge of the aircraft in terms of exit location, sizes and flow rates. The results for Model 3 produced the lowest mean on-ground times from all of the new models developed and more closely resembled the distribution results of the Optimal Exit Scenario (base case) with paxs travelling further on average to reach an available exit. There was very little difference between the results of the Model 3 and it variations (a,b and c) for Phase 1 which is discussed in Chapter 8. In Model 3a Phase 1, the average use of the nearest exit was **72.2%** which is only **4.7%** higher than in the Optimal Scenario simulations carried out. If more complexity is brought into the model with Phase 2, the on ground times for Model 3a increase slightly but the average use of the nearest exit decreases to **69%.** ***These results have shown that by providing accurate information regarding exit sizes and flow rates, the efficiency of the aircraft evacuation will be improved and hence save lives.***

11.3 FUTURE WORK

Aircraft paxs travelling in a group was found to represent a significant number [5] with just under half of the paxs found to be travelling alone. The nature and composition of the groups was investigated during the analysis with these groups gave rise to further investigation into the assistance that may have been administered by passengers to each other (parents helping children and spouses helping each other) within the groups. Of those travelling with a companion or in a group, it is reported that 16% stated having to provide some form of assistance [5] to other paxs. AASK analysis [5] suggests that the family or companion bonds during aircraft evacuation may not be continued indefinitely due to some statements given by survivors. It is suggested that crew procedures developed from the analysis of certification trials where no social bonds exist may become irrelevant during a real emergency where social bonds do exist [5]. Currently certification trials do not include the notion of groups or family bonds, while the simple model with path evaluation algorithm developed within the work of this thesis doesn't include anything to do with social or family bonds. This is an area that really needs attention. **A questionnaire should be created to survey and understand this type of human behaviour. Implementing this type of behaviour into the model would correspond well with pax behaviour reported [5]**.

The evacuation certification trial requires that 50% of exits be made available (see FAR 25.803 [1]). In contrast to these requirements, the AASK V4.0 study suggests that a third (33%) of the emergency evacuations examined involve aircraft in which less than 50% of the exits are available [2]. The data also suggests that the available exit distribution for small (i.e. aircraft with three exit zones) and large aircraft (i.e. aircraft with four exit zones) is different with smaller aircraft having a greater tendency than larger aircraft to have less than 50% of their exits available during an emergency evacuation. In addition, the accident analysis suggests that over half (55%) of the accidents investigated involve a cabin section in which no exits were available [2]. It is therefore suggested that further simulations be carried out and outputs analysed for both narrow bodied and wide bodied aircraft with less than 50% of the exits being available.

When considering the path algorithm developed within the airExodus model during this thesis and discussed within Chapter 9, some assumptions were made and further work is needed to validate these. For example when redirection was switched on, paxs were only permitted to redirect once. This was done in order to prevent the paxs from redirecting too many times and hence hindering the evacuation from progressing. Research should be carried out using AASK or accident reports to ascertain whether there is evidence of multiple redirection attempts or occurrences during aircraft evacuation.

Also within the developed path evaluation algorithm, the decision making pax always makes perfect decisions when counting the number of passengers who are in the queue waiting in the aisle adjacent to the target exit. Further work should be introduced which would include a form of imperfect decisions being made. A fuzzy logic model [134] could be included in the determination of the number of passengers still located in the seat rows ahead and bring a more accurate representation of aircraft evacuation.

Within Phase 2 of the path evaluation algorithm developed, the decision making pax assumed that 50% of the pax still located in the seat rows ahead will make it into the aisle before them. This 50% value postulated and should therefore be researched further to substantiate a more realistic measure. This would be best researched by way of a survey where participants were presented with questions which included images in which some evacuating paxs were still located in the seat rows ahead and asked what percentage they might perceive to get ahead. These survey questions should be designed to determine a more accurate or realistic value of paxs perception before being validated within the path evaluation algorithm within airExodus.

There is a requirement for the path evaluation algorithm developed to be extended into use with the wide bodied aircraft as it has currently only been test to work with a narrow bodied aircraft geometry.

REFERENCES

1. FAR Part 25.807 Airworthiness Standards. Transport Category Airplanes. Including amendment 25-67 as published in the Federal Register on June 16th, 1989, Washington DC, USA, 1989.
2. Galea, E.R., Finney, K., Dixon, A.J.P., Siddiqui, A., and Cooney, D.P. "An analysis of exit availability, exit usage and passenger exit selection behaviour exhibited during actual aviation accidents." The Aeronautical Journal of the Royal Aeronautical Society, Vol 110, Number 1106, pp 239-248, 2006.
3. Owen, M., Galea, E.,R., Lawrence, P.,J., and Filippidis, L. AASK – Aircraft Accident Statistical Knowledge: A Database of Human Experience in Evacuation Reports, The *Aeronautical Journal of the Royal Aeronautical Society*, August/September 1998, pp 353- 363.
4. Galea, E.R., Finney, K.M., Dixon, A.J.P., Siddiqui, A. and Cooney, D.P. THE AASK DATABASE V4.0: Aircraft Accident Statistics and Knowledge. A Database to Record Human Experience of Evacuation in Aviation Accidents. Report for CAA Project 560/SRG/R+AD, December 2003.
5. Galea, E.R., Finney, K., Dixon, A.J.P., Cooney, D. and Siddiqui, "The AASK Database V4.0: Aircraft Accident Statistics and Knowledge, A Database to Record Human Experience of Evacuation in Aviation Accidents", In Proceedings of the International Aircraft Fire & Cabin Safety Conf, Nov 15-18, 2004, Lisbon Portugal. http://www.fire.tc.faa.gov/2004Conference/html/evac.htm
6. Galea, E.R., Finney, K., Dixon, A.J.P., Siddiqui, A., and Cooney, D.P. "An analysis of the passenger to cabin crew ratio and exit reliability based on past survivable aviation accidents.". Human Factors and Aerospace Safety, Ashgate publishing, 5(3), pp 239-256, 2005.
7. Galea, E.R., Finney, K., Dixon, A.J.P., Siddiqui, A., and Cooney, D.P. "Aircraft Accident Statistics and Knowledge Database: Analyzing Passenger Behaviour in Aviation Accidents.", AIAA Journal of Aircraft, Vol 43, Number 5, pp 1272-1281, 2006.
8. Galea E.R., Blake S. and Lawrence P.J., Report on Testing and Systematic Evaluation of the airEXODUS aircraft evacuation model. ISBN 0860399664, CAA PAPER 2004/2005. April 2005
9. Galea E.R., "Proposed Methodology for the Use of Computer Simulation to Enhance Aircraft Evacuation Certification.", AIAA Journal of Aircraft, Vol 43, Number 5, pp 1405-1413, 2006.
10. Cherry, R., 'Analysis of Factors Influencing the Survivability of Passengers in Aircraft Accidents', Report presented to the commission of the European Communities- Directorate General for Transport, R.G.W. Cherry & Associates, January 1995.
11. Ranter, H., The Aviation Safety Network, http://aviation-safety.net/database/
12. Owen, M., Galea, E.R., Dixon A.J.P., "90-second Certification Trial Data Archive Report", Prepared for the U.K. CAA for project 049/SRG/R&AD, March 1999.
13. Finney, K., Galea, E., R., Gwynne, S., Dixon, A.J.P., "Analysis of 90-second Certification Trial ", Report in preparation 2002.
14. Blake, S., "The Development and Use of Aircraft Evacuation Modelling as a viable Tool for the Certification and Safety Analysis of Passenger Aircraft", Thesis for completion of Doctorate of Philosophy 2003.

15. "OTA Aircraft Evacuation Testing: Research and Technology Issues. Background Paper", Technical Report. OTA-BP-SET-121, Office of Technology Assessment Congress of the United States, 1993.
16. Snow C., Carroll J.J., Allgood M.A., "Survival in emergency escape from passenger aircraft", Survival in emergency escape from passenger aircraft", DOT/FAA/AM/70-16, Department of Transport, Federal Aviation Administration, 1970.
17. Schaffer, F. "Passenger Emergency Exit Usage in Actual Emergencies of Jet Airliners 1960-1989", Proceedings European Cabin Safety Conference 1990, CAP 583, pp68-89, 1990.
18. Civil Aviation Authority, "Survivable Accidents Database, Software V 2.0", Data Issue 8, 1998.
19. Safety Study, "Emergency Evacuation of Commercial Airplanes", National Transport Safety Board (NTSB), Washington, D.C., NTSB/SS-00/01, 2001.
20. Galea E.R., Blake S.J., Lawrence P.J., "Report on the Testing and Systematic Evaluation of airExodus Aircraft Evacuation Model", CAA (Civil Aviation Administration) Paper 2004/2005, ISBN 0 86039 966 4.
21. Galea, E.R., and Gwynne, S. Principles and Practice of Evacuation Modelling – A collection of lecture notes for a short course prepared by the Fire and Safety Engineering Group, University of Greenwich, 03/IM/104, ISBN 1 904521 05 3, March 2003.
22. Galea, E.R., Finney, K.M., Dixon, A.J.P., Siddiqui, A. and Cooney, D.P., An Analysis of Human Behaviour during Aircraft Evacuation Situations using the AASK V3.0 Database. Aeronautical Journal, April 2003, 107, (1070), pp219-231.
23. Muir, H., and Corbett, A., Influence of Cabin Crew during Emergency Evacuations at Floor Level Exits, CAA Paper 95006, 1996, Part A, ISBN 0 86039 649 5.
24. 767-300 Full Scale Evacuation Demonstration FAA/JAA Certification, BOEING *Proprietary Report of the Full scale Evacuation Demonstration*, performed on February 11th, 1995.
25. Muir, H., Marrison, C. and Evans, A., Aircraft Evacuations: The Effect of Passenger Motivation and Cabin Configuration Adjacent to the Exit, Technical Report, 1989, CAA Paper 89019, ISBN 0 86039 406 9.
26. Gourary Associates, "Demosntration Manual for Microcomputer Model, Version 6.1, 22nd October, 1990", User documentation for Gourary Associates Evacuation Model, Version 6.1, 1990.
27. Air Accident Report, "World Airways, Inc., Flight 30H McDonnell Douglas DC-10-30CF, N113WA, Boston-Logan International Airport, Boston, Massachusetts, January 23rd, 1982", National Transportation Safety Board (NTSB), Washington, D.C., NTSB/AAR-82-15, 1982.
28. Galea, E. R. and Owen, M., "THE AASK DATABASE: A Database of Human Experience In Evacuation Derived from Air Accident Reports", Proc, International Aircraft Fire & Cabin Safety Conference, Nov 16-20, 1998, Atlantic City, DOT/FAA/AR-99/68, 1998.
29. The AASK Database V3.0: A database of Human Experience during Aircraft Evacuation Incidents". Galea E.R., Finney K.M., Dixon A.J.P., Cooney, D.P. Siddiqui, A. Proceedings of 7th IAFS Symposium WPI, USA, Ed: David Evans, ISBN 0-9545348-08, pp865-876, 2003
30. Garner J.D., Chandler, R.F., Cook, E.A., "GPSS Computer Simulation of Aircraft Passenger Emergency Evacuations", DOT/FAA/AM-78-23, US Department of Transport, Federal Aviation Administration, 1978

31. Folk, E.D. “GPSS/360 Computer Models to Simulate Aircraft Passenger Emergency Evacuation”, DOT/FAA/AM-72-30, US Department of Transport, Federal Aviation Administration, 1972
32. Kisko, T.M and Francis, R. L., “EVACNET+: A Computer Program to Determine Optimal Evacuation Plans”, Fire Safety Journal, 9, 211-220, 1985.
33. Taylor , I. R., “A Revised Interface for Evacnet+”, Proc of 7th Int. Fire Science and Engineering Conference, Interflam ‘96, 1010-1017, 1996
34. Takahashi, K., Tanaka, T., Kose, S.,”A Evacuation Model For Use In Fire Saftey Design of Buildings”, Proc of 2nd International Symp on Fire Safety Science, 551-560, 1989.
35. Ozel, F., “ Simulation modelling of human behaviour in buildings”, Simulation, 377-384, 1992
36. Donegan, H. A., Pollock, A., J., Taylor, I.R., “Egress Complexity of a Building”, Proc of 4th Int Symp on Fire Saftey Science, 601-612, 1994.
37. Levin, B., “EXIT, A Simulation Model of Occupant Decisions and Actions in Residential Fires”, Proc of the 2nd Int Symp on Fire Safety Science, 561-570, 1989.
38. Levin, B.M., “EXIT, A Simulation Model of Occupant Decisions and Actions in Residential Fires: User’s Guide and Program Description”, NBSR 87-3591, NBS, 1987.
39. Ketchel, N., Cole, S. S. Webber, D.M., “THE EGRESS Code for Human Movement and Behaviour in Emergency Evacuation”, Engineering for Crowd Safety, Elsevier, 361-370, 1993.
40. Ketchel, N., “Evacuation Modelling: A New Approach”, Proceeding for the Intl Conference on Fire Science and Engineering, ASIAFLAM ’95, 499-505, 1985.
41. Reisser-Weston, E., “Simulating Human behaviour in Emergency Situations”, RINA, Int Conference of Escape, Fire and Rescue, 19/20 Nov 1996.
42. Poon, L. S., and Beck, V.R., “EVACSIM: Simulation of Occupants with Behavioural Attributes in Emergency evacuation of High Rise Buildings”, -Proc of Fourth Int Symp on fire Saftey Science, 681-692, 1994.
43. Poon, L. S., “Numerical Modelling Of Human Behaviour During Egress In Multi-Storey Office Building Fires Using Evacsim – Some Validation Studies”, Proc of the Int Conf on Fire Safety Science and Engineering, ASIAFLAM ’95, 163-174, 1985.
44. Fahy, R. F., “An Evacuation Model for High Rise Buildings”, Proc of the 3rd Int Symp on Fire Safety Science, 815-823, Elsevier, London 1991.
45. Fahy, R. F., “Modelling contra flows during building evacuations”, Proceedings of the 9th Int Conf of Interflam, Volume 2, ISBN 0953231291, 2001.
46. Thompson, P. and Marchant, E., “A Computer Model for the Evacuation of Large Building Polpulations”, Fire Saftey Journal, 24, 131-148, 1995.
47. Thompson, P. and Marchant, E., “Simulex: Developing New Computing Modelling Techniques for Evaluation” Proc of the 4th Int Symp on Fire Safety Science, 613-624, 1994.
48. Thompson, P., Wu and Marchant, E., “Modelling Evacuation in Multi-Storey Buildings with Simulex”, Fire Engineers Journal, 7-11, Nov 1996.
49. Okasaki, S. and Matsushita, S., “A Study of Simulation Model For Pedestrian Movement With Evacuation and Queuing”, Eng For Crowd Safety, 271-280, 1993.
50. Barton, J. and Leather, J., “Paxport – Passenger and Crowd Simulation”, Passenger Terminal ’95, 71-77, 1995.

51. Bulman, E. and Clifford, P., "Customer Service. Interchangeable?", Passenger Terminal World, 18-23, 1995.
52. Still, K., "New computer system can predict human response to buiding fires", FIRE 84, 40-41, Jan, 1993.
53. Still, G. K., "Simulating Egress Using Virtual Reality-A Perspective View Of Simulation And Design", Paper 25, IMAS 94, Fire Safety on Ships 26-27 May 1994.
54. Blake, S.J., Galea, E.R., Gwynne, S., Lawrence, P.J. and Filippidis, L., "Examining the Effect of Exit Separation on Aircraft Evacuation Performance During 90-Second Certification Trials using Evacuation Modelling Techniques", The Aeronautical Journal of the Royal Aeronautical Society, Volume 106, Number 1055, January, 2002, pp1-16.
55. Owen, M., Galea, E.R. and Lawrence, P.J., "The Exodus Model Applied to Building Evacuation Scenarios", Journal of Fire Protection Engineering. 8(2) pp65-86, 1996.
56. Gwynne, S., Galea, E.R., Owen, M. and Filippidis, L., "A Systematic Comparison of Model Predictions produced by the buildingEXODUS Evacuation Model and the Tsukuba Pavilion Evacuation Data", Applied Fire Science, Vol. 7, No 3, pp235-266, 1998.
57. Gwynne, S., Galea, E.R., Lawrence, P.J. and Filippidis, L., Modelling Occupant Interaction with Fire Conditions Using the buildingEXODUS Model", Fire Safety Journal, 36, pp327-357, 2001
58. Galea, E.R., "A General Approach to Validating Evacuation models with an application to EXODUS", Journal of Fire Sciences, Vol 16, pp414-436 Sept/October, 1998.
59. Galea, E.R., "Safer by design: Using computer simulation to predict the evacuation performance of passenger ships", in Proc I Mar E Conf Vol112, 2, Safety of Large Passenger Ships, ISBN 1-902536-31-2, London, pp 23-32, 2000.
60. Galea, E.R., Gwynne, S., Blackshields, D., Lawrence, P. and Filippidis, "Predicting the Evacuation Performance of Passenger Ships using Computer Simulation", Interflam 2001, Proceedings 9th International Fire Science and Engineering Conference, pp853-864, ISBN 0 9532312 7 5.
61. Galea, E.R. and Galprarsoro, J.M.P. "EXODUS: An Evacuation Model for Mass Transport Vehicles", Technical Report, UK CAA Paper 93006, ISBN 086039 543X, 1993.
62. Owen, M., Galea, E.R., Lawrence, P.J. and Filippidis, L., "The Numerical Simulation of Aircraft Evacuation and its Application to Aircraft Design and Certification". The Aeronautical Journal of the Royal Aeronautical Society, June/July 1998, pp 301-312.
63. Galea, E.R., Owen, M. and Lawrence, P., "The Role of Evacuation Modelling in the Development of Safer Air Travel", AGARD-CP-857, proceedings of AGARD pep 88th Meeting on Aircraft Fire Safety, Dresden, 14-18 October 1996, 36-1-36-13,1997.
64. Galea, E.R., Owen, M. and Lawrence, P., "Computer Modelling of Human Behaviour in Aircraft Fire Accidents", Toxicology, 1996, 115, (1-3), pp63-78.
65. Galea, E.R., Blake, S.J. and Lawrence, P.J. "The airEXODUS Evacuation Model and its Application to Aircraft Safety" Presented at FAA/JAA conference in Atlantic City October 2001, to appear in conference proceedings and official FAA/JAA aviation report. Check this
66. Blake, S.J., Galea, E.R., Gwynne, S., Finney, K., Dixon, A., J., P., Lawrence, P.J. and Filippidis, L., "The Validation of airEXODUS Against 90-Seconds

Certification Trials of Four Wide and Two Narrow-bodied Aircraft", To be published as a formal Civil Aviation Authorty Technical Report.

67. Gwynne, S., Galea, E.R., Lawrence, P.J. and Filippidis, L., "Modelling Occupant Interaction with Fire Conditions using the buildingEXODUS Evacuation Model", Fire Safety Journal, 36, pp327-357, Elsevier, 2001.
68. Gwynne, S., "The Intorduction of Adaptive Social Decision-Making in the Mathematical Modelling of Egress Behaviour" PhD. Thesis, University of Greenwich, London, 2000.
69. Fraser-Mitchell, J.N., "An Object-Oriented Simulation (CRISPII) for Fire Risk Assessment. " Proc of the 4th Int Symp of Fire Safety Science, 793-804, 1994.
70. Fraser-Mitchell, J.N., "The Lessons Learnt During the Development of CRISPII, A Monte Carlo simulation for Fire Risk Assessment", Proc of the 7th Int Fire Science and Eng Conf, Interflam '96 , 631-639, 1996.
71. Shetsopal, V.O./Grubits, S.J., "Evacuation Model For Merging Traffic Flows In Multi-Room and Multi-Storey Buildings.", Proc of 4th Int Symp on Fire Safety Science, 625-632, 1994.
72. Predtechenskii, V.M. and Milinskii, " Planning for Foot Traffic Flow in Buildings", Published for the National Bureau of Standards, Amerind Publishing Co., 1978, translated from the Russian publication which appeared in 1969, STROIZDAT Publishers, Moscow, 1969.
73. Fruin, J.J., "Pedestrian Planning Design", Metropolitan Association of Urban Designers and Environmental Planners Inc., 1971, New York.
74. Stahl, F., "BFIRES-II: A behaviour based computer simulation of emergency egress during fires", Fire Technology, 18, 49-65, 1982.
75. Kady, R. K., Gwynne, S., Davis, J., "A Review of the sources of Occupant Performance Data used in Building Evacuation Models", Proc of 4th Int Symposium on Human Behaviour in Fire, Robinsons College, Cambridge, 13-15th July 2009.
76. Kuligowski, E. & Peacock, R.D., (2005). A Review of Building Evacuation Models (NIST Technical note 1471). Gaithersburg, MD: National Institute of Standards and Technology.
77. Gwynne, S., Galea, E.R., Owen, M., Lawrence, P. J., and Filippidis, L. "A Review of Methodologies used in Evacuation Modelling", Fire and Materials, Volume 23, pp 383-388, 1999.
78. Galea, E.R., "The Use of Computer simulation for Aircraft Evacuation Certification: A report from the VERRES Project", Proceedings of the International Aircraft Fire & Cabin Safety Conf, Nov 15-18, 2004, Lisbon Portugal. http://www.fire.tc.faa.gov/2004Conference/html/evac.htm
79. Galea, E.R., Blake, S., and Gwynne, S., A Survey of Aircraft Evacuation Models, Related Data and the Role of Evcuation Modelling in Aircraft Certification, VERRES/UOG/WP2/UOG_D2.2_1.0.doc, 02/07/02. Available at http://fseg.gre.ac.uk/fire/VERRES_Project.html.
80. Galea, E.R., and Owen M., 1996, "Initial EXODUS Model Predictions for Certification Evacuation Scenarios of the B767-304ER Aircraft", Confidential Report for the UK. CAA.
81. Galea, E. R., "a General Approach to Validating Evacuation Models with an Application to Exodus", Journal of Fire Sciences, Vol 16, pp414-436 Sept/Oct, 1998.
82. Galea, E.R., Finney, K.M., Dixon, A.J.P., Siddiqui, A. and Cooney, D.P., An analysis of human behaviour during aircraft evacuation situations using the

AASK V3.0 database. *The Aeronautical Journal Of The Royal Aeronautical Society*, Vol 107 No 1070April 2003, pp 219-231.

83. Galea, E.R., Finney, K.M., Dixon, A.J.P., Cooney, D.P., and Siddiqui.A. “An analysis of human behaviour during aircraft evacuation situations using the AASK V3.0 database.” Interim report by UofG on data AASK analysis for CAA project Project 560/SRG/R+AD, September 2002.
84. Galea, E.R., Finney, K., Dixon, A.J.P., Cooney, D. and Siddiqui, A. An Analysis of Human Behaviour during Aircraft Evacuation Situations using the AASK V3.0 Database. Report 02/IM/96, ISBN 1899991 97 2, published by CMS Press University of Greenwich UK, September 2002.
85. Snow C., Carroll J.J. and Allgood M.A., "Survival in emergency escape from passenger aircraft", Survival in emergency escape from passenger aircraft”, DOT/FAA/AM/70-16, *Department of Transport, Federal Aviation Administration*, 1970.
86. Galea, E.R., Finney, K.M., Dixon, A.J.P., Cooney, D.P., and Siddiqui.A. “The AASK Database” Final report by UofG on data AASK analysis for CAA project Project 560/SRG/R+AD, August 2003. ?
87. Marcus, J., H., “A Review of Computer Evacuation Models and Their Data Needs”, Final report by Civil Aeromedical Institute, FAA, Oklahoma City, DOT/FAA/AM-94/1, May 1994.
88. Gourary, B.S., “PC – Based Simulation of the Evacuation of Passengers from a Transport Airplane.” Proceedings of the Eleventh International Cabin Safety Symposium, Southern California Safety Institute, Los Angeles, California, 1994.
89. Gourary, B.S., Simulation of Evacuation from a Single Aisle Airplane: A Comprehensive Report, draft final report submitted to the FAA, October 1992.
90. Snow, C. S., Caroll J.J., Allgood, M. A., “Survival in Emergency Escape From Passenger Aircraft”, FAA- AM-70-16, U. S. Department of Transportation, Federal Aviation Administration, October 1970.
91. Schroeder, J.E., Grant, T., Tuttle, M. L., „Modelling Human Behaviour in aircraft Evacuations,“ in J.J. Swain and D. Goldsman (ed), Prodeedings of the 1992 Winter Simulation Conference, School of Industrial and Systems Engineering, Georgia Institute of Technology, 1992.
92. Schroeder, J.E., Tuttk, M. L., Development of an Aircraft Evacuation (AIREVAC) Computer Model, Phase 1: Front End Analysis and Data Collection, Final Report to the Air Transport Association of America, September 30, 1991, published by Southwest Research Institute, San Antonio, Texas, SwRI Project No. 12-4099.
93. Deere, S., Galea, E.R., Lawrence, P., Filippidis, L. and Gwynne, S., 2006, The impact of the passenger response time distribution on ship evacuation performance, International Journal of Maritime Engineering, Vol 148, Part A1, pp 35-44, ISSN 1479-8751.
94. Deere, S. J., Galea, E. R. Lawrence, P., 2008a, Optimising Vessel Layout using human factors simulation', Pedestrian and Evacuation Dynamics 2008, Heidelberg Germany, Berlin Germany, Springer-Verlag, pp. 597-603, ISBN 978-3-642-04503-5
95. Galea, E.R., and Gwynne, S., "Evacuating an Overturned Smoke Filled Rail Carriage", Proceedings of the 2nd International Symposium Human Behaviour in Fire, ISBN 0953231267, Boston, USA, 2001, pp 135-146.
96. E. R. Galea, “A Preliminary Investigation of the Evacuation of the WTC North Tower using Computer Simulation”, Proceedings of the 3rd International

Symposium on Human Behaviour in Fire,1-3 September, 2004, Europa Hotel, Belfast, UK, pp167-180

97. P Boxall, S.Gwynne, L. Filippidis, E.R.Galea, and D.Cooney. "Advanced Evacuation Simulation Software and its use in Warships", Proceedings of the Human Factors in Ship Design, Safety and Operation, London UK, Publisher The Royal Institute of Naval Architects, 23-24 Feb 2005, pp 49-56.
98. Galea, E.R., Togher, M., and Lawrence, P., "Investigating the Impact of Exit Availability on Egress Time using Computer Based Evacuation Simulation", 5th Triennial International Fire and Cabin Safety Research Conference, Atlantic City, 29th Oct- 1 Nov 2007, publishers US FAA, Full conference proceedings can be downloaded from FAA website: http://www.fire.tc.faa.gov/2007Conference/proceedings.asp
99. Galea, E.R., Filippidis, L., Wang, Z., Lawrence, P., and Ewer, J., "Fire and Evacuation Analysis of 1000+ Seat Blended Wing Body Aircraft Configurations: Computer Simulations and Large Scale Evacuation Experiment", 6th Triennial International Fire and Cabin Safety Research Conference, Atlantic City, 25th Oct-28th Oct 2010, publishers US FAA, Full conference proceedings can be downloaded from FAA website: http://www.fire.tc.faa.gov/2010Conference/proceedings.asp
100. Wang, Z., Jia, F., Togher, M., Galea, E.R. and Lawrence, P., "Post-Crash Cabin Fire and Evacuation as a Function of Cabin Ventilation: A Numerical Study using Fire and Evacuation Simulation", 6th Triennial International Fire and Cabin Safety Research Conference, Atlantic City, 25th Oct- 28th Oct 2010, publishers US FAA, Full conference proceedings can be downloaded from FAA website: http://www.fire.tc.faa.gov/2010Conference/proceedings.asp
101. Wang, Z., Galea, E.R., Jia, F., "A Computational Study of the Characteristics of Aircraft Post-Crash Fires", Proceedings of the International Aircraft Fire & Cabin Safety Conf. Oct 29 – Nov 1, 2007, Atlantic City, USA.
102. Galea, E.R., Wang, Z., Togher, M., Jia, F. and Lawrence, P., "Predicting the likely impact of aircraft post-crash fire on aircraft evacuation using fire and evacuation simulation", Proceedings of the International Aircraft Fire & Cabin Safety Conf. Oct 29 – Nov 1, 2007, Atlantic City, USA.
103. King, D., F., Report on the Accident to Boeing 737-236 series 1, G-BGJL at Manchester Airport on 22nd August 1985, Aircraft Accident Report 8/88, HMSO London 1988.
104. Galea, E.R., Blake, S., and Gwynne, S., A Methodology and Procedure for the Introduction of Aircraft Evacuation Simulation to the Aircraft Certification Process, VERRES/UOG/WP2/UOG_D2.2_1.1.doc, 20/09/03. Available at http://fseg.gre.ac.uk/fire/VERRES_Project.html.
105. "Detailed Test Report 737-300 Escape Systems Certification Demonstrations-Full Scale Evacuation", BOEING Proprietary Report of the Full Scale Evacuation Demonstration performed on December 19th 1984.
106. FAR Part 25. Appendix J Airworthiness Standards: Transport Category Airplanes. Including amendment 25-98 as published in the Federal Register on Feb 8th, 1999, Washington DC, USA.
107. CAAPS, "Surviving the crash: the need to improve lifesaving, measures at our nation's airports", *International Association of Fire fighters, 1999.*
108. Randy, T., Boeing Report, "Current Market Outlook 2013-2032*"*.
109. International Civil aviation Organisation, "*Airworthiness of Aircraft*" (Edition Eleven).

110. Gwynne, S., Galea E.R., Owen, M. and Lawrence, P., J. "*An Investigation of the Aspects of Occupant Behaviour Required for Evacuation Modelling*", Journal of Applied fire Science, Volume 8, Number. 1--1998-99.

111. Yu Liu, Weijie Wang, Hong-Zhoung Huang, Yanfeng Li, Yuanjian Yang, "*A New Simulation Model for Assessing Aircraft Emergency Evacuation Considering Passenger Physical Characteristics*", Reliability Engineering and System Safety, http://dx.doi.org/10.1016/j.ress.2013.09.001.

112. JAR, Section 1 JAR-25 Large Aeroplanes: Subpart D Design and Construction, as published in Joint Aviation Requirements (Amendment 20) 2007.

113. JAR, Section 1, JAR-21, Certification Procedures for Aircraft, Products and Related Parts, as published in Joint Aviation Requirements (Amendment 7) 2007.

114. Galea, E. R., et al. "Evacuation analysis of 1000+ seat blended wing body aircraft configurations: Computer simulations and full-scale evacuation experiment." *Pedestrian and Evacuation Dynamics*. Springer US, 2011. 151-161.

115. Title 14, Code of Federal Regulations (14 CFR), FAR patrt 25: Transport Category Aeroplanes as published in the Federal Register, 1st December 2001 Washington DC, USA.

116. Miyoshi, T., Nakayasu, H., Ueno, Y., et al., "*An emergency aircraft evacuation simulation considering passenger emotions*". Computers & Industrial Engineering, 2012, 62(3): 746-754.

117. Miyoshi, T., Nakayasu, Mori, M., Nakagawa, M., "*Analysis of Evacuation Behaviour in Aircraft Accidents using Evacuation Model based on MAS*". DOI: 10.1109/ICBAKE.2013.34 In proceeding of: Biometrics and Kansei Engineering (ICBAKE), 2013 International Conference.

118. Miyoshi, T.; Nakagawa, M.; Ueno, Y.; Nakayasu, H., "Urgent evacuation simulation in aircraft accident using AAMAS," *Computers and Industrial Engineering (CIE), 2010 40th International Conference*, pp.1,6, 25-28 July 2010 DOI: 10.1109/ICCIE.2010.5668251

119. Minesh P, Rakia KJ. Modeling of aircraft emergency evacuation: a multiagent approach, ICST, SIMUTOOLS2009.6112.

120. Sharma S, Singh H, Prakash. A. Multi-agent modelling and simulation of human behaviour in aircraft evacuations. IEEE Transactions on Aerospace and Electronic Systems 2008; 44(4):1477–88.

121. MacKenzie A, Miller JO, Hill RR, Chambal SP. Application of agent based modelling to aircraft maintenance manning and sortie generation. Simulation Modelling Practice and Theory 2012;20(1):89–98.

122. Hedo JM, Martinez-Val R. Assessment of narrow-body transport airplane evacuation by numerical simulation. Journal of Aircraft 2011;48(5):1785–94.

123. Johnson, N.R., Freiberg, W.E., and Johnson, D.M., "*Microstructure and Panic: The Impact of Social Bonds on Individual Action from Collective Flight from the Beverly Hills Supper Club Fire*", In Disaster, Collective Behaviour and social Organisation, Eds: R.Dynes and K. Tierney, Delaware Univ Press, pp168-189, 1994.

124. Wilson, R., Phd Thesis, 2008, "*Factors in influencing passemger evacuation from smaller transport aircraft including the operation of the Type III exit*", School of Engineering, Canfield University

125. Wilson, R.L., Caird-Daley, A.K. and Muir, H.C., "The Effect Of Operators' Briefing, Seating Configuration And Operating Handle Mechanism On Type III Exit Operation", Proceedings of the International Aircraft Fire & Cabin Safety Conf. Oct 29 – Nov 1, 2007, Atlantic City, USA.

126. Wilson, R.L., Muir, H.C., "*The Effect Of Type III Hatch Placement On Evacuation From Smaller Transport Aircraft***",** Proceedings of the International Aircraft Fire & Cabin Safety Conf. Oct 29 – Nov 1, 2007, Atlantic City, USA.
127. Richard, W., Bukowski, P.E., et al., "*Sensitivity Examination of the airExodus Aircraft Evacuation Simulation Model*", NIST Building and Fire Resarch Laboratory, Gathersburg, MD 20899. International Aircraft Fire and Cabin Safety Research Conference. Proceedings. November 16-20, 1998, Atlantic City, NJ, 1-14 pp, 1998.
128. Green G., Muir H., "Cranfield wide-bodied simulator", FAA/JAA conference presentation in Atlantic City, October 2001
129. Marcus, J. H., "A flight cabin simulator", DOT/FAA/AM/97-18, US Department of Transport, Federal aviation administration.
130. Blethrow, J. G., Garner, J. D., Lovey, D.L., Busby, D.E., Chandler, R.E., "Escape Emergency of Handicapped Air Travellers", DOT/FAA/AM/77-11, US Department of Transport, Federal Aviation Administration 1977.
131. Fennell, P.J., Muir, H., " The Influence of Hatch Weight and Seating Configuration on the Operation of Type-III Hatch", Civil Aviation Authority UK, CAA Paper 93015, 1993
132. Muir, H., "The Effect of Aircraft Evacuations of Changes to the Vertical Projections between seat rows Adjacent to the Over wing Exit from 3" to 6", 10" and 13", Cranfield University, CAA Report No. 9408, 1996.
133. Ramussen, P. G., Chesterfield, B. P., Lowrey, D.L., "Readability of self-illuminated signs in a smoke obscured environment", DOT/FAA/AM/79-22, US Department of Transport, Federal Aviation Administration, 1979.
134. Novák, V., Perfilieva, I. and Močkoř, J. (1999) *Mathematical principles of fuzzy logic* Dodrecht: Kluwer Academic. ISBN 0-7923-8595-0
135. 747-121 Full Scale Evacuation Demonstration FAA/JAA Certification*", BOEING Proprietary Report of the Full Scale Evacuation Demonstration performed on November 16th, 1969*
136. "Runway collision of USAir Flight 1493, Boeing 737 and Skywest Flight 5569 Fairchild Metroliner at Los Angeles International Airport", Los Angeles, California, February 1st, 1991. *NationalTransport Safety Board (NTSB), Washington, D.C., NTSB/AAR-91/08*
137. "Runway Departure following landing American Airline flight 102 McDonnell Douglas DC-10-30, N139AA Dallas/Fort Worth International Airport", Texas, April 14, 1993, *Nation Transport Safety Board (NTSB), Washington, D.C. NTSB/AAR-94/01*
138. CAA Report, "Report on the Testing and Systematic Evaluation of the airexodus Aircraft Evacuation Model", Safety Regulation Group, Civil Aviation Authority, 2004/05.
139. Robbins, CR & McKee, S 2001, 'Simulating the evacuation of a commercial airliner' *Aeronautical Journal*, vol 105, no. 1048, pp. 323-328.
140. Xue Z, Bloebaum CL. "Experimental design based aircraft egress analysis using VacateAir-an aircraft evacuation simulation model". In: Proceedings of the 12th AIAA/ISSMO multidisciplinary analysis and optimization conference, Victoria, Canada; 2008.
141. A. MacKenzie, J.O. Miller, R.R. Hill, S.P. Chambal, "Application of agent based modelling to aircraft maintenance manning and sortie generation", Simulation Modelling Practice and Theory, 20 (1) (2012), pp. 89–98

142. **Xue**, **Z**., **Bloebaum**, **C. L.,** (2009) **Human** Behavior Effects on Cabin Configuration Design Using VacateAir, 47th AIAA Aerospace Sciences Meeting and Exhibition.
143. Hedo JM, Martinez-Val R., “Computer Model for Numerical Simulation of Emergency Evacuation of Transport Aeroplanes,” The Aeronautical Journal, Vol 114, No. 1161, 2010, pp737-746.
144. Veeraswamy, A., (2011) “*Computational modelling of agent based path planning and the representation of human wayfinding behaviour within egress models.”* PhD thesis, University of Greenwich.
145. Passini, R., 1992, Wayfinding in Architecture Van Nostrand Reinhold: New York.
146. Arthur, P., Passini, P., 1992 Wayfinding: People, Signs and Architecture. McGraw-hill Ryerson: Canada
147. Galea, E., Wang, Z., Veeraswamy, Fuchen, Lawrence, P.J., Ewer, J., 2008, “Coupled Fire/Evacuation Analysis of the Station Nightclub Fire,” In the 9th International Symposium on Fire Safety Science.

APPENDIX A - *Questionnaire*

AIRCRAFT PASSENGER QUESTIONNAIRE

PARTICIPANT'S EXPERIENCE (***Please tick***)

1. Would you describe yourself as having any ailments or disabilities that would affect your movement capabilities (e.g. advanced age, leg injury, back injury, overweight, etc.)

☐ *Yes* ☐ *No*

If (Yes) please specify disability…………………………………………………………………..

2. How long has it been since your last flight?

☐ *Never flown*	☐ *Within the last 12 months*	☐ *1-2 years*
☐ *2-5 years*	☐ *More than 5 years*	☐ *Can't remember*

3. Was your last flight?

☐ *Short haul*	☐ *Long haul*	☐ *Don't Know*
(e.g. Within U.K. or Europe)	*(e.g. to USA, Australia, Asia)*	

4. In the past 3 years how many return flights have you made?

☐ *0 return trips*	☐ *1 return trip*	☐ *2-4 return trips*
☐ *5 or 6 return trips*	☐ *More than 6 return trips*	☐ *Can't remember*

5. Have you ever been involved in an aircraft evacuation?

☐ *Yes* ☐ *No (go to question 6)* ☐ *Can't remember (go to question 6)*

a) How long ago was this incident?

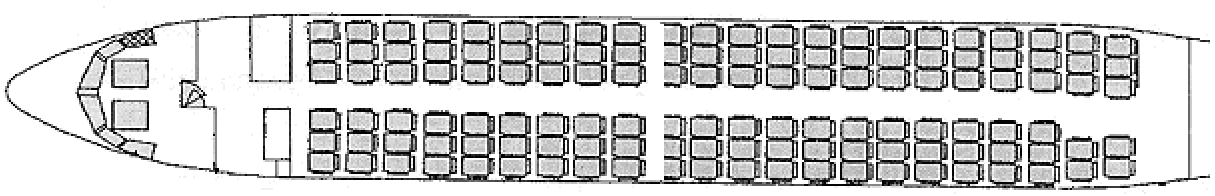
☐ *Within last 12 months*	☐ *1-2 years*
☐ *2-5 years*	☐ *More than 5 years*

b) What kind of flight was it?

☐ *Short haul* ☐ *Long haul* ☐ *Don't Know*

RESEARCH QUESTIONS

This is a typical short haul aircraft in which the exits are not shown. This aircraft would be typical of a B737 or A320 aircraft series.



6a. How many exits would you typically expect to find on this aircraft?

☐ *1* ☐ *2* ☐ *3* ☐ *4* ☐ *5* ☐ *6* ☐ *7* ☐ *8* ☐ *> than 8*

6b. Please mark the approximate exit location/locations on the diagram above using crosses.

7a. Are all the exits that you have indicated approximately the same size?

☐ *Yes (Go to Question 8.)* ☐ *No* ☐ *Don't Know (Go to Question 8.)*

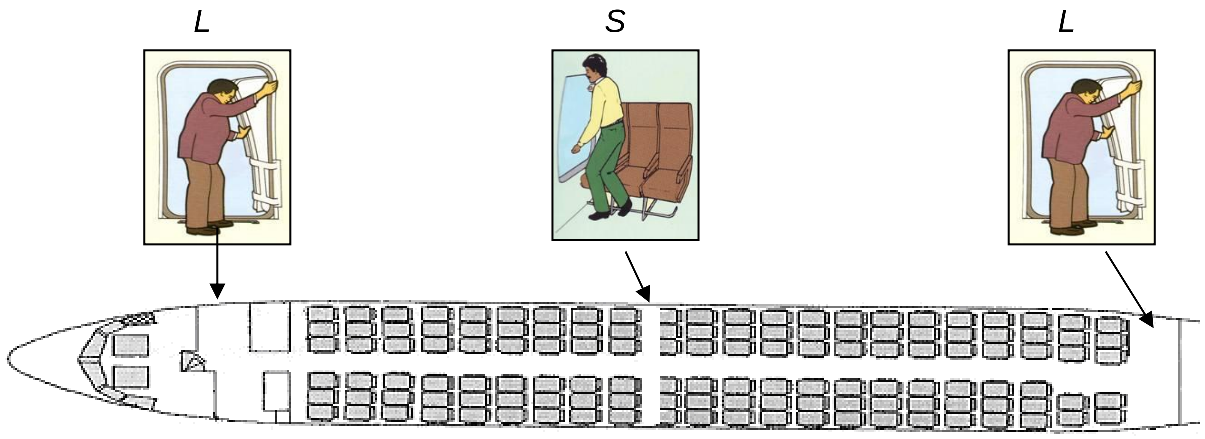
7b. Please indicate on above diagram which exits are Large and which are Small.

Use the letter (L) on the diagram to indicate location of large exits and (S) to indicate small exits.

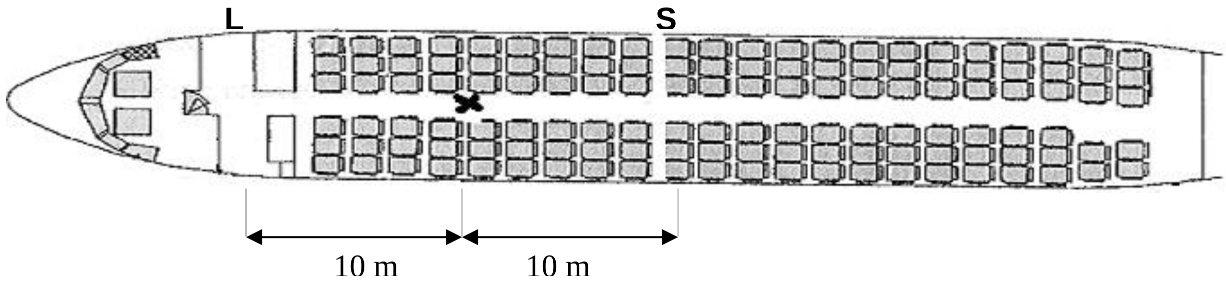
To answer the remaining questions you require the following information. This type of aircraft typically has two sizes of exit: the larger - type L – is located at the front and rear; the smaller – type S – located in the centre.

Type L

Type S



8a. In an emergency situation, which exit would you use if you were alone and standing in the aisle half way between exit L and S at the position marked with a cross, assuming there is a slide at each exit?



☐ *Exit **L***　　☐ *Exit **S***　　☐ *Don't Know*

8b. In the previous question, what influenced your decision? (*Tick all that apply*)

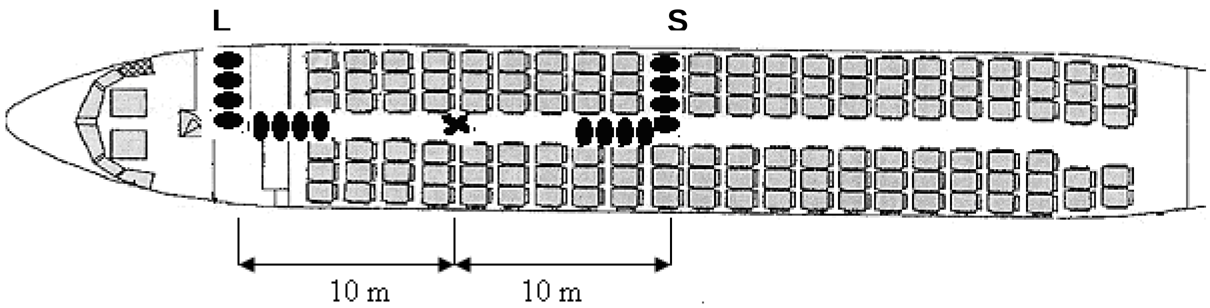
☐ *Size of exit*　　☐ *Distance to exit*　　☐ *No seats in front of exit*

☐ *N^{O} of seats in front of exit*　　☐ *Prefer front*　　☐ *Prefer middle*

☐ *Faster exit*　　☐ *Easier exit*　　☐ *don't know*

☐ *other*

9a. In an emergency situation, which exit would you use if you were standing in the aisle half way between exit L and S at the position marked with a cross, and there was a queue of 8 people at each of the exits? You can assume there is a slide at each exit.



☐ *Exit* ***L*** ☐ *Exit* ***S*** ☐ *Don't Know*

9b. ***In the previous question, what influenced your decision?*** *(Tick all that apply)*

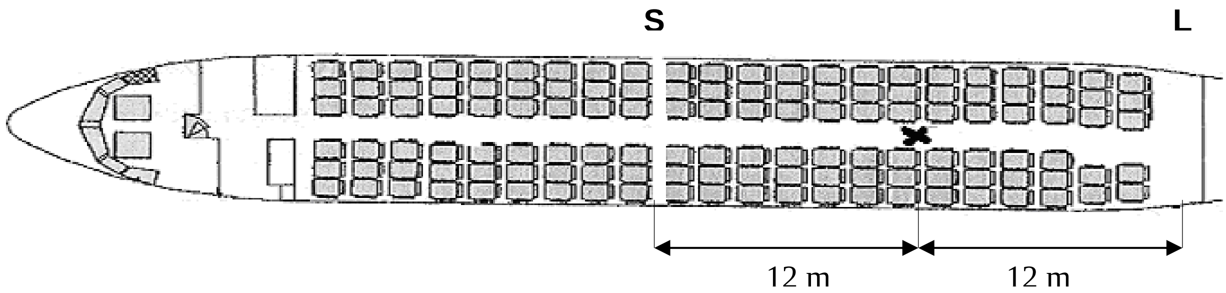
☐ *Queue speed* ☐ *Size of exit* ☐ *Distance to exit*

☐ *Length of queue* ☐ *Prefer front* ☐ *Prefer middle*

☐ *Faster exit* ☐ *Looked like it would be faster* ☐ *Easier exit*

☐ *Don't know* ☐ *Other*

10a. In an emergency situation, which exit would you now use if you were alone and standing in the aisle half way between exit L and S at the position marked with a cross, assuming there is a slide at each exit?



☐ *Exit* ***L*** ☐ *Exit* ***S*** ☐ *Don't Know*

10b. In the previous question, what influenced your decision? *(Tick all that apply)*

☐ *Size of exit* ☐ *Distance to exit* ☐ *No seats in front of exit*

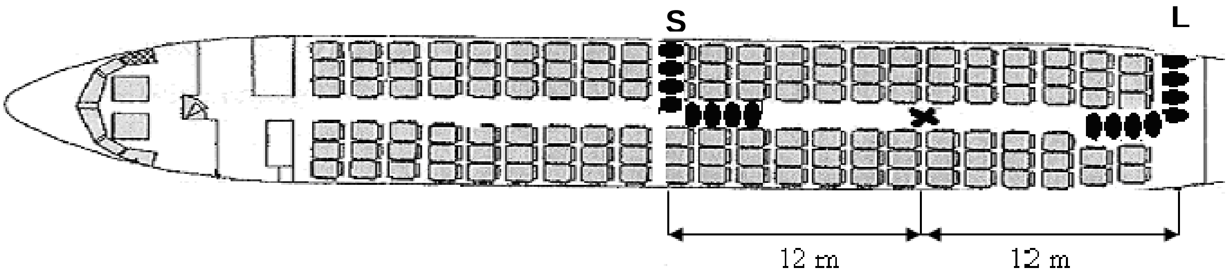
☐ *N^{O} of seats in front of exit* ☐ *Prefer back* ☐ *Prefer middle*

☐ *Faster exit* ☐ *Easier exit* ☐ *don't know*

☐ *other*

11a. In an emergency situation, which exit would you use if you were standing in the aisle half way between exit L and S at the position

marked with a cross, and there was a queue of 8 people at each of the exits? You can assume there is a slide at each exit.



☐ *Exit **L***　☐ *Exit **S***　☐ *Don't Know*

11b. In the previous question, what influenced your decision? *(Tick all that apply)*

☐ *Queue speed*　☐ *Size of exit*　☐ *Distance to exit*

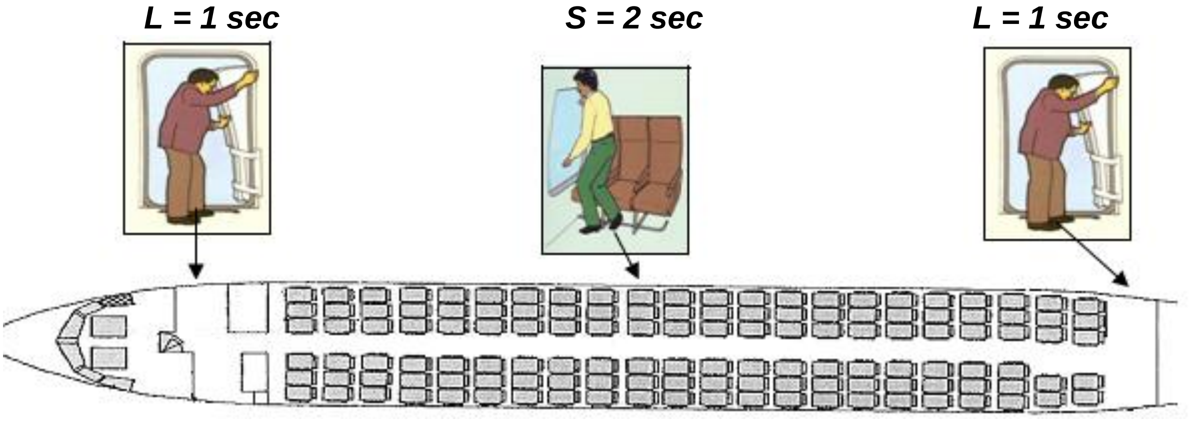
☐ *Length of queue*　☐ *Prefer back*　☐ *Prefer middle*
☐ *Faster exit*　☐ *Looked like it would be faster*　☐ *Easier exit*

☐ *Don't know*　☐ *Other*

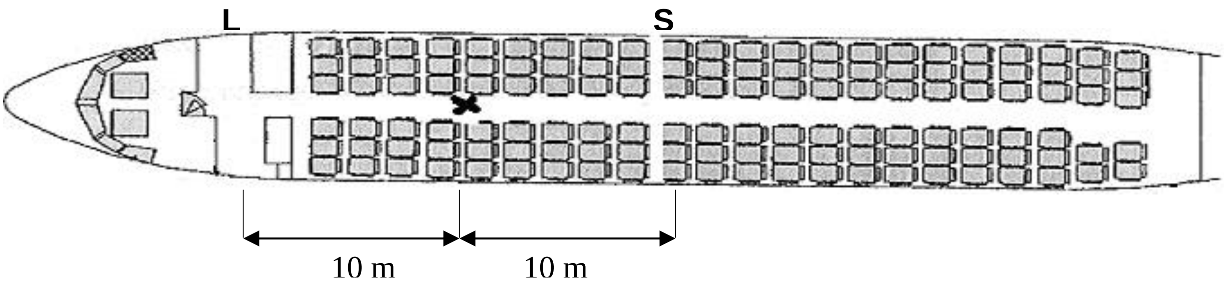
12. If it takes the average person about 1 second to pass through an **OPEN** ***type L exit, relative to this, approximately how long do you think it would take the average person to pass through an*** **OPEN** ***type S exit, assuming that they are standing in front of the exit and alone***. *(Tick an approximate estimate for exit S below)*

☐ *Much less*　*(less than half as long)*
☐ *A little less*　*(up to half as long)*
☐ *Approx. the same*
☐ *A little more*　*(up to twice as long)*
☐ *Much more*　*(more than twice as long)*

To answer the remaining questions you need the following information. The type S exit typically takes the average person approximately twice as long to pass through as a type L exit.



13a. In an emergency situation, which exit would you now use if you were alone and standing in the aisle half way between exit L and S at the position marked with a cross, assuming there is a slide at each exit?



☐ *Exit **L*** ☐ *Exit **S*** ☐ *Don't Know*

13b. In the previous question, what influenced your decision? (*Tick all that apply*)

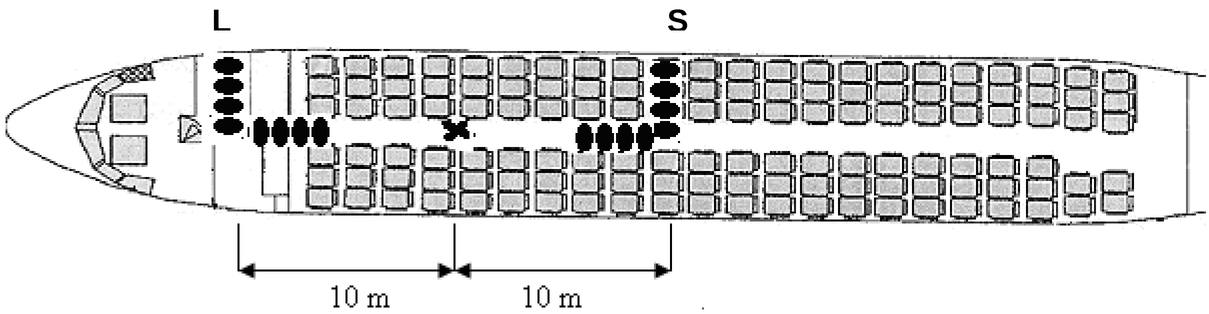
☐ *Size of exit* ☐ *Distance to exit* ☐ *No seats in front of exit*

☐ *N^{O} of seats in front of exit* ☐ *Prefer front* ☐ *Prefer middle*

☐ *Faster exit* ☐ *Easier exit* ☐ *don't know*

☐ *other*

14a. In an emergency situation, which exit would you now use if you were standing in the aisle half way between exit L and S at the position marked with a cross, and there was a queue of 8 people at each of the exits? You can assume there is a slide at each exit.



☐ *Exit **L*** ☐ *Exit **S*** ☐ *Don't Know*

14b. In the previous question, what influenced your decision? *(Tick all that apply)*

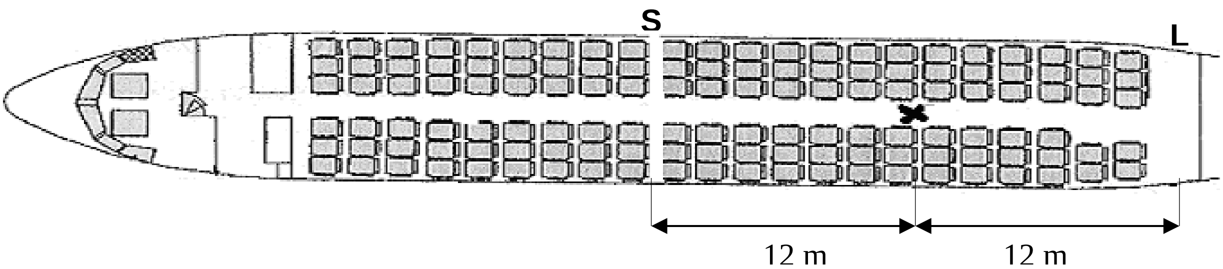
☐ *Queue speed* ☐ *Size of exit* ☐ *Distance to exit*

☐ *Length of queue* ☐ *Prefer front* ☐ *Prefer middle*

☐ *Faster exit* ☐ *Looked like it would be faster* ☐ *Easier exit*

☐ *Don't know* ☐ *Other*

15a. In an emergency situation, which exit would you now use if you were alone and standing in the aisle half way between exit L and S at the position marked with a cross, assuming there is a slide at each exit?



☐ *Exit **L*** ☐ *Exit **S*** ☐ *Don't Know*

15b. In the previous question, what influenced your decision? *(Tick all that apply)*

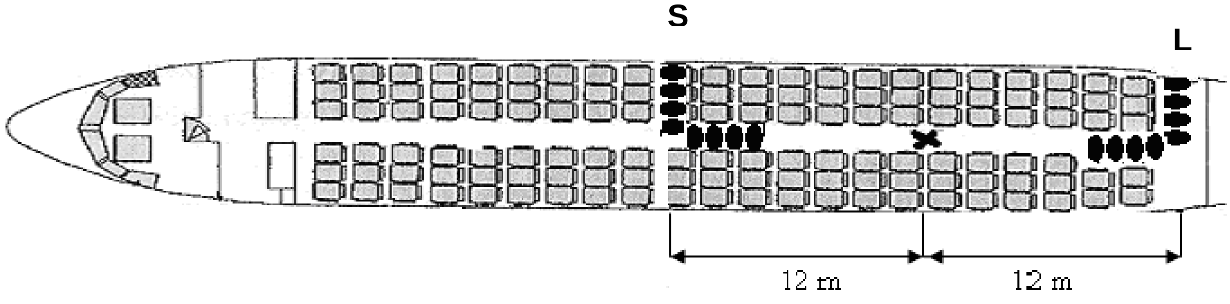
☐ *Size of exit* ☐ *Distance to exit* ☐ *No seats in front of exit*

☐ *N^{O} of seats in front of exit* ☐ *Prefer back* ☐ *Prefer middle*

☐ *Faster exit* ☐ *Easier exit* ☐ *don't know*

☐ *other*

16a. In an emergency situation, which exit would you now use if you were standing in the aisle half way between exit L and S at the position marked with a cross, and there was a queue of 8 people at each of the exits? You can assume there is slide at each exit.



☐ *Exit* ***L*** ☐ *Exit* ***S*** ☐ *Don't Know*

16b. In the previous question, what influenced your decision? *(Tick all that apply)*

☐ *Queue speed* ☐ *Size of exit* ☐ *Distance to exit*

☐ *Length of queue* ☐ *Prefer back* ☐ *Prefer middle*

☐ *Faster exit* ☐ *Looked like it would be faster* ☐ *Easier exit*

☐ *Don't know* ☐ *Other*

APPENDIX B – *Participant Information Sheet*

The University of Greenwich Public Understanding of Aircraft Evacuation Systems

Participant Information Sheet

Thank you for agreeing to participate in this study. This study is being conducted by the University of Greenwich and your participation in this study is helping to improve aviation safety.

Have you completed this questionnaire before?

THE QUESTIONNAIRE:

- As part of this study, you will be asked to fill out a questionnaire with the help of an assistant.
- While you are under no obligation to answer any of the questions we would appreciate if you could provide an answer to all of the questions.
- If you have any problems in completing the questionnaire please ask the research assistant and they will explain the question.
- There are no right or wrong answers.
- The entire process should take 10-15 minutes of you time.
- Once the questionnaire is complete you will be free to go.

THE MEASUREMENTS:

- After this questionnaire, your answers will be analysed and the data stored.
- We will keep the data for research purposes and some of the analysed data may be published and shown in public fora.
- Your name and any unique identifying personal details will not be associated with your questionnaire.
- The questions have been designed to collect information which will help us in our understanding of human behaviour during aircraft evacuation.

RIGHT TO WITHDRAW:

- The questionnaire in which you are about to participate, involves simple questions and answers and should present no difficulties to you.
- However, if at any time you wish to withdraw from the questionnaire, please inform the member of staff and you will be free to leave.

CONDIFENTIALITY:

- We request that you do not discuss the questionnaire with any of your fellow participants.

For further information about this survey please contact:

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APPENDIX C – *Participant Consent Form*

University of Greenwich Public Understanding of Aircraft Evacuation Systems

PARTICIPANT CONSENT FORM

Title of Research: Public understanding of aircraft evacuation systems.		
Investigator's name: Madeleine Togher		
To be completed by the participant/patient/volunteer/informant/interviewee/ parent/guardian (delete as necessary)		
1.	Has the researcher explained the study to you?	YES/NO
2.	Have you had an opportunity to ask questions and discuss this study?	YES/NO
3.	Have you received satisfactory answers to all your questions?	YES/NO
4.	Do you understand that you do not have to complete the questionnaire	YES/NO
5.	Do you agree to take part in this study?	YES/NO
Signed		Date
Name in block letters		
Signature of investigator		Date

This Project is Supervised by: Prof. Edwin Galea
Contact Details (including telephone number): **University of Greenwich, Fire Safety Engineering Group, Room QM355, Queen Mary Building, 30 Park Row, Greenwich, London, SE10 9LS** Telephone number : 0208 331 8730 (Direct Line) Email : E.R.Galea@gre.ac.uk

APPENDIX D – *Validation of 90s Certification Trials*

A Validation of 90 Second Certification Trials– using an analysis of exit availability, exit usage and passenger exit selection behaviour exhibited during actual aviation accidents.

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1 ABSTRACT

This paper will examine the influence that exit availability has upon the evacuation of narrow bodied aircraft during 90 second certification trials conducted by aircraft manufacturers. Many of these 90 second certification trials are conducted using one exit from each pair often along one side of the aircraft. The purpose of this analysis is to look at the effects of still using 50% of exits but using a different combination of available exits which may mirror reality more closely. The analysis will make use of the airExodus evacuation model and is based on a narrow bodied aircraft cabin (Boeing 737-300) containing two Type-C exits, two Type-B exits, two Type III exits and a maximum loading of 149 seated passengers. The decreasing order of likelihood of exit availability found during real emergency evacuations according to the Aircraft Accident Statistics and Knowledge database AASK V4.0, has been used as a basis for choosing the available zones during this analysis. The AASK database incorporates information from 105 survivable air crashes with over 2000 survivors.

2 INTRODUCTION

Fires in aircraft do not only affect one side of the fuselage as can be seen in the 1985 Manchester Air Disaster [1] where an engine caught fire in the aft of the aircraft making both aft exits and one over wing exit totally unavailable. During the 90 s certification trials however, a large majority of the serviceable exits are on one side of the aircraft. Why, are half of the exits required and why are they all to be situated on one side using only one exit from each pair? Is this scenario used because it is the most challenging, the most difficult or the most common? According to data held in the Aircraft Accident Statistics and Knowledge (AASK) database [6,7], this is quite an unlikely scenario.

The decreasing order of likelihood of exit availability [3] has been derived from data held in the AASK V4.0 database. This database is a repository of accounts given from the survivors of aviation accidents which were investigated by organisations such as the U.S. National Transportation Safety Board (NTSB) and the U.K. Air Accident Investigation Branch (AAIB) [6,7]. This decreasing order of likelihood has been used as a base for choosing available zones during this analysis, but cannot be considered conclusive as it was based upon only a small number of aviation accidents.

This paper will initially look at the evacuation of a typical 90 second certification trial scenario and then make comparisons to evacuations under the same certification requirements but using different available exits zones according to the decreasing order of likelihood. This analysis and validation aims to prove the impact that different available exit locations on board a narrow bodied aircraft will have on the over all evacuation time.

3 THE AASK DATABASE

3.1 The Database

The AASK database is a repository of survivor accounts from aviation accidents conducted by investigative organisations such as the U.S. NTSB and the U.K. AAIB. Its main purpose is to store observational and anecdotal data from the actual interviews of the occupants involved in aircraft accidents. The quality and quantity of this data is variable ranging from short summary reports of the accident to transcripts from most of the surviving passengers and crew involved in the accident. The database has wide application to aviation safety analysis, being a source of factual data regarding the evacuation process.

With support from the UK Engineering and Physical Sciences Research Council (EPSRC) and the UK Civil Aviation Authority (CAA) research on the development of a relational database containing passenger and crew experience of aircraft evacuation commenced in 1997 and lead to the development of the prototype database AASK V1.0. Today, the most recent version of the database, AASK V4.0 contains accounts from over 2000 survivors of aviation accidents. The database consists of four main components which address; the nature of the accident, accounts from surviving passengers, accounts from surviving cabin crew and information relating to fatalities [6]. Access to the database is available on-line at http://fseg.gre.ac.uk/aask/index.html. The database has a powerful query engine allowing investigators to mine the data.

3.2 The Data

AASK V4.0 [6,7] has been expanded to include 50 additional accidents/incidents, additional accounts from 622 surviving passengers and 45 surviving crew and data relating to 11 fatalities. In addition, the structure of the database and its user interface has been improved with a number of new and enhanced features. Unlike previous versions of the database, data within AASK V4.0 has been re-categorised according to the nature of the evacuation incident. Three types of evacuation are considered; Emergency Evacuation (which is further categorised into planned and unplanned), Precautionary Evacuation and Post-Incident Deplaning [6,7]. The latest version of the database contains information from 105 accidents and detailed data from 1917 passengers and 155 cabin crew with information relating to some 338 fatalities. The accidents included in AASK V4.0 cover the period 04/04/77 – 23/09/99.

4 airEXODUS V4.1 OVERVIEW

EXODUS is a suite of software tools designed to simulate the evacuation of large numbers of people from a variety of complex enclosures. Development of the EXODUS concept began in 1989. Today, the family of models consists of buildingEXODUS, maritimeEXODUS and airEXODUS for the built, maritime and aviation environments respectively.

airEXODUS is designed for applications in the aviation industry including, aircraft design, compliance with 90-second certification requirements, crew training, development of crew procedures, resolution of operational issues and accident investigation. The airEXODUS model and its validation has been described previously [2,4] and so only a brief overview is presented here.

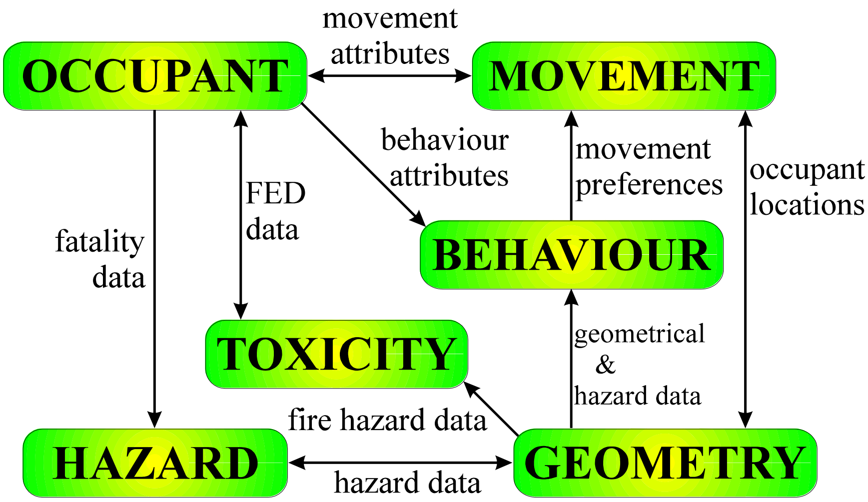


Figure 1: EXODUS Submodel interaction

The EXODUS software takes into consideration people-people, people-fire and people-structure interactions. It comprises five core interacting sub-models: the **Passenger, Movement, Behaviour, Toxicity and Hazard** sub-models (see **Figure**). The software describing these sub-models is rule-based, the progressive motion and behaviour of each individual being determined by a set of heuristics or rules. These submodels operate on a region of space defined by the **GEOMETRY** of the enclosure. Each of these components will be briefly described in turn.

4.1 THE GEOMETRY REPRESENTATION

The ***GEOMETRY*** of the enclosure can be defined manually or read from a Computer Aided Design using the DXF format. Internally the entire space of the geometry is covered in a mesh of nodes that are typically spaced at 0.5m intervals. The nodes are then linked by a system of arcs. Each node represents a region of space typically occupied by a single passenger.

4.2 THE MOVEMENT SUBMODEL

The ***MOVEMENT SUBMODEL*** controls the physical movement of individual passengers from their current position to the most suitable neighbouring location, or supervises the waiting period if one does not exist. The movement may involve such behaviour as overtaking, side stepping, or other evasive actions.

4.3 THE PASSENGER SUBMODEL

The ***PASSENGER SUBMODEL*** describes an individual as a collection of defining attributes and variables such as name, gender, age, maximum unhindered fast walking speed, maximum unhindered walking speed, response time, agility, etc. Each passenger can be defined as a unique individual with their own set of defining parameters. Cabin crewmembers require additional attributes such as, range of effectiveness of vocal commands, assertiveness at using voice commands, assertiveness when physically handling passengers and their visual access within certain regions of the cabin. Some of the attributes are fixed throughout the simulation while others are dynamic, changing as a result of inputs from the other submodels. Passengers with disabilities may be represented by limiting these attributes.

4.4 THE HAZARD SUBMODEL

The ***HAZARD SUBMODEL*** controls the atmospheric and physical environment. It distributes pre-determined fire hazards such as heat, radiation, smoke and toxic fire gases throughout the atmosphere and controls the opening and closing times of exits.

4.5 THE TOXICITY SUBMODEL

The ***TOXICITY SUBMODEL*** determines the effects on an individual exposed to toxic products distributed by the hazard submodel. These effects are communicated to the behaviour submodel which, in turn, feeds through to the movement of the individual.

4.6 THE BEHAVIOUR SUBMODEL

The ***BEHAVIOUR SUBMODEL*** determines an individual's response to the current prevailing situation on the basis of his or her personal attributes, and passes its decision on to the movement submodel. The behaviour submodel functions on two levels, global and local. The local behaviour determines an individual’s response to the local situation e.g. jump over seats; wait in queue, etc while the global behaviour represents the overall strategy employed by the individual. This may include such behaviour as, exit via the nearest serviceable exit, exit via most familiar exit or exit via their allocated exit. In the most recent version of the software, cabin crewmembers can be identified and their behaviour specified to represent crew procedures. In this version, cabin crewmembers may perform specified duties during an evacuation such as opening exits, halting passenger flow, redirecting passengers to specific exits, continuous cabin flow monitoring with appropriate redirection, final cabin sweeps, etc.

4.6.1 PASSENGER BEHAVIOUR

For certification applications the non-extreme behavioural regime is used and this includes the type of behaviour typically observed in certification type evacuation conditions including:

(i) Assertive cabin crew located at each floor level exit and fully compliant passengers,
(ii) Orderly passenger behaviour,
(iii) No seat jumping or unessential aisle swapping.

airEXODUS also has the ability to represent “extreme” passenger behaviour of the type reported in actual aviation accidents [6,7], such as seat jumping.

4.6.2 CABIN CREW BEHAVIOUR

Previous research suggests that there is a relationship between the assertiveness of cabin crew members at exits and the achieved exit flow rates. To reflect this passenger Exit Delay Time distributions have been determined to represent the varied levels of cabin crewmember assertiveness and their impact upon the flow rates through exits [4,5].

airEXODUS can also represent a range of crew interaction behaviours through a feature known as Active Cabin Crew Management (ACCM). If ACCM features are not activated, crew initiated actions are achieved implicitly through the setting of model parameters. However, using the ACCM system, the procedures are explicitly modelled. Thus the cabin crewmember is modelled as are their actions and the passengers' response to those actions. Cabin management procedures are usually employed by cabin crew during certification trials and during real emergency evacuation situations. These procedures may involve crew instigated exit by-pass or other passenger re-direction strategies. In applying these techniques the crew are attempting to either achieve a more efficient use of exits thereby reducing the overall evacuation time, or direct passengers away from a potentially dangerous cabin section. When attempting to reduce the overall evacuation time, crew are assessing the situation in their cabin zone and deciding when to redirect passengers onto another cabin zone or nearby exit.

In reality, the decisions made by the crew will be based on the information that they have on conditions around their exit and what they may know about other exits. The knowledge that the crew has of cabin conditions can be restricted due to line of sight, congestion, visibility in smoke, noise, etc. Alternatively, it may be enhanced by technical means such as conventional communication systems or novel new devices such as crew head-set communication systems, door visual display systems, etc. A feature of the ACCM procedures within airEXODUS is that the decision making capability of the crew can be restricted according to the prevailing conditions and the equipment at their disposal. The crewmember can also be given a radius of effectiveness. This dictates the region over which the commands made by the crewmember will be effective.

During certification evacuations, passengers are more compliant and are thus more likely to follow a crew command to redirect to another exit while in real situations this may be somewhat more difficult to achieve as passengers are more likely to be concerned with their own self interest. Both these situations can be represented within airEXODUS using the ACCM procedures. The first mode of operation is akin to 90-second certification trials in which passengers are generally compliant to all crew commands. The second mode attempts to model real emergency evacuations in which passengers are less compliant. In airEXODUS, when modelling certification evacuations, passengers are made to be compliant and thus follow all instructions issued by cabin crew.

In summary, within airEXODUS it is possible to represent crew actions in three ways:

a) Fully implicitly thereby assuming that the crew will be able to perform the required tasks.

b) Fully explicitly utilising the ACCM features thereby modelling the crew undertaking their assigned tasks.
c) Partially using the ACCM features to explicitly model some of the crew functions while implicitly modelling the other tasks.

4.7 airEXODUS LEVEL OPTIONS:

Version 4.1 of the airEXODUS software is available in two distinct capability levels. These are,

Level 1: This version can handle unlimited aircraft and population sizes. Limitations are dictated only by computer resources. This version does not include a toxicity submodel and so does not include the effects of smoke, heat and toxic gases.

Level 2: As level 1 but includes the capability of including the fire hazards of heat, toxic gases and smoke within a simulation.

4.8 CERTIFICATION DATA USED IN airEXODUS

airEXODUS makes use of 90-second certification data to specify certain key parameters. In particular, data concerning the ***EXIT READY TIME, PASSENGER EXIT DELAY TIMES and OFF-TIME***, and parameters for all the exits must be specified. These are described briefly as follows:

4.8.1 EXIT READY TIME

Exits are opened by cabin crew or passengers. Within airEXODUS it is possible to specify the time require to open the exit. In addition, the exit ready time can include the time required for the slide to deploy. In effect the exit ready time specifies the time from the start of the simulation to when the exit is ready to allow passengers to pass through the exit. Exit ready times for aircraft involved in past certification trials have been analysed as part of the data extraction exercise reported in [4,5].

4.8.2 PASSENGER EXIT DELAY TIME

One the most important parameters in airEXODUS is the pax exit delay time. This time represents two stages of the exiting process, the exit hesitation time and the exit negotiation time. In virtually all cases, the paxs exhibit a hesitation at the exit, before negotiating it. Typically, this starts when an out-stretched hand first touches the exit. The latter time considers the amount of time taken to pass through the exit. The precise points at which hesitation begins and ends is based on a somewhat subjective decision and sometimes impossible to judge due to crowding, camera angle, light intensity etc.

In general, the hesitation time is due in main to paxs either waiting at the exit for the path to clear and/or contemplating how to negotiate the exit. In either case, the negotiation stage does not usually start until there is space for it to commence. Furthermore, the process of passing through the exit and travelling from the exit to the ground are considered as separate events (controlled by exit delay time and Off-Time respectively within airEXODUS) which can occur in parallel.

Within airEXODUS, each passenger is randomly assigned a delay time as they pass through the exit. The delay time is assigned using a probability distribution derived from past certification trials [4,5]. The delay time is dependent upon a number of factors. The following list represents the most prevalent of these factors:

- **exit type** - the exit type (thus size) causes different kinds of exiting technique for each exit type, for example passengers tend to crouch and climb out of Type-III exits, and jump out of Type-A exits.

- **exiting behaviour** - different behaviour traits may be exhibited by different passengers, even on the same exit type. For example, some passengers jump through Type-A exits, whereas others sit on the sill and push off.

- **passenger physical attributes** - The gender, age and physical size of the passengers has also been found to have an impact on the hesitation time. However, there is currently insufficient data available to perform a meaningful analysis on all exit types.

- **presence of cabin attendants** - the presence (or absence) of cabin attendants at exits can enormously influence the behaviour exhibited by passengers at exits. Undirected passengers tend to take more time deciding how to use the exit, and indeed, which exit to use.

- **behaviour of cabin attendants** - when cabin attendants are present at an exit, the degree of assertiveness they display also influences the hesitation times. As the level of assertiveness increases, the range of slower hesitation times decreases, thus increasing the overall flow throughput of the exit.

The technique is dependent on the user having a good representation of the actual delay time distribution. In the current release of the software this data is extracted from past certification trials.

4.8.3 OFF TIME

In airEXODUS, when a passenger has reached an exit, a further time penalty is added to reflect the time spent either travelling down a slide or across a wing. The time penalty added is randomly assigned between user specified limits, similar to the passenger exit hesitation time. In reality, this time will depend upon a number of factors, such as slide sill height and slide travel technique. When added to the exit time of a passenger, this produces the *on-ground* time. Off Times for aircraft involved in past certification trials have been analysed as part of the data extraction exercise reported in [5].

As stated previously, evacuation times quoted in this report include out of aircraft time (excluding the Off-Time) and the on-ground time. In addition, times are quoted for paxs only and for paxs and crew.

4.8.4 MEASURING LEVEL OF AIRCRAFT/CREW PERFORMANCE

The measure of success/failure of an aircraft/crew in the FAR part 25.803 type certification demonstration is simply whether or not the paxs can be evacuated within the specified 90-seconds. However, this pass/fail criterion does not indicate how efficient the aircraft/crew is in achieving the outcome. If a comparison is made of two evacuation trials simply on the basis of the evacuation time it would be possible to find superficial agreement between the trials while the details of the evacuation could be quite different. It is thus desirable to define other measures of performance rather than simply rely on total evacuation time. To assist in the determination of optimal performance, FSEG have developed two measures that can be applied to actual evacuation observations and model simulations. These measures are known as OPS and MNS.

4.8.5 OPS: A MEASURE OF OPTIMAL PERFORMANCE

In aircraft which have more than one exit available for evacuation, the total evacuation time will typically be reduced if the flow through each exit terminates at the same time. Failure to achieve the simultaneous termination of exit flows is usually a result of poor distribution of paxs between exits, which in turn results in an unnecessarily prolonged evacuation time. Note that there is no mention of the number of paxs using each exit is made, simply that the flow through each exit terminates simultaneously.

Thus in optimal evacuation situations exit flows will be completed at approximately the same time. Sub-optimal cases occur when one or more exits exhaust their supply of paxs before the remaining exits. As a measure of optimal performance FSEG have developed a statistic known as the OPS or Optimal Performance Statistic. The OPS can be calculated for each evacuation, providing a measure of the degree of performance.

5 EXIT AVAILABILITY

An exit is considered ‘available’ when the exit and its evacuation assisted means are fully/safely functional and passengers are permitted to use it by crew []. From the statistics previously carried out on AASK V4.0 it is appears that 67 % of accidents investigated involve exit availability of 50% or more. Therefore as the most frequently occurring exit availability to occur during emergency evacuations involves more than 50% of the exits, there would appear to be quite a strong argument for disabling half of the exits and possibly even one exit from each pair. The pool of data however in the AASK V4.0 database is not conclusive.

What are the most commonly available exits during an emergency and what kind of impact would these make on the overall evacuation? During the actual certification trial for the narrow bodied B737-300 aircraft, the available exits can be seen in Table. The most likely combination of available exits for narrow bodied aircraft in ascending order according to data in the AASK V4.0 database is displayed in Table .

Table1:Exits available during a certification trial scenario for narrow bodied aircraft

Scenario	Right Exits			Left Exits		
	R1 Type C (Forward right)	**R2 Type III (Right Over Wing)**	**R3 Type C (Aft Right)**	**L1 Type B (Forward Left)**	**L2 Type III (Left Over Wing)**	**L3 Type B (Aft Left)**
Certification	Y	Y	Y	N	N	N

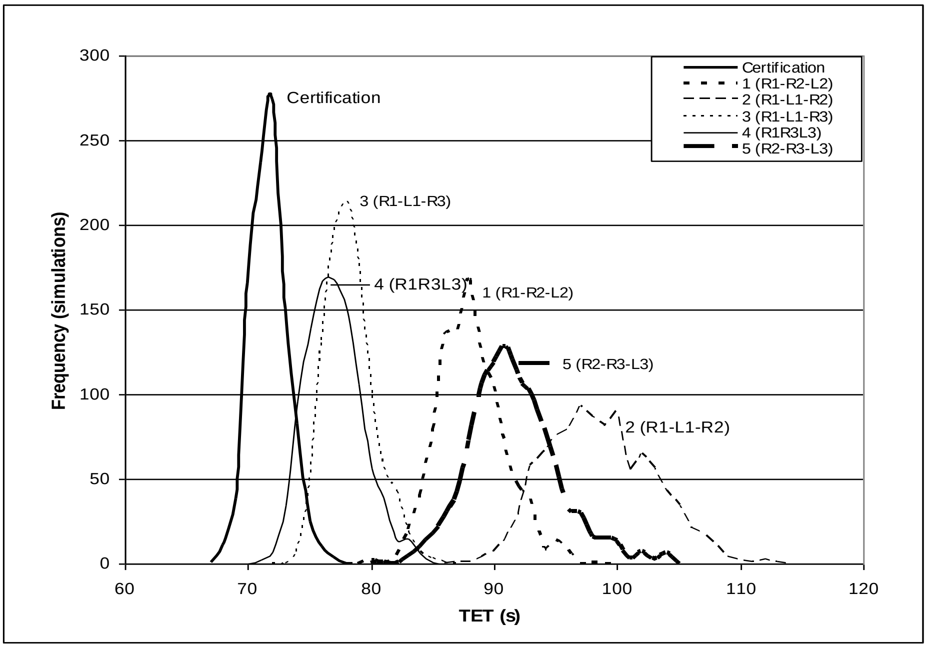
Table 2 : Most Likely scenarios of exit availability in ascending order according to AASK Database with indication of usable and unusable exits

Scenario	Right Exits			Left Exits		
	R1 Type C (Forward right)	**R2 Type III (Right Over Wing)**	**R3 Type C (Aft Right)**	**L1 Type B (Forward Left)**	**L2 Type III (Left Over Wing)**	**L3 Type B (Aft Left)**
1	Y	Y	N	N	Y	N
2	Y	Y	N	Y	N	N
3	Y	N	Y	Y	N	N
4	Y	N	Y	N	N	Y
5	N	Y	Y	N	N	Y

6 RESULTS

Systematic testing and validation, of the five most likely scenarios plus the certification scenario displayed in Table & Table , were carried out using the airExodus software. One thousand random and repeat simulations were carried out for each scenario. Ten different populations were created and used for all of the scenarios. Only optimal results were used during this analysis, with suboptimal results being discarded and later rerun.

From the optimal results obtained, it appears that the narrow bodied B737-300 aircraft under normal certification standards with exits on one side produces the most optimal evacuation time (on-ground time) from all other scenarios described. The optimal simulation results for the certification trial scenario produced on ground times below the 90 second threshold (see Table and Figure 2).



Figure

The on-ground times for the certification scenario vary from 67.0 s to 76.8 s with a mean of 71.2 s and a 95th Percentile of 73.8 s. When the exits are all located on one side of the aircraft (R1, R2 & R3); the passengers will travel an average distance of 6.5 m. On average a passenger will take 39.6 seconds to evacuate from the aircraft and will normally spend an average of 24.7 s waiting in queues. During this scenario, the passengers wasted approximately 62% of their PET in congestion. The simulation results of the certification scenario using the airExodus software are very similar to those produced during the actual certification trial using members of the public.

Table 3:Results for Certification Trial with exits located on one side only

Scenario		**Out of aircraft time (s)**	**On- ground time (s)**	**Av. PET (s)**	**Av. CWT (s)**	**Av. DIST (m)**
Certification (R1-R2-R3)	**Min**	65.5	67.0	37.8	23.1	6.4
	Mean	**69.3**	**71.2**	**39.6**	**24.7**	**6.5**
	Max	74.8	76.8	41.7	26.8	6.7
	95th%ile	71.7	73.8	40.8	6.6	25.8

Table displays the results for the most likely scenarios in ascending order of exit availability. Scenario 1 which had one exit located forward right (R1) and two over wing exits (R2 & L2) had on-ground times which varied between 79.5 s and 99.6 s with a mean of 87.7 s and a 95th percentile time of 92.4 s. This would represent an increase of 23% over the mean on ground time whilst comparing this scenario to the certification scenario. Passengers were required to travel an average of 8.5 m during Scenario 1 which was an increase of 2 m from the certification scenario. The average PET for a passenger was 46.6 s, while the average CWT is 29.3 s. Therefore approximately 63% of the PET is in fact wasted in congestion which also represents a 1% increase when compared to the certification scenario.

Scenario 2, which had two exits located forward right (R1) and left (L1) and, one right over wing exit (R2), had on-ground times which varied between 86.7 s and 112.3 s with a mean of 98.1 s and a 95th percentile time of 105.4 s. This would represent an increase of 38% over the mean on ground time whilst comparing this scenario to the certification scenario. Passengers were required to travel an average of 10.2 m during Scenario 2 which was an increase of 3.7 m from the certification scenario. The average PET for a passenger was 49.8 s, while the average CWT is 31.0 s. Therefore approximately 62% of the PET is in fact wasted in congestion which is the same when compared to the certification scenario.

Scenario 3, which had two exits located forward left and right, and one aft right exit, had on-ground times which varied between 73.5 s and 85.3 s with a mean of 77.7 s and a 95th percentile time of 81.4 s. This would represent an increase of 9 % over the mean on ground time whilst comparing this scenario to the certification scenario. Passengers were required to travel an average of 8.3 m during Scenario 3 which was an increase of 1.8 m from the certification scenario. The average PET for a passenger was 41.9 s, while the average CWT is 25.5 s. Therefore approximately 61 % of the PET is wasted in congestion which represents a reduction by 1 % when compared to the certification scenario.

Table 4: Optimal results for the most likely scenarios in ascending order of exit availability, according to AASK Database

Scenario		Out of aircraft time (s)	On ground time (s)	Av. PET (s)	Av. CWT (s)	Av. DIST (m)
1 (R1-R2-L2)	Min	77.5	79.5	43.6	27.1	7.7
	Mean	**85.7**	**87.7**	**46.6**	**29.3**	**8.5**
	Max	97.4	99.6	50.3	32.6	8.8
	95$^{th\%ile}$	90.5	92.4	48.4	30.9	8.7
2 (R1-L1-R2)	Min	84.8	86.7	46.5	27.5	9.7
	Mean	**96.1**	**98.1**	**49.8**	**31.0**	**10.2**
	Max	110.9	112.3	54.8	35.9	10.6
	95$^{th\%ile}$	103.4	105.4	52.3	33.4	10.4
3 (R1-L1-R3)	Min	71.4	73.5	39.3	23.1	8.3
	Mean	**75.8**	**77.7**	**41.9**	**25.5**	**8.3**
	Max	83.0	85.3	45.9	29.4	8.4
	95$^{th\%ile}$	79.3	81.4	43.7	27.3	8.3
4 (R1-R3-L3)	Min	68.7	70.8	39.0	22.3	8.5
	Mean	**74.5**	**76.5**	**41.7**	**25.1**	**8.5**
	Max	82.5	84.5	45.2	28.8	8.6
	95$^{th\%ile}$	78.6	80.5	43.6	26.9	8.5
5 (R2-R3-L3)	Min	78.8	80.7	44.2	25.8	8.6
	Mean	**89.2**	**91.1**	**48.3**	**29.9**	**9.9**
	Max	102.2	103.7	55.3	37.1	10.5
	95$^{th\%ile}$	95.8	97.8	50.8	32.4	10.3

Scenario 4, which had one exit located forward right and two aft, left and right exits, had on-ground times which varied between 70.8 s and 84.5 s with a mean of 76.5 s and a 95th percentile time of 80.5 s. This would represent an increase of 7 % over the mean on ground time whilst comparing this scenario to the certification scenario. Passengers were required to travel an average of 8.5 m during Scenario 4 which was an increase of 2.0 m from the certification scenario. The average PET for a passenger was 41.7 s, while the average CWT is 25.1 s. Therefore approximately 60 % of the PET is wasted in congestion which represents a reduction by 2 % when compared to the certification scenario.

Scenario 5, which had one exit located forward right and two aft, left and right exits, had on-ground times which varied between 80.7 s and 103.7.5 s with a mean of 91.1 s and a 95th percentile time of 97.8 s. This would represent an increase of 22 % over the mean on ground time whilst comparing this scenario to the certification scenario. Passengers were required to travel an average of 9.9 m during Scenario 5 which was an increase of 3.4 m from the certification scenario. The average PET for a passenger was 48.3 s, while the average CWT is 29.9 s. Therefore approximately 62 % of the PET is wasted in congestion which is the same when compared to the certification scenario.

The optimal results in **Error! Reference source not found.** represent the most likely scenarios of exit availability in ranked order of average on-ground time. It should be noted that the certification scenario which is not ranked on this list would in fact be listed first if included. During the first three of the ranked scenarios (4, 3 and 1) the average distance travelled by the passengers varies only slightly between 8.3 to 8.5 m. The first two ranked scenarios (4, 3) are almost mirror images of one another so it was expected that the average on ground-times would be very similar.

During Scenario 1 which is ranked third, the passengers travel a similar distance as passengers in Scenarios 4 and 3 which are ranked 1 and 2 respectively; however the on-ground time is significantly higher. Although passengers travel a similar distance during Scenario 1, the exits available to the passengers do not allow such good flow rates as the exits available in the higher ranked scenarios 4 and 3 (see Table). Scenario 1 only allows passengers to travel in a forward direction while escaping to available exits whereas the higher ranked Scenarios 4 and 3, allows passengers to escape in two directions (forward and aft). When passengers are able to travel in two directions, this seems to assist in the overall evacuation time. Scenarios 5 and 2 are ranked 4 and 5 respectively and are almost mirror images of one another. The slight difference between these scenarios is due to the fact that the available over wing exit is not located directly in the middle of the fuselage. In Scenarios 5 and 2, the passengers can only travel in an aft direction to available exits unlike Scenarios 4 and 3. During Scenario 5 the average distance travelled by the passengers is 9.9 m whereas in Scenario 2, the passengers must travel on average a greater distance of 10.2 m which is an increase of approximately 3 %. Although the exits which are available to the passengers in Scenario 5 and 2 allow similar flow rates (Table), the slight difference in the distance travelled sorts the ranking positions.

Table 5: Optimal Results for the most likely scenarios of exit availability in ranked order of average on- ground time

Scenario	Out of aircraft time (s)	On ground time (s)	Av. PET (s)	Av. CWT (s)	Av. DIST (m)
4 (R1-R3-L3)	74.5	76.5	41.7	25.1	8.5
3 (R1-L1-R3)	75.8	77.7	41.9	25.5	8.3
1 (R1-R2-L2)	85.7	87.7	46.6	29.3	8.5
5 (R2-R3-L3)	89.2	91.1	48.3	29.9	9.9
2 (R1-L1-R2)	96.1	98.1	49.8	31.0	10.2

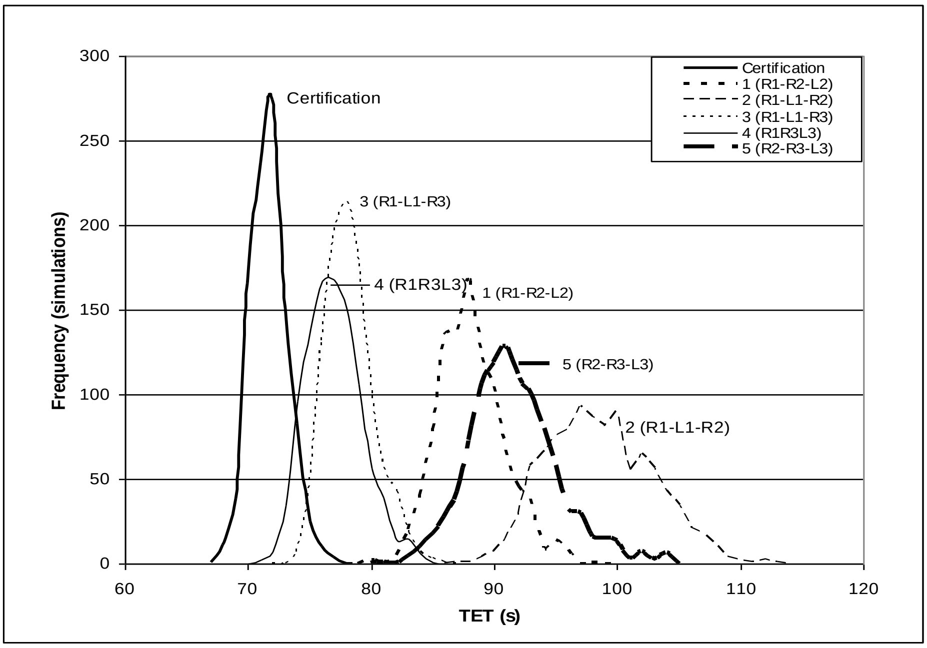


Figure 2: Frequency Distribution for TET (On-Ground Times) for all Scenarios

6.1 FLOW RATES ACHIEVED

The flow rates achieved during the simulations are displayed in Table & **Table**. Flow rates achieved during the certification trial scenarios Table were consistent with flow rates normally achieved by the particular type of exits available. These flow rates were also consistent with flow rates which had been achieved during the actual certification trial carried out for this type of aircraft.

Table 6: Flow rates achieved for exits used during certification trial

Scenario		**Flow Rates (right exits)**			**Flow Rates (left exits)**		
		R1 Type C (Forward right)	**R2 Type III (Right Over Wing)**	**R3 Type C (Aft Right)**	**L1 Type B (Forward Left)**	**L2 Type III (Left Over Wing)**	**L3 Type B (Aft Left)**
Certification (R1-R2-R3)	**Min**	53.9	32.4	54.5	0.0	0.0	0.0
	Mean	**58.8**	**39.2**	**58.9**	**0.0**	**0.0**	**0.0**
	Max	63.3	47.2	63.8	0.0	0.0	0.0
	$95^{th\%ile}$	61.6	43.2	61.4	0.0	0.0	0.0

Flow rates achieved during the Scenarios 1 to 5 (see Table) were in some cases not consistent with flow rates normally achieved by the particular type of exits available. For instance, the flow rate of the forward right type C exit (R1) yielded a mean of 58.8 appm (average persons per minute) during the certification trial scenario yet the same exit could only yield a mean of 38.4 appm during Scenario 2. During the analysis, understanding why moving three available exits to different locations, could have such an effect on exit flow rates, was a critical factor. After all it is the flow rates of the exits which play a large part

in governing the total evacuation time of the aircraft as a whole. It was therefore important to understand how this could happen and why.
During certification trials at the moment, it is the case that only one exit is used from each exit pair. To challenge the validity of the certification trial it would be necessary to test the possibility of exits being used in a pair. Before be able to examine more challenging and realistic exit combinations, a smaller series of methodical computer simulations had to carried out to verify the possible flow rates that could be achieved using these new exit locations. Two exits in a pair had to be analysed in order to ensure the correct flow rates were being achieved. This would prove to be a difficult task as there appeared to be no available data to check if the flow rates being achieved for exits in pairs were in fact valid. These methodical tests had to be broken down into single exits (i.e. an exit on its own) and dual exits (i.e. exits in pairs) flow rate tests.

The single exit test, gave flow rate results which were normally associated and seen with these types of exits (Type C, Type B and Type III). The flow rates however for the same type of exits in pairs were completely different and much lower than expected. The Type C exit for instance would normally give a flow rate of around 60 appm but when in a pair of exits, the flow rate would be reduced to around 40 appm. It was also deduced from the results that the flow rate of the aisle leading to the pair of exits greatly determined their flow rates. The sum of the flow rates for the pair of exits would be very similar to the flow rate of the aisle leading towards them. When in pairs, the Type III exit also yielded flow rates that were slightly slower than normal. The flow rates achieved during the simulations for different exit availability (see Table) corresponded well with the prior series of methodical tests. It appears from these results that the exit when in a pair, performs worse than when in fact on its own. Could this be a reason why only one exit from each pair is tested during the certification test?

Table 7: Flow rates achieved for exits used in Scenarios 1 to 5

Scenario		Flow Rates (right exits)			Flow Rates (left exits)		
		R1 Type C (Forward right)	**R2 Type III (Right Over Wing)**	**R3 Type C (Aft Right)**	**L1 Type B (Forward Left)**	**L2 Type III (Left Over Wing)**	**L3 Type B (Aft Left)**
1 (R1-R2-L2)	**Min**	48.1	25.4	0.0	0.0	27.1	0.0
	Mean	**58.7**	**32.9**	**0.0**	**0.0**	**33.8**	**0.0**
	Max	63.1	42.7	0.0	0.0	43.9	0.0
	95th%ile	61.6	37.1	0.0	0.0	37.8	0.0
2 (R1-L1-R2)	**Min**	30.5	28.2	0.0	28.2	0.0	0.0
	Mean	**38.4**	**35.1**	**0.0**	**35.2**	**0.0**	**0.0**
	Max	46.2	42.1	0.0	42.4	0.0	0.0
	95th%ile	42.7	38.9	0.0	39.1	0.0	0.0
3 (R1-L1-R3)	**Min**	32.6	0.0	54.2	30.2	0.0	0.0
	Mean	**41.2**	**0.0**	**59.0**	**38.0**	**0.0**	**0.0**
	Max	48.9	0.0	63.7	44.9	0.0	0.0
	95th%ile	45.6	0.0	61.4	41.9	0.0	0.0
4 (R1-R3-L3)	**Min**	54.1	0.0	33.4	0.0	0.0	33.0
	Mean	**58.8**	**0.0**	**41.1**	**0.0**	**0.0**	**41.0**
	Max	63.2	0.0	50.7	0.0	0.0	48.0
	95th%ile	61.2	0.0	45.4	0.0	0.0	45.1
5 (R2-R3-L3)	**Min**	0.0	29.4	30.9	0.0	0.0	28.7
	Mean	**0.0**	**37.5**	**41.5**	**0.0**	**0.0**	**41.4**
	Max	0.0	45.3	49.6	0.0	0.0	48.6
	95th%ile	0.0	41.8	45.6	0.0	0.0	45.5

7 CUMULATIVE EXIT COUNTS

The flow curves produced for all scenarios are displayed in Figure & Figure . Each curve depicts the cumulative exit count results from 1000 simulations. The slope of the curves in

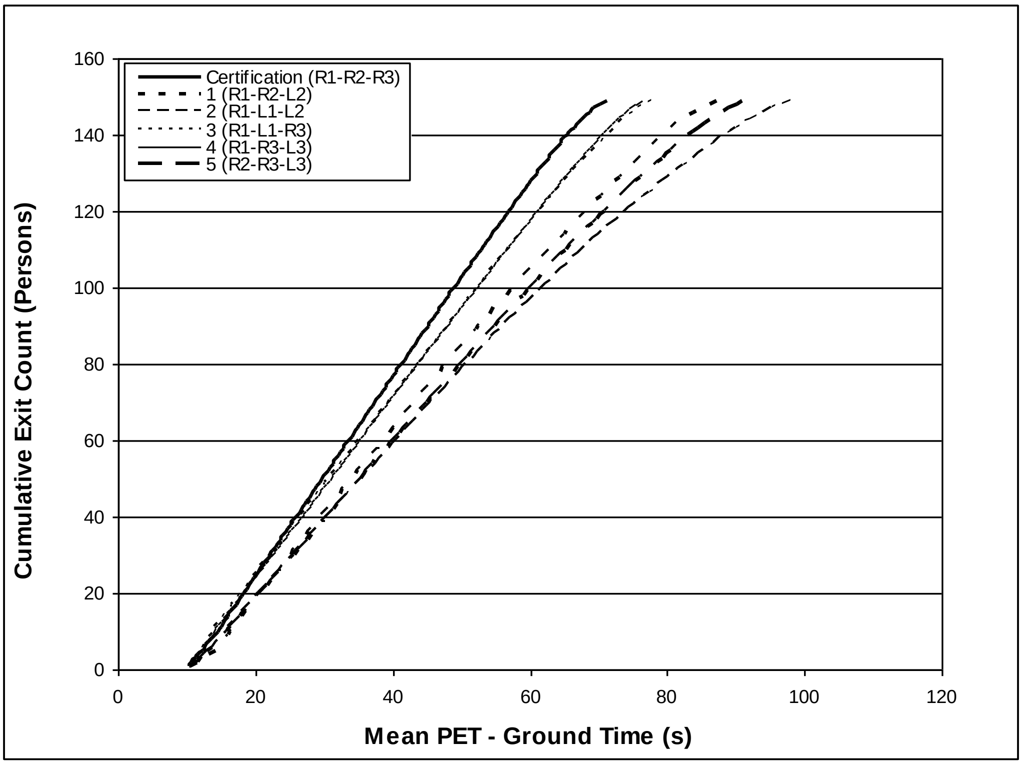


Figure & Figure represents the mean and maximum flow behaviour from the aircraft. The constant slope of the curves indicates that exits are working and producing their maximum flow rate capacity. What must be noted is that the slope is steepest for the certification test scenario which indicates the fastest overall flow rate. The least steep gradient and therefore the worst case, belongs to the exit availability configuration for scenario 5 which has two aft exits plus one over wing exit.

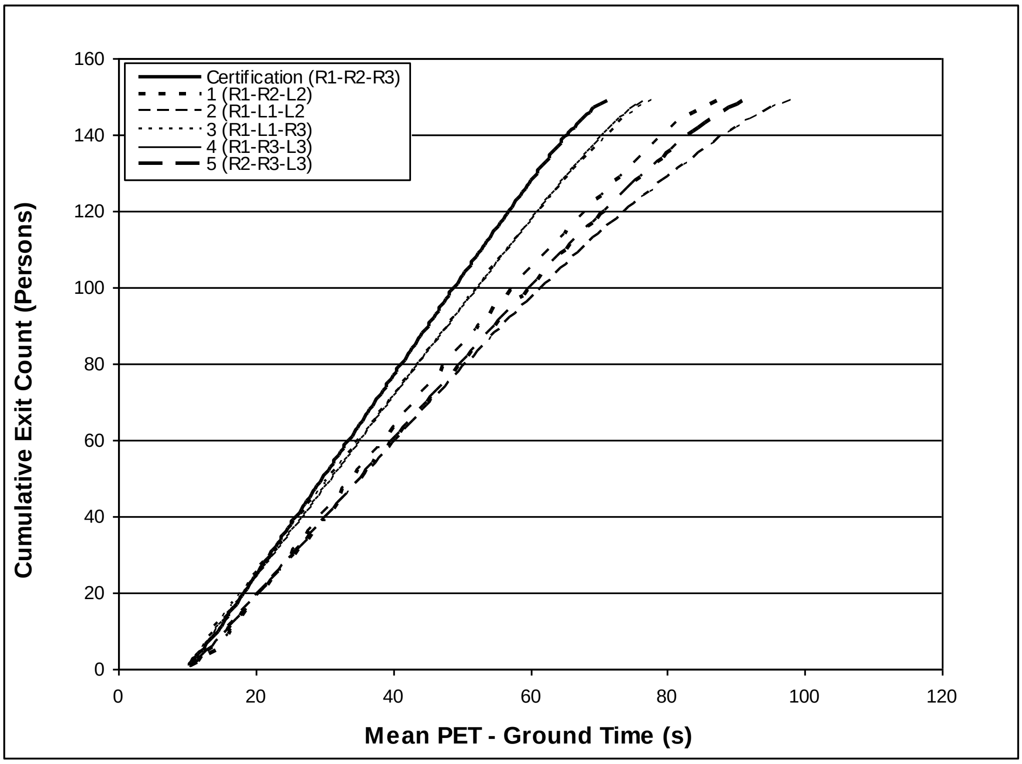


Figure 4: Average PET Cumulative Exit Counts for Scenarios 1 to 5

Scenarios 3 and 4 have an almost identical gradient with both the mean and maximum PET due to the fact that they are almost mirror images of one another. The slope of the graphs in scenarios 1, 2 & 5, are much lower than in scenarios 3 and 4 (see Figure & Figure). A possible explanation for this appears to be the use of the slower, over wing Type III exit, together with the passengers only having the ability to travel in one direction, during their evacuation. Passengers have the opportunity to travel in both a forward and aft direction during scenarios 3 and 4 which will almost inevitably assist in the optimisation of the evacuation. The same is also true for the passengers during the certification test scenario.

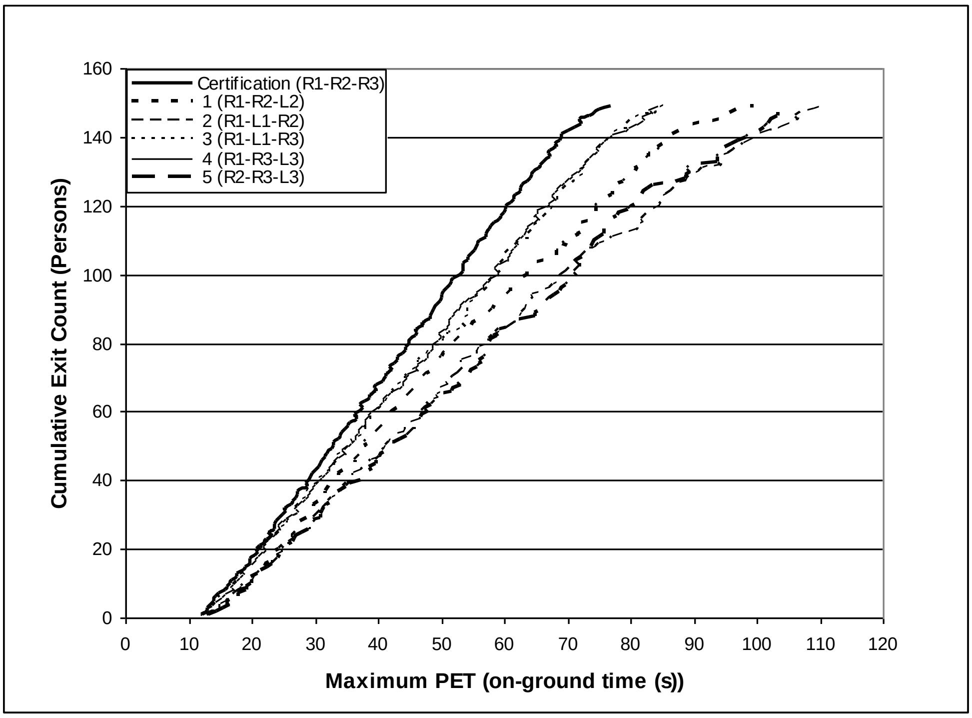


Figure 4: Maximum PET Cumulative Exit Counts for Scenarios 1 to 5

8 CONCLUSIONS

- Why are the aircraft regulators using a test scenario that will give the most optimal time? Surely the certification test should be more robust with a range of other possible scenarios being tested. Not only does the certification configuration not represent typical or common accident analysis, it is the optimal configuration. It is therefore not a challenge, so what is the point of the certification test. Should the strength of an aircraft depend rather on the most difficult test available?

From the results presented, it is apparent that the aircraft regulators are using a test scenario that will give the optimal time in most cases. The certification test scenario with exits available on one side of the narrow bodied aircraft in question will always pass the test according to the results of this paper. It is therefore not a challenge, so what is the point of this certification test?

In this paper, attempts have been made to test a range of realistic scenarios which have been found in the AASK V4.0 database. The scenarios tested were previously extracted and ranked by order of likeliness from this database. Three of the five test scenarios presented a very high chance of failure, with one of the cases failing in nearly every attempt. What is most startling with this particular test case (scenario 2) is the fact that it completely exemplifies the exit availability which occurred during the Manchester Air Crash in 1985; where 55 lost their lives. Another worrying factor is that the scenarios which ranked in the top two of the most likely list both had a very high risk of failure.

Not only is the certification configuration unrepresentative of a typical or common accident, but it is the optimal configuration. Should the strength of an aircraft depend rather on the most difficult test available? The most difficult test available appears to be scenario

2 where evacuating passengers are required to travel the greatest overall distance while having the possibility of travelling in only one direction.

During real evacuations it is expected that approximately 85 % of passengers will use their nearest exit. If this were to be the case, then the times would more than certainly increase. With the mean on ground times for scenarios 1,2 & 5 being so close to the 90 seconds threshold and with less room to expand, the results start to look more and more frightening.

Why do aircraft regulators only test one exit availability configuration? From the results presented, it appears that the current requisite certification test case will assure that the aircraft will certainly pass with the greatest possible number of passengers. This would be a good enough reason to limit the test to 50 % of available exits but only on one side of the aircraft. Swapping the available exit locations around would not assure a certainty to aircraft manufacturers that their newly designed aircraft will smoothly pass the test. A rigorous testing of many different scenarios such as the ones analysed in this paper would give a better understanding of the real safety of the aircraft under scrutiny. The real safety of an Aircraft should be judged upon its most difficult test. The most difficult test according to this paper appears to be scenario 2 where there are two forward exits and one exit over wing. The least difficult test according to this paper is the one currently being used for the certification of aircraft.

- During real evacuations it is expected that 85% of pax will use their nearest exit. With results of cases for both optimal and 85 % nearest exits the results look more and more frightening if passengers must vacate within 90 seconds.

- Why do aircraft regulators only test one exit availability configuration? Would it also be important to test other scenarios which occur more frequently during air crash accidents? Surely this would make more sense. Suggest other configurations that should be used which may be more challenging.

9 REFERENCES

1 King D., "Report on the accident to the Boeing 737-236 Series 1, G-BGJL at Manchester International Airport on 22 August 1985", Aircraft Accident Report 8/88. HMSO, London, 1988

2 Galea E.R., Blake S., Gwynne S. and Lawrence P. "The use of evacuation modelling techniques in the design of very large transport aircraft and blended wing body aircraft". The Aeronautical Journal, Vol 107, Number 1070, pp 207-218, 2003.

3 Galea E.R., Finney K., Dixon A., Siddiqui A. and Cooney D.P., "An analysis of exit availability, exit usage and passenger exit selection behaviour exhibited during actual aviation accidents", ????

4 Galea E.R., Blake S. and Lawrence P.J., Report on Testing and Systematic Evaluation of the airEXODUS aircraft evacuation model. ISBN 0860399664, CAA PAPER 2004/2005. April 2005.

5 Owen, M., Dixon A.J.P., Galea, E.R., 90-second Certification Trial Data Archive Report, Prepared for the U.K. CAA for project 049/SRG/R&AD, March 1999

6 Galea E.R., Finney, K.M., Dixon, A.J.P., Siddiqui A., and Cooney D.P. "An Analysis of human behaviour during aircraft evacuation situations using the AASK V3.0 database.". The Aeronautical Journal, Vol 107, Number 1070, pp 219-231, 2003.

7 Galea, E. R., Cooney, D., Dixon, A., Finney, K., and Siddiqui, A., The AASK Database: Aircraft Accident Statistics and Knowledge. UK CAA Paper 2002/3 ISBN 0 86039 803 X, 2002.

APPENDIX E – *An Investigation of Pax Exit Selection Decisions*

Human Behaviour in Fire Symposium 2009

09/12

AN INVESTIGATION OF PASSENGER EXIT SELECTION DECISIONS IN AIRCRAFT EVACUATION SITUATIONS

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ABSTRACT

This paper presents results from a questionnaire study of participant exit awareness and suggested exit selection in the event of emergency evacuations involving narrow body aircraft. The study involved 459 participants with varying flight experience. The results of this study supports the hypothesis that poor understanding by passengers of aircraft exit location and configuration may be a contributory factor in the resulting poor exit selection decisions made by passengers in emergency situations. These results have important safety implications for airlines and also provide important insight to evacuation model developers regarding the decision making process in agent exit selection.

INTRODUCTION

In aircraft accidents, 89% of passengers attempt to utilise their nearest exit during evacuation [1]. However, using the nearest exit is not necessarily the most efficient evacuation strategy, especially if there is a significant difference in exit flow rate capacity or exit performance between the available exits. The most common aircraft type in the world is the narrow body (single aisle) aircraft typically used for short haul flights. The most common examples of this type of aircraft are the B737 and A320 family of aircraft. These aircraft types typically have three pairs of exits, two in the front, two over the wing and two in the rear. The front and rear exits are large floor level exits that allow passengers to walk through the exit and jump onto the slide. These exits are usually of exit type Type-C and can typically produce an average flow rate of 64 people/minute. The over wing exits are smaller exits which require the passenger to climb through the exit. These smaller exits are of exit type Type-III and typically produce an average flow rate of 35 people/minute.

In an analysis of survivable aircraft accidents involving narrow body aircraft with three exit pairs [1] (based on data derived from the AASK database [2,3]) over 50% of passengers were found to use the over wing exit. On the one hand this is of little surprise as over 89% of passengers use their nearest exit, and the central exits are the closest to the majority of passengers. However, the centre Type-III exit is the smallest exit on the aircraft and is 45% slower than the larger Type-C exits in the front and rear. Furthermore, in the aircraft industry standard evacuation certification trial, we find that on average only 28% of passengers use the over wing exit. Thus we find that in aircraft accidents, the central small Type-C exits tend to be over used, while in the industry standard evacuation certification trial, a smaller more appropriate proportion of passengers utilise the exit, representing the slower flow rate capability of the exit.

The most probable reason for the difference in exit usage between certification trials and real accidents lies in the behaviour of the passengers. Essentially, in real accident situations passengers have a higher motivation to escape than they do in evacuation trials and tend to do so by what they perceive to be the most direct method – their nearest exit. In certification trials, cabin crew procedures work quite well and achieve a well-balanced and highly efficient evacuation with most of the exits working in a near optimal manner. However, in real emergency situations, where passengers may have a choice of directions in which to escape, they may ultimately ignore crew commands – or not even be aware of the crew commands due to adverse environmental conditions - and attempt to use what they perceive to be their best exit i.e. their nearest exit. This would appear to be a logical behaviour as it is reasonable to assume that by travelling to your nearest exit you are likely to minimise your evacuation time – assuming that all the exits have similar flow capabilities. It is also possible that while passengers may be aware of the location of their nearest exit, they may not be aware of the flow capabilities of the various exits and so are unaware that their nearest exit may be an inherently slow exit due to its physical characteristics. The pre-flight safety briefing makes no mention of the size of the exits and the impact this may have on evacuation times. It is conjectured that in real emergency situations the disproportionably large number of passengers utilising the over wing exits are due to a lack of passenger knowledge concerning the size and flow capabilities of the Type-III exit. They are simply moving towards their nearest exit without taking into consideration the flow capabilities of the exit.

It is important to understand why passengers over utilise these exits in order to provide better safety briefing instructions for passengers allowing them to make more informed exiting decisions. Furthermore, in order to improve the decision making capabilities of aircraft evacuation models such as airEXODUS [4] it is important to understand the decision making process involved in the exit selection process. To better understand the decision making process associated with passenger aircraft exit selection the authors have developed a questionnaire which they did administered to members of the travelling public. This paper describes the results from the analysis of the participants' responses to the questionnaire.

AIRCRAFT EVACAUTION QUESTIONNAIRE AND SAMPLE POPULATION

A total of 488 members of the public were approached to complete the questionnaire, of which 459 people were considered eligible to take part in the analysis. The questionnaire consisted of 16 multi-part questions and required approximately 20 minutes to complete. The questionnaire focused on narrow body aircraft with a single passenger aisle and a pair of large Type-C exits in the front and rear with a pair of Type-III exits over the wing as shown in Figure 1. Two pilot trials were conducted prior to launching the main campaign.

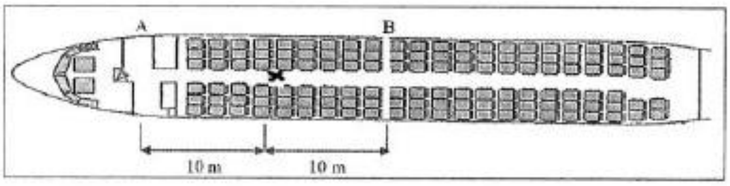

Figure 1: Aircraft layout as presented to the participants in Question 8 without exit size or type information. The "X" marks the location of the participant which is equi-distant between two exits.

The first pilot trial, involving 25 participants revealed some inconsistencies in the questions and highlighted several difficulties that the participants had in addressing the questions. These were corrected and a second pilot was conducted, again involving 25 participants which revealed that the questionnaire was acceptable. The first five questions in the questionnaire were intended to establish the flying experience of the participant; the next two questions were intended to ascertain the understanding the participant had of the aircraft layout with regards to the number of exits on board the aircraft, the location of the exits and the size of the exits. The participant was later told the correct number and location of the exits, but not the size of the exits, and the next four questions asked the participant to identify which exit they would use if they were placed at an equal distance between two exits (the position "X" in Figure 1). The question was asked twice, once with no other passengers in their way (to remove the complication of queuing) as in Figure 1 (i.e. question 8 for forward and over wing exit) and with eight other passengers queuing up at each exit (i.e. question 9 for the forward and over wing exit). This was repeated for the rear exits (i.e. questions 10 and 11). The participant was then told which were the large and small exits and was shown a picture of the various exits. The next two questions then repeated the exit selection questions relating to the forward two exits (i.e. question 12 without queuing passengers and question 13 with queuing passengers).

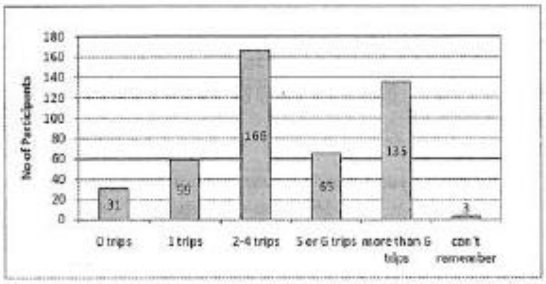

Figure 2: Number of return trips of participants in the last 3 years

The participant was then asked to estimate how long they thought it would take for a single person to exit through the smaller Type-III exit if they required 1 sec to pass through the large Type-C exit (question 14). This was intended to establish if the participant could come up with a reasonable estimate for the flow rate of the smaller exit. The participants were then told what the correct relative performance of each exit would be and were then asked to repeat the exit selection process for the forward exits (i.e. question 15 without queuing passengers and question 16 with queuing passengers).

The questionnaire was completed by 459 members of the public. The sample consisted of 61% (280) males and 39% (179) females with 25% (115) in the 18-30 year age bracket, 52% (240) in the 31-50 age bracket and 23% (104) in the over 50 age bracket. Over 93% of the sample had flown at least once in the past three years (Figure 2). Results were analysed as a function of age, gender, flight experience and aircraft knowledge. Here we present an overview of the results.

MAIN RESULTS

The analysis presented here will first consider the participants knowledge of the cabin layout and then will examine the exit choices made by the various participants. The analysis will be based on the participants' frequency of travel and knowledge of cabin layout.

Participant knowledge of cabin layout

Of the entire sample population, 78% (357) could correctly identify that there are three exit pairs on the aircraft while 75% (344) could correctly identify the location of the three exit pairs (see Table 1).

This indicates that a quarter of the participants (25% or 115) did not know that the aircraft had three exit pairs and where they were located. Presented in Figure 3 is an example of some of the erroneous exit information provided by the participants.

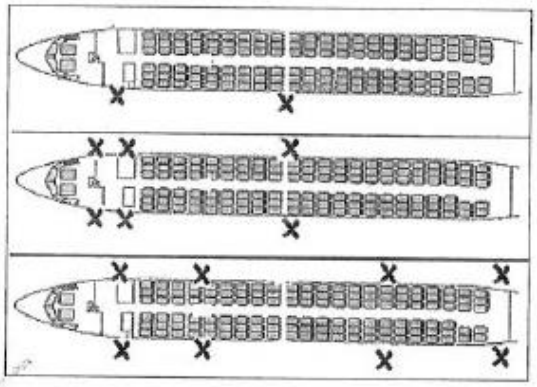

Figure 3: Example exit locations suggested by participants who did not know correct number and location of exits.

When asked if all the exits were the same size, only 37% (172) of the population realised that the exits were not the same size. This suggests that a significant proportion of the sample population - over three fifths (287) - did not know that the exits were of different sizes. ***Of greater concern was the fact that only just over one fifth of the entire population - 22% (99) – knew the number, location and relative sizes of the three exit pairs*** (see Table 1). These results clearly indicate that the sample population have a poor configurational awareness of the aircraft. It is suggested that this poor level of understanding is a contributory factor in the poor exit selection decisions made by passengers in emergency situations.

It is often claimed that frequent fliers have a good knowledge of the aircraft and that recent fliers also have a good knowledge of the aircraft layout. This possibility was examined by comparing the sub-populations who had flown in the past 12 months (367 participants) with those who had not flown in the past 12 months (92 participants), and frequent flyers who had flown in the past 12 months (194 Participants) with infrequent flyers who had flown in the past 12 months (173 Participants). For this analysis, frequent flyers are defined as those people who have flown five or more return trips in the past three years. From Table 1 we note that the results for the sub-population that have flown within the past 12 months ("recent flyers") are not significantly different to the results for the entire population. This is because 80% (367 participants) of the sample have flown within the past 12 months. Thus the conclusions drawn for the entire population apply equally well to those who have flown within the previous 12 months. In particular, ***just under a quarter of the "recent flyer" sub-population - 23% (84) – knew the number, location and relative sizes of the three exit pairs*** (see Table 1).

We can also compare the sub-population who has flown within the past 12 months (367 participants) with those who have not flown within the past 12 months (92 participants). Here we find that the correct knowledge of the number and location of the exits is almost identical, with the proportion of those having flown in the past 12 months only being some 3% greater than the proportion of those who had not flown in the past 12 months. ***Simply having flown recently does not convey good knowledge of the aircraft layout.***

Table 1: Knowledge of cabin configuration for various sub-populations

Configurational knowledge	Entire Sample (459 people)	Sub-population – flown in the previous 12 months (367 people)	Sub-population – NOT flown in the previous 12 months (92 people)	Sub-population – frequent flyers who have flown in the previous 12 months (194 people)	Sub-population – infrequent flyers who have flown in the past 12 months (173 people)
Correct number of exit pairs	78% (357)	79% (289)	74% (68)	89% (172)	72% (125)
Correctly locate the three exit pairs	75% (344)	76% (277)	73% (67)	82% (159)	68% (118)
Knew that exits were of different sizes.	37% (172)	40% (145)	30% (27)	45% (91)	31% (54)
Correctly identify number, location and size of exit.	22% (99)	23% (84)	16% (15)	27% (53)	18% (31)
If 1 sec to pass through L, a little more to pass through S	62% (285)	62% (228)	60% (55)	62% (121)	62%(107)
If 1 sec to pass through L, much more to pass through S	12% (55)	13% (46)	13% (12)	13% (25)	12%(21)
If 1 sec to pass through L, approx the same to pass through S	19% (87)	19% (68)	22% (20)	18%(34)	20%(34)

However, we find that those who have flown in the past 12 months have a better understanding of the difference in size of the exits than those who have not flown in the past 12 months, the difference in knowledge between the two groups being some 10%. We find however that this is not significantly different (note, all χ^2 analysis presented in this paper are two tailed and make use of the Yates correction, χ^2 test, $X^2 = 3.32$) at the 5% confidence limit, thus the null hypothesis, that having flown within the past 12 months does not imply better knowledge of the size of the available exits on the aircraft is supported. When we compare the complete configurational knowledge of the two sub-populations, we find that 7% more of the sub-population that has flown in the past 12 months could identify the three key configurational facts relating to; the number of exits, the location of the exits and that the central exits were smaller in size. This reduces from 23% (84) for the sub-population that has flown in the past 12 months to 16% (15) for the population that has not flown in the past 12 months (see Table 1). However, we find that this difference is not statistically significantly different (χ^2 test, $X^2 = 2.034$), which does support the null hypothesis that having flown within the past 12 months does not convey a better configurational knowledge. ***Once again, simply having flown recently does not imply that people will have a good knowledge of the aircraft exit layout and configuration.***

Comparing the response of frequent flyers who have flown in the previous 12 months (194 participants) ("recent frequent flyers") with infrequent flyers who have flown in the past 12 months (173 participants) ("recent infrequent flyers") does present some interesting differences. Of the recent frequent fliers sub-population, 89% (172) could correctly identify that there are three exit pairs on the aircraft compared with 72% (125) for the recent infrequent flyer sub-population – a difference of 17%. We find that this is statistically significantly different (χ^2 test, $X^2 = 15.93$) at the 0.01% confidence limit, thus there is a strong departure from the null hypothesis of no association between the flight frequency of those passengers who have flown in the last 12 months and the knowledge of the correct number of exits on the aircraft. The greater observed than expected result of the recent frequent flyers strongly suggests that they are likely to have better knowledge of the correct number of exits than do recent infrequent fliers. Furthermore, 82% (159) of the recent frequent fliers compared with 68% of the recent infrequent fliers could correctly locate all three exit pairs – a difference of 14%. We find that this is statistically significantly different (χ^2 test, $X^2 = 9.34$) at the 0.5% confidence limit, thus there is a departure from the null hypothesis of no association between the flight frequency of those passengers who have flown in the last 12 months and the knowledge of the correct location of the exits on the aircraft. The results strongly suggest that recent frequent fliers have a much better understanding of the exit locations than do recent infrequent fliers. ***More than four fifths (82%) of frequent fliers who have flown in the previous 12 months can locate the position of the three exit pairs.***

When asked if all the exits were the same size, only 45% (91) of the recent frequent fliers realised that the exits were not the same size, while only 31% (54) of the recent infrequent fliers knew. This suggests that over half the population of recent frequent fliers do not know that the exits are of different sizes. Furthermore, only 27% (53) of the recent frequent fliers could identify the three key configurational facts relating to; the number of exits, the location of the exits and that the central exits were smaller in size. This compared to only 18% (31) for the recent infrequent fliers. We find that this difference is statistically significant (χ^2 test, $X^2 = 4.61$) at the 5% confidence limit, thus there is a departure from the null hypothesis of no association between flight frequency of those passengers that have flown in the last 12 months and the knowledge of the number, location and size of the exits on the aircraft. The observed result of the recent frequent flyer is higher than its expected result, strongly suggesting that this type of flyer has a much better knowledge of the number, location and size of the exits on the aircraft.

Thus, simply having flown recently or simply being a frequent flyer does not in itself convey a better knowledge of the aircraft exit configuration and layout. However, being a recent frequent flyer does convey a better understanding of the aircraft exit configuration and layout. While being a recent frequent flyer conveys better knowledge of the aircraft exit configuration and layout, ***of great concern is the result that only a little more than a quarter of the recent frequent flier sub-population - 27% (53) - could correctly identify the number of exits, locate their position and identify their relative size*** (see Table 1). These results clearly indicate that even having flown recently and frequently does not mean that passengers will have a good configurational awareness of the aircraft.

When asked to estimate how much longer would it take to pass through the smaller over wing exit, approximately 62% correctly stated that it would take a little longer to pass through (up to twice as long). Approximately 13% thought it would take significantly longer (more than twice as long).

These responses were uniform across all groups of participants. Thus approximately 75% of the population correctly estimated that it take longer to pass through the smaller over wing exit. This suggests that three quarters of the entire population (74% or 340 participants) understood that the smaller exit meant a slower egress time through the exit. ***However, a quarter of the entire population (26% or 119 participants) thought that the smaller exit would allow them to pass through in approximately the same amount of time or quicker than the larger exit. This result appears to be independent of flyer experience.***

Not only does approximately three quarters of the sample population have a poor configurational awareness of the aircraft, a quarter of the sample population does not appreciate that the smaller exit will produce a slower egress rate. It is suggested that this lack of knowledge contributes to poor exiting decisions in aircraft accidents.

Participant exit selection decisions

Thus far we have demonstrated that the participant population had a poor understanding of the exit configuration and layout. In this part of the analysis we investigate the exit choices the participants would make under a variety of conditions (see Table 2).

When asked which exit they would select if they were alone on the aircraft and equi-distant between the forward (Type-C) exit and the central over wing (Type-III) exit, 72% (333) of the entire population (459) correctly selected the forward exit (see Table 2). This exit is the correct exit to select as it is the larger of the two exits and has a better exit flow rate. When the question was repeated for the central over wing (Type-III) and rear (Type-C) exits, a smaller proportion, 52% (239) correctly selected the rear exit. ***On average almost two fifths (38% or 346 taking both forward and aft exits) of the entire population elect to use the centrally located smaller over wing exit rather than the larger forward/rear (Type-C) exits.*** When we consider the sub-population with the most flying experience, the "recent frequent flyer" group, the percentage electing to use the over wing exit decreases slightly to one third (33% or 129). However, we find that this difference is not statistically significantly different (χ^2 test, $X^2 = 2.35$) supporting the null hypothesis that flyer experience does not make a difference in exit choice.

The question is then repeated but this time, eight people are shown to be queuing at each exit. The correct reply to this question is that the larger forward/aft (Type-C) exits should again be used, in fact there is an even greater compulsion to use the large exits as the queue will take some time to pass through the centrally located smaller (Type-III) exit. We find that even fewer people elect to use the forward (Type-C) exit (68% or 310) and slightly more people elect to use the rear (Type-C) exit (54% or 247). ***Even with a queue at each exit, on average, almost two fifths (39% or 361 taking both forward and aft exits) of the entire population again elect to use the centrally located smaller over wing exit. These results clearly demonstrate that a significant proportion – two fifths - of the general population do not correctly perceive that it will take them longer to exit via the smaller over wing exit.***

However, it should be recalled that a significant number of the population are not aware of the differences between the exits and the implications that these differences may have on exit performance. To test whether or not the participants would change their answers if they were presented with detailed information concerning the size and flow rate these questions were repeated progressively providing the participants with more information concerning the exit configurations.

Table 2: Participant exit selection for various sub-populations based on frequency of flight

Which exit would you use?	Entire Sample (459 people)	Sub-population – flown in the previous 12 months (367 people)	Sub-population – NOT flown in the previous 12 months (92 people)	Sub-population – frequent flyers who have flown in the previous 12 months (194 people)	Sub-population – infrequent flyers who have flown in the past 12 months (173 people)
A - Forward Type I empty	72% (333)	74% (270)	69% (63)	78% (152)	68% (118)
A – Forward Type I queue	68% (310)	69% (253)	62% (57)	73% (141)	65% (112)
Large – forward Type I empty	88% (402)	89% (327)	82% (75)	90% (175)	88% (152)
Large – forward Type I queue	90% (415)	91% (335)	87% (80)	92% (178)	91% (157)
Large fast – forward Type I empty	91% (420)	92% (338)	89% (82)	92% (179)	92% (159)
Large fast – forward Type I queue	93% (427)	93% (342)	91% (84)	96% (186)	90% (156)
C - Rear Type I empty	52% (239)	52% (190)	53% (49)	55% (107)	48% (83)
C – Rear Type I queue	54% (247)	55% (201)	50% (46)	58% (112)	51% (89)

When the population is informed that the forward and rear exits are larger than the over wing exit, the proportion electing to use the forward Type-C exit increases to 88% (402), and further increases to 90% (415) when there is a queue at each exit (see Table 2). The population is then informed that the larger exit is also faster than the smaller over wing exit. We now find that the proportion electing to use the forward Type-C exit increases to 91% (420) and further increases to 93% (427) when there is a queue present at each exit. When compared with the case where the participants are given no additional configuration information, we find that the proportion of participants selecting the larger exit is statistically significantly different (χ^2 test, $X^2 = 44.35$) at the 0.0000005% confidence limit, thus there is a very strong departure from the null hypothesis that providing additional exit configuration and performance information does not result in better exit selection. ***These results clearly show that the participants are capable of making an appropriate choice if they are provided with the appropriate configurational and exit performance information.***

All flight experience groups, produce similar results, suggesting even recent frequent flyers make significantly better decisions if they are provided with appropriate exit configuration and performance information. To better address the question of level of prior knowledge, the exit selection analysis was repeated with the analysis focusing on level of configuational knowledge rather than flight experience (see Table 3).

In Table 3 we present the breakdown of the exit choice decisions for the entire population (459), the sub-population with complete exit knowledge i.e. with knowledge of the number, location and sizes of the exits (99) and the sub-population with incomplete exit knowledge i.e. at least aspect of exit number, location or size unknown (360). We note from Table 3 that the sub-population with incomplete exit knowledge make similar exit choice decisions to those of the entire population while the exit choice decisions of those with complete exit knowledge appear to be different to those with incomplete exit knowledge.

Table 3: Participant exit selection for various sub-populations based on configurational knowledge

Which exit would you use?	**Entire Sample** (459 people)	**Entire sample complete configurational knowledge (99 people)**	**Entire sample incomplete configurational knowledge (360 people)**
A - Forward Type I empty	72% (333)	78% (79)	71% (254)
A – Forward Type I people	68% (310)	78% (77)	65% (233)
Large – forward Type I empty	88% (402)	87% (86)	88% (316)
Large – forward Type I people	90% (415)	91% (90)	90% (325)
Large fast – forward Type I empty	91% (420)	94% (93)	91% (327)
Large fast – forward Type I people	93% (427)	95% (94)	92% (332)
C - Rear Type I empty	52% (239)	71% (70)	47% (169)
C – Rear Type I people	54% (247)	73% (72)	49% (175)

When asked which exit they would select if they were alone on the aircraft and equi-distant between the forward (Type-C) exit and the central over wing (Type-III) exit, 78% (79) of the sub-population with complete exit knowledge (99) correctly selected the forward exit (see Table 3). When the question was repeated for the central over wing (Type-III) and rear (Type-C) exits, a slightly smaller proportion, 71% (70) correctly selected the rear exit. ***On average almost one quarter (24% or 24) of the population with complete exit knowledge elect to use the centrally located smaller over wing exit***

rather than the larger forward/rear (Type-C) exits. When we compare the responses of the sub-population with incomplete exit knowledge with the sub-population with complete exit knowledge, we find the difference is statistically significantly different (χ^2 test, $X^2 = 9.54$) at the 0.5% confidence limit, thus there is a strong departure from the null hypothesis that there is no association between complete/incomplete exit knowledge and correct exit selection. Results suggest that having complete exit knowledge appears to result in significantly better exit selection.

The question is then repeated but this time, eight people are shown to be queuing at each exit. We find that the same number of people elect to use the forward (Type-C) exit (78% or 77) and slightly more people elect to use the rear (Type-C) exit (73% or 72). ***Even with a queue at each exit, on average, one quarter (25% or 25) of the sub-population with complete exit knowledge elect to use the centrally located smaller over wing exit. These results clearly demonstrate that a significant proportion – one quarter - of the sub-population with complete exit knowledge do not correctly perceive that it will take them longer to exit via the smaller over wing exit***

When the sub-population with complete exit knowledge is informed that the forward and rear exits are larger than the over wing exit, the proportion electing to use the forward Type-C exit increases to 87% (86), and further increases to 91% (90) when there is a queue at each exit (see Table 3). The population is then informed that the larger exit is also faster than the smaller over wing exit. We now find that the proportion electing to use the forward Type-C exit increases to 94% (93) and further increases to 95% (94) when there is a queue present at each exit. When we compare the case where the participants are given no additional configuration information with the case where the participants are given complete configurational information for the sub-population who have complete exit knowledge, we find that the proportion of participants selecting the larger exit is statistically significantly different (χ^2 test, $X^2 = 8.68$) at the 0.5% confidence limit, thus there is a strong departure from the null hypothesis that providing additional exit configuration and performance information does not result in better exit selection, even for the sub-population that has complete exit knowledge.

These results clearly demonstrate that even participants with a good knowledge of the exit configuration are capable of making a more appropriate exit choice if they are provided with configurational and exit performance information.

DISCUSSION

The main findings of this work can be summarised as follows. Regarding participant knowledge of the aircraft exit configuration:

- Just under a quarter - 23% (84) – of the sub-population, "people who had flown in the previous 12 months", had good understanding of the aircraft exit layout and configuration i.e. knew the number, location and relative sizes of the three exit pairs.
- Having flown recently (within the previous 12 months) does not imply a better understanding of the aircraft exit layout and configuration when compared with those who have not flown recently.
- Being a recent frequent flyer does imply a significantly better understanding of the aircraft exit layout and configuration when compared with being a recent infrequent flyer.
- However, just over a quarter - 27% (53) - of the sub-population, "people who have flown recently who are also frequent flyers", knew the number, location and relative sizes of the three exit pairs.

These results are of great concern as they suggest that of the most experienced fliers (recent frequent fliers) a little more than a quarter understand the aircraft exit layout and configuration prior to boarding. This inherent lack of exit knowledge is likely to have a negative impact on overall evacuation efficiency and hence passenger safety. From a general view of aircraft passenger safety, it is suggested that the pre-flight safety briefing should more strongly emphasise the location and type of exits available on the aircraft. Furthermore, rather than simply point out the location of the exits on board, the affordance of the exits should be enhanced, perhaps through lighting systems that could be used to emphasise the location of the exits to seated passengers. For example, a halo of lights could be used to surround the exit frame and in addition, an arch of lighting could be placed in the aisle perpendicular to the exit plane. In addition, these results clearly demonstrate that even the frequent flier community – who have a tendency to ignore pre-flight briefings because of their perceived "experience" and "knowledge" – lack a detailed understanding of the exit configuration on board aircraft. The pre-flight briefing should emphasise that even frequent flyers do not fully appreciate the nature of the exit configurations and so they should take note of the briefing. Finally, the safety cards used on board aircraft should focus on emphasising the location and type of exits available on board the aircraft.

From an evacuation modelling view, these results are extremely important as they suggest that the majority of passengers (approximately 75%) have poor inherent exit knowledge. Agent based decision models used to select which exit an agent may decide to use must reflect this lack of inherent exit knowledge. Factors such as opportunistically "seeing" an exit, following the crowd, following instructions or simply going to the nearest exit may be appropriate drivers for the majority of passengers/agents.

Regarding participant exit choice:

- On average two fifths – 39% (361) – of the entire population (459) would elect to use the centrally located smaller over wing exit rather than the larger forward/rear exits, even when faced with a queue at each exit.
- Being a recent frequent flyer – the most experienced sub-population – does not statistically significantly alter this decision.
- When provided with complete exit information (size and flow rate), less than one tenth – 7% (32) – of the entire population elect to use the centrally located smaller over wing exit rather than the larger forward exit, even when faced with a queue at each exit.
- On average one quarter – 25% (25) – of the sub-population (99) with complete exit knowledge would elect to use the centrally located smaller over wing exit rather than the larger forward/rear exits, even when faced with a queue at each exit.
- Having complete exit knowledge does statistically significantly alter the decision to use the centrally located smaller over wing exit.
- Providing the sub-population "with the best exit knowledge" with information relating to the size and flow rate capability of the exits resulted in only a twentieth – 5% (5) - of the sub-population electing to use the centrally located smaller over wing exit rather than the larger forward exit, even when faced with a queue at each exit.

These results are of great concern as they suggest that irrespective of participant flight experience, two fifths (39% or 361) of the participants would elect to use a sub-optimal exit. This high number of participants electing to utilise the over wing exit supports the observation from real accidents that a significantly high number of participants elect to utilise the over wing exit. Perhaps of greater surprise, a quarter (25% or 25) of the sub-population that demonstrated complete knowledge of the aircraft exit layout and configuration also elected to use a sub-optimal exit. ***However, it was shown that by providing the participants with complete knowledge of the size and performance capabilities of the exits, the proportion making sub-optimal exit decisions could be reduced to less than one tenth (7% or 32) of the population.*** A similar result was found even for the knowledgeable sub-population. When this sub-population was provided with additional information relating to the exit size and performance capabilities, the proportion electing to use the sub-optimal exit fell to only one twentieth (5% or 5) of the sub-population.

These findings support the hypothesis that poor understanding of cabin layout is a contributory factor to sub-optimal exit selection decisions made by passengers in emergency situations. Furthermore, the results demonstrate that providing participants – even apparently knowledgeable participants – with additional information concerning the size and flow capabilities of the exits greatly improves the exit selection capabilities of the participants. Even providing information simply related to the relative size of the exits significantly improves exit selection capabilities. These observations support the earlier suggestion of improving the nature of the pre-flight briefing, the affordance of exits and the safety cards provided on aircraft. From an evacuation modelling perspective, these results suggest that as many as 39% of passengers will make sub-optimal exit selection decisions. It is suggested that these poor exit decisions are due to poor understanding of the exit layout and performance capabilities. It is further suggested that these factors should be taken into consideration when developing agent decision models concerned with identifying which exit to use.

CONCLUSIONS

The results from this survey suggest that even the most experienced fliers - recent frequent fliers – have little inherent understanding of aircraft exit configuration – only 27% (53) correctly knew the number, location and relative sizes of exits on narrow body aircraft. Furthermore, irrespective of flight experience, a substantial number (39% or 361 considering both forward and aft exits) of participants would elect to use a sub-optimal exit in the event of an emergency evacuation. It was shown that by providing participants with good knowledge of the exit layout, involving location, relative size and performance of the exits, the proportion making sub-optimal exit decisions could be dramatically reduced (to 7% or 32). These results have important safety implications for airlines and the nature of the pre-flight briefing and to evacuation model developers.

REFERENCES

[1] Galea, E.R., Finney, K.M., Dixon, A.J.P., Siddiqui, A., Cooney, D.P. "An analysis of exit availability, exit usage and passenger exit selection behaviour exhibited during actual aviation accidents.", The Aeronautical Journal of the Royal Aeronautical Society, Vol 110, Number 1106, pp 239-248, 2006.

[2] Galea, E.R., Finney, K.M., Dixon, A.J.P., Siddiqui, A., Cooney, D.P. "Aircraft Accident Statistics and Knowledge Database: Analyzing Passenger Behaviour in Aviation Accidents", AIAA Journal of Aircraft, Vol 43, Number 5, pp 1272-1281, 2006.

[3] Galea, E.R., Finney, K.M., Dixon, A.J.P., Siddiqui, A. Cooney, D.P. "An analysis of the passenger to cabin crew ratio and exit reliability based on past survivable aviation accidents.", Human Factors and Aerospace Safety, Ashgate publishing, 5(3), pp 239-256, 2005.

[4] Galea, E.R., Togher, M., Lawrence, P., "Investigating the impact of exit availability on egress time using computer based evacuation simulation". Proceedings, 5th Triennial International Fire and Cabin Safety Research Conference, Atlantic City, USA, 29 Oct – 1 Nov 2007, publishers US FAA, website: http://www.fire.tc.faa.gov/2007Conference/proceedings.asp.