An analysis of exit availability, exit usage and passenger exit selection behaviour exhibited during actual aviation accidents

E. R. Galea, K. M. Finney, A. J. P. Dixon, A. Siddiqui and D. P. Cooney
Fire Safety Engineering Group
University of Greenwich
London, UK

ABSTRACT

The exits which passengers select in evacuation situations and the exits which are available post-crash is of great interest to aviation safety regulators who make rulings defining exit separation and aircraft evacuation certification, aircraft designers who develop the interior layout of aircraft cabins and position exits within the fuselage, cabin safety specialists who develop procedures for managing aircraft evacuation and cabin crew who must control aircraft evacuations. In this paper we examine issues associated with passenger exit selection behaviour and exit configurations frequently experienced during survivable crashes. This work makes use of the latest version of the Aircraft Accident Statistics and Knowledge database AASK V4.0, which contains information from 105 survivable crashes and over 2,000 survivors.

1.0 INTRODUCTION

A considerable amount of misinformation and mythology related to issues of passenger safety exists within the aviation business. A common held belief is that the majority of passengers evacuate via their most familiar exit, thereby ignoring closer but unfamiliar emergency exits. For example[1],'Passengers will often try to exit the aircraft via the same door they entered, regardless of better options'

A related myth is that passengers tend to move towards the front of the aircraft i.e. in the direction that they are seated, towards an exit regardless of whether there is an available exit behind them. Comments such as these are defined in this paper as 'beliefs', or 'misinformation' or 'myths' as they are often passed off as being fact or go unchallenged even though they generally cannot be substantiated by factual, reliable and reproducible observational data.

This type of misinformation is dangerous as they are often held, not by misinformed members of the travelling public but by safety professionals. For example, the cited quotation was found in a formal report produced by a national accident investigation agency. These types of misinformation (or myth) usually have their origins based on misinterpretations of observed passenger behaviour found in actual incidents, or from incorrectly elevating to a universal truth an observation of passenger behaviour found in a single particular incident. This type of miss-information in the hands of safety professionals can have serious repercussions as it is these individuals who develop and maintain crew procedures for use in emergency situations and train cabin crew in the correct use of these procedures. Furthermore, they provide input into the design of aircraft interior layouts and may also advise regulators in the development of passenger safety related requirements.

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Regulation can also have a role in perpetuating or generating myths. Take for example the FAR 25·803[2] evacuation demonstration. In these trials half the exits are usually made inoperative and usually all or the majority of the serviceable exits are on one side of the aircraft. Why half the exits, why generally on one side and why one exit in each exit pair? It is a commonly held (and not unreasonable) belief by safety professionals that this exit configuration is selected because it is most frequently found in survivable accident situations or that it is the most challenging exit configuration for an aircraft to pass. While the origins of this particular part of the evacuation demonstration are not clear, it possibly stems from the belief that in a crash/emergency situation fire is most likely to occur on one side of the aircraft (e.g. due to ruptured fuel lines/wing tank) and so it would be reasonable to assume that the exits on that side of the aircraft would be unavailable. Furthermore, the regulatory community would (rightly) argue that the evacuation demonstration is not intended to represent a real situation, but is intended to be a benchmark examination of evacuation performance allowing both absolute (i.e. better than 90 seconds) and relative (i.e. one aircraft configuration against another) performance. While valid, this position could be strengthened and certification analysis made more relevant as a measure of evacuation capability by utilising exit configuration data derived from accident analysis suggesting likely or challenging exit configurations.

In this paper we attempt to tackle some of these safety myths and misconceptions through the latest version of the Aircraft accident statistics and knowledge (AASK) database[3-7]. Using AASK we explore several issues associated with passenger exiting behaviour and exit configurations experienced during survivable accidents. This work revisits some of the previous analysis undertaken with an earlier version of the AASK database[4] but with the significantly larger dataset available in AASK V4.0.

2.0 THE AASK DATABASE

2.1 The database

The Aircraft accident statistics and knowledge (AASK) database is a repository of survivor accounts from aviation accidents conducted by investigative organisations such as the US National Transportation Safety Board (NTSB) and the UK Air Accident Investigation Branch (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. It should be noted that the majority of the data within AASK is derived from interviews with survivors. As such the data does not necessarily reflect behaviours that may have lead directly or indirectly to unsuccessful actions resulting in fatalities.

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 2,000 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[3-6]. 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.

2.2 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 1,917 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.

3.0 ANALYSIS OF PASSENGER EXITING BEHAVIOUR USING AASK V4.0

In this paper we utilise AASK V4.0 to explore issues associated with the availability of exits in survivable crashes and the choices passengers make in selecting their exit.

3.1 Exit availability

One of the key factors that will influence the speed of evacuation is the number of available exits. During an accident, exits may become unusable due to damage to the exit mechanism, failure of the evacuation assist means (e.g. slide) to deploy or adverse conditions outside the exit. In this section we examine the availability of exits in survivable accidents. Included in this analysis are accidents involving ruptures to the cabin.

3.1.1 Total exit availability

Here we simply consider exit availability as a function of total number of exits on board, irrespective of the exit positions or whether exits are single or paired. Before undertaking this analysis it is essential to define what is meant by an available exit. In this analysis an exit is considered to be 'available' when the exit and its evacuation assist means are physically and fully/safely functional, and passengers are permitted to use it by the crew. In addition, exits which may not meet the specified criteria, but which were actually used by at least one passenger are also considered to be 'available'. Furthermore, here we consider exit availability as a function of the total number of exits on board the aircraft, irrespective of the exit position (e.g. forward, aft, left, right) or whether exits are associated with exit pairs or are single exits.

Incidents within the database which are classed as precautionary evacuations or post-incident deplanings are not included in this analysis. These incidents are excluded as crew normally elect to evacuate passengers by convenient exit(s), such as forward or aft exits to which airstairs have been made available by airport personnel. 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. In this analysis, emergency evacuations in which passengers were instructed to use a single exit by cabin crew are considered to be situations in

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which only a single exit was available, unless passengers disobeyed instructions and made use of other exits. Only aircraft with three and four exit zones, as depicted in Fig. 1 and Fig. 2, are considered. Within AASK V4.0, 42 accidents were found to meet the criteria, 31 accidents involving aircraft with three exit zones and 11 accidents involving aircraft with four exit zones. The analysis considered the following accident reference numbers from the database: for the three exit zones analyses, accidents 2, 3, 7, 10, 16, 41, 43, 46, 49, 51, 55, 59, 61, 64, 66, 67, 70, 73, 75, 76, 80, 87, 90, 95, 96, 98, 100, 101, 102, 105 and 110, and for the four exit zone analyses, accidents 1, 6, 9, 17, 18, 30, 45, 53, 54, 62 and 79. This is significantly more data than in the earlier study which involved a total of 17 accidents[4].

The analysis shows (see Table 1) that for accidents involving aircraft with three exit zones, 11 (36%) have less than 50% of the exits available, (accidents 2, 10, 41, 55, 61, 67, 73, 75, 101, 102 and 110) six (19%) had exactly 50% of the exits available (accidents 16, 70, 90, 95, 96 and 98) and the 14 (45%) remaining had more than 50% of the exits available. Of the six accidents involving aircraft that had exactly 50% exit availability, three had all the exits available on one side (accidents 90, 95 and 96) and one had only the over-wing exit quad set of exits available (accident 98). For the 11 accidents involving aircraft with four exit zones, three (27%) accidents involved aircraft with less than 50% of the exits available (accidents 6, 30 and 79), one (9%) had exactly 50% of the exits available (accident 45, not down one side), and seven (64%) had more than 50% of the exits available (accidents 1, 9, 17, 18, 53, 54 and 62). As may be expected, smaller aircraft (i.e. those with only three exit zones) have a greater tendency than larger aircraft (i.e. those with four exit zones) to have less than 50% of their exits available following a crash. Combining the results for accidents involving aircraft with three and four exit zones, of the 42 accidents suitable for examination, 14 (33%) had less than 50% of exits available; 7 (17%) had exactly 50% of exits available and 21 (50%) had more than 50% exits available.

Furthermore, of the 42 accidents examined, 23 (55%) accidents involved an aircraft cabin section in which no exits were available. For three exit zone aircraft, accidents 2, 3, 10, 16, 41, 46, 51, 55, 61, 64, 66, 67, 70, 73, 75, 76, 98, 101 and 110 were used. For four exit zone aircraft, accident 6, 30, 45 and 79 were used. Only in three (7%) cases were all the exits available on one side of the aircraft. All three cases were three exit zone aircraft. Of these, one case involved a planned emergency evacuation of an in-tact cabin with no fire while the aircraft was waiting for departure (accident 95), while another involved an unplanned emergency during taxi following an engine fire (accident 90). In the third case (accident 96) passengers commenced unauthorised evacuation via left exits, and were then ordered to deplane via the Tailcone exit.

Table 1

Availability of exits in planned and unplanned emergency evacuations

Type of Accident	Less than 50% of exits available	Exactly 50% of exits 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%

In an earlier investigation Fons Schaeffer[8] studied exit availability in 114 accidents. His study was particularly concerned with situations where 'emergency exits were, or could have been, vital for survival'. In this study Schaeffer noted that 48% of accidents had less than 50% of exits available, 19% had exactly 50% of exits available and 33% of accidents had more than 50% of the exits available. The results from AASK V4.0 suggest that a smaller proportion of aircraft had less than 50% exits available. The Schaeffer study considered accidents from 1960 to 1989, while the AASK V4.0 study investigates accidents from 1977 – 1999, 79% of which occurred after 1989. A possible explanation for the lower occurrence of less than 50% exit availability in the AASK study could be the large number of less severe accidents contained in AASK V4.0 and the fact that AASK only contains data relating to survivable crashes.

As stated previously, the evacuation certification trial[2] invariably makes use of an exit configuration in which 50% of the exits are available and that one exit from each exit pair is available. This rule is applied regardless of the size (for aircraft with 44 seats or more) and type of aircraft.

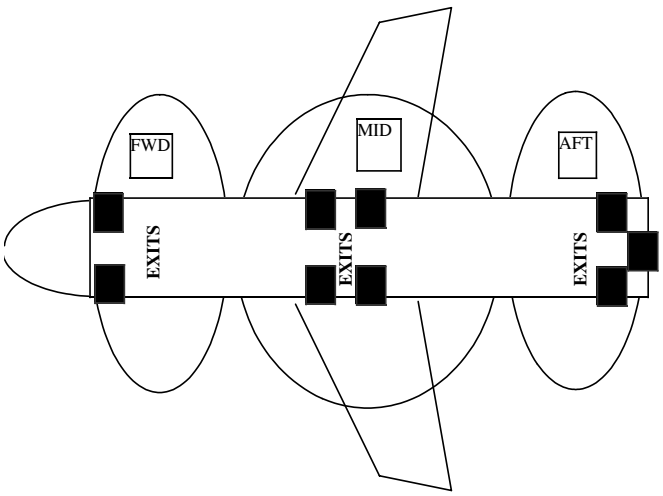


Figure 1. Aircraft showing three exit zones with the maximum possible exit configuration.

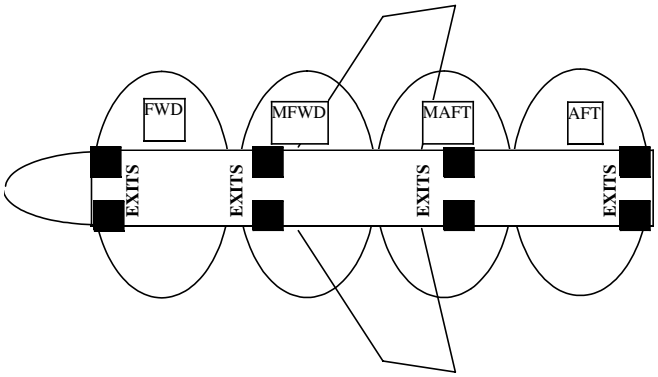


Figure 2. Aircraft showing four exit zones with the usual exit configuration.

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Table 2

Aircraft used in three exit pair aircraft exit availability analyses

Accident reference	Aircraft	Type of evacuation	Accident reference	Type of evacuation	Aircraft
2	B727-232	Unplanned Emergency	81	Precautionary	MD-82
16	MD-82	Unplanned Emergency	87	Unplanned Emergency	B737
43	B737-222	Unplanned Emergency	90	Unplanned Emergency	MD-88
46	B737-204	Unplanned Emergency	95	Planned Emergency	B737
49	B737-300	Unplanned Emergency	96	Unplanned Emergency	B727
52	B727-251	Post-Incident Deplaning	98	Planned Emergency	A320
59	B737-222	Unplanned Emergency	101	Planned Emergency	B737
70	B737-236	Unplanned Emergency	102	Planned Emergency	B737
73	MD-88	Planned Emergency	105	Unplanned Emergency	MD-80
80	B727-223	Unplanned Emergency			

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. In addition, the data 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. Furthermore, the accident analysis suggests and that over half (55%) of the accidents investigated involve a cabin section in which no exits were available. And of the accidents in which there were more than 50% of the exits available, almost half of these (43%) involve a cabin section in which no exits were available (accidents 3, 66, 76, 46, 51 and 64).

However, the statistics suggest that approximately 67% of the accidents investigated involve an exit availability of 50% or more. Thus, as the most frequently occurring exit availability involves more than 50% of the exits, it would not be unreasonable to require 50% exit availability in certification evacuation scenarios. Indeed, if frequency were the sole driver for selecting exit number in certification trials, taking 50% of the available exits would be considered conservative.

This line of argument ignores the fact that a significant minority (33%) of the accidents investigated had less than 50% exit availability, resulting in a significantly more challenging evacuation scenario. In addition, based on the data, there would be a strong argument to assume a configuration in which at least one exit zone had no available exits.

3.1.2 Exit availability as a function of location

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. In this analysis, the availability of exits within exit pairs is examined. The accidents used in this analysis ignore all those where the aircraft 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 passengers actually used an exit, 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 permitted to use it by cabin crew.

In accident 46 for example, Aft exits were successfully opened but the slides were not deployed due to orientation of the fuselage, and in accident 70 an Aft exit and slide were successfully deployed but smoke prohibited their use. Passengers in either accident did not use these exits. Exits not used due to the prevailing conditions or through specific crew instruction are considered unavailable. Using this definition, 19 accidents were selected, each one involving an aircraft with three pairs of exits (see Table 2). All cases included here have a strict arrangement of exit pairs in forward, mid and aft positions.

The additional data included for this analysis in Table 2 contains data derived from a precautionary evacuation and a post-incident deplaning (incidents 81 and 52 respectively) as well as several other orchestrated evacuations. The later group of evacuations are those in which the crew order the passengers to use particular exits in order to minimise the risks to passengers of using slides and to avoid the use of off-wing exits. Accidents 73, 98 and 102 entailed all passengers using one exit under Flight Crew orders. In accident 101 passengers were ordered to deplane via two exit positions, but using airport ladders, not the aircraft's escape assistance means, even though the accident scenario was far more serious than a precautionary evacuation. What characterises all these accidents is the wilful overlooking of available exits due to crew intervention. Finally accident 96 was an unauthorised, passenger-driven evacuation. Part way through this incident, the crew intervened and instructed all the passengers to evacuate via the Tailcone exit.

The frequency of exit availability for the remaining aircraft involved in these 12 accidents is displayed in Table 3. This analysis reveals a different result from that derived using the AASK V3.0 database[4] – which involved seven aircraft (accidents 2, 43, 46, 49, 52, 59 and 70 in Table 2).

Here we find that at the FWD generalised location, two exits are available in the majority of cases (50%), with a single exit available being the next most likely (42%). 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 very 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 significant number of cases, (25%) there are no AFT exits available.

The exit availability found using AASK V4.0 is different to that found using AASK V3.0, with the difference between the frequency of having one exit and two exit availability in the FWD and MID sections significantly decreasing in the current analysis. Also, the frequency of having no exits in the AFT section has increased significantly in the current study.

As part of the 90-second certification exercise, the trial criteria stipulate that only half of the available exits can be used. Without exception, where aircraft have exit pairs, only one exit of each

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pair is selected. If this scenario represented reality we would expect to see the highest percentages in the 'One Exit' column of Table 3. For aircraft with three exit zones, the current study 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 two exits available in the AFT section is almost equally likely.

The same analyses can be undertaken for aircraft with four exit pairs. Using the same selection criteria as that used for aircraft with three exit pairs we find that there are seven suitable aircraft (see Table 4). This analysis was not undertaken in the previous study using AASK V3.0[4] as there were insufficient accidents available for a meaningful analysis.

Here we find that the most common combination is to have both exits in an exit pair available in the FWD position, both exits in the MID-FWD position, and one exit in the MID-AFT position and one exit in the AFT position (see Table 5). In none of the cases examined were no exits available in the FWD and MID-FWD positions, but in four cases, no exits were available in the MID-AFT and AFT positions.

As can be seen from this analysis, the exit configuration used in certification analysis bears little resemblance to exit combinations frequently experienced in the investigated accidents. In addition – and consistent with the findings of the previous section – the exit availability distribution for aircraft with three exit zones is different to that for aircraft with four exit zones. Furthermore, the exit configuration actually used in the 90-second certification exercise is not a particularly onerous configuration as an exit is available in each cabin section.

While it is understood that the evacuation certification trial is intended to benchmark aircraft evacuation performance, this does not mean that the selected benchmark evacuation scenario should be both unchallenging and unrepresentative. For the benchmark to be effective it should serve as an indicator of safety, and to do so the benchmark should be as representative of reality as practical, taking into account relevant accident data.

Indeed, if the evacuation certification process was intended to convey a measure of safety, it would be preferable to examine several scenarios. If several scenarios were to be examined, in order not to unduly increase the chance of injury to participants and to keep costs to a reasonable level, these could be analysed using a combination of a full-scale trial and computer simulation as suggested in[17]. A suite of representative evacuation certification scenarios could be developed using the data available in AASK V4.0. Such a suite of evacuation scenarios would be sensitive to the type of aircraft, with aircraft possessing three exit zones possibly having a different configuration of available exits to aircraft with four exit zones.

For example, consider aircraft with three exit zones. A more challenging exit combination – while maintaining the 50% exit availability condition that is also consistent with the observed exit availability (i.e. consistent with findings from Sections 3.1.1 and 3.1.2) – would involve both exits in one of the locations and a single exit available in one other location. Suitable combinations of exits based on the frequency data identified in Table 3 in decreasing order of likelihood include:

(*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.

Table 3
Proportion of exit availability in terms of generalised exit positions for three-exit pair aircraft

	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%

Table 4
Aircraft used in four exit pair aircraft exit availability analyses

Accident reference	Aircraft	Type of evacuation
1	DC-10-30	Unplanned Emergency
9	A300-B4	Unplanned Emergency
17	B757-225	Unplanned Emergency
18	MD-11	Unplanned Emergency
30	L-1011-385-1	Unplanned Emergency
62	DC-10	Unplanned Emergency
79	A300B4-605R	Planned Emergency

Table 5
Proportion of exit availability in terms of generalised exit positions for four-exit pair aircraft

	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%

For aircraft with four exit pairs more challenging exit combinations – while maintaining the 50% exit availability condition that is also consistent with the observed exit availability (i.e. consistent with findings from Sections 3.1.1 and 3.1.2) – would include, in decreasing order of likelihood based on the frequency data identified in Table 5:

(*i*) Both FWD exits, both MID-FWD exits, no exits in the MID-AFT and no AFT exits available.

(*ii*) Both FWD exits, no exits in the MID-FWD, one exit in the MID-AFT and one AFT exit available.

(*iii*) No exit in the FWD, both exits in the MID-FWD, one exit in the MID-AFT and one AFT exit available.

(*iv*) Both FWD exits, one exit in the MID-FWD, one exit in the MID-AFT and no AFT exits available.

Table 6
Passenger use of nearest exit. Note values after the '/' include passengers where exit use and/or seat location is inferred

Category	Result
Pax reporting exit usage	879/1,441
Pax not using nearest available exit	291/503
% of pax with reported exit usage not using nearest available exit	15·2%/26·2%
Pax not using actual nearest exit (available or not)	355/598

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Table 7
Reasons for exit choice given by those passengers NOT using nearest exit. Note values after the '/' include pax where exit use and/or seat location is inferred

Reason for exit choice	Number of passengers
insufficient information provided	98/230
N/A (e.g. rescued)	3/5
nearest exit was/became unavailable	35/54
followed Attendant instructions	53/72
followed other passengers	27/38
shorter queue than other exits	16/20
choice made before egress	11/16
passenger thought this was his/her nearest exit (when it was not)	27/37
found exit during egress	9/12
followed emergency lights	4/4
only available exit	5/6
followed companion	2/2
helped through exit	1/7

(*v*) Both FWD exits, no exits in the MID-FWD, no exits in the MID-AFT and both AFT exits available.

(*vi*) No exits in the FWD, both exits in the MID-FWD, no exits in the MID-AFT and both AFT exits available.

Here it is again important to note that results presented above refer to a relatively small number of accidents and so cannot be considered conclusive.

3.2 Analysis of exit usage

The exits which passengers select in evacuation situations is of great interest to aviation safety regulators who make rulings defining exit separation and design aircraft evacuation certification requirements, aircraft designers who develop the interior layout of aircraft cabins and position exits within the fuselage, cabin safety specialists who develop procedures for managing aircraft evacuation and cabin crew who must control aircraft evacuations. It is often assumed that passengers have a tendency to select the exit from which they have entered the aircraft as this is the most familiar exit to the passenger. While this is thought to be the case in building evacuation situations – and there is a considerable amount of evidence to support this view[9] – it is not necessarily true in aircraft evacuations. Indeed, if this were the case in aircraft emergencies, the time required to evacuate the aircraft would be excessive. In addition, it is often assumed that passengers will move forwards towards an exit, ignoring exits which may be behind them. Studies using earlier versions of the AASK database – which contain considerably less data – have suggested that this is not the case in aircraft evacuation situations[3,4]. The analysis presented here examines these issues using the larger dataset available in AASK V4.0.

These analyses were based on the following accidents: 1, 2, 3, 4, 7, 8, 10, 16, 18, 19, 30, 43, 45, 46, 49, 51, 52, 53, 54, 55, 59, 60, 61, 62, 65, 66, 70, 72, 75, 78, 79, 80, 81, 84, 87, 89, 90, 92, 95, 96, 98, 99, 100, 101 and 110.

3.2.1 *Nearest exit usage*

This analysis is based on passenger accounts that clearly state both the seating location and exit used by the passenger. However, in some cases either the seat location or exit used is not clearly stated by the passenger. In most of these cases, the missing information can be inferred from other information such as other passenger accounts. Both results are presented, values appearing before the '/'are for those passengers who provide all the necessary information and values appearing after the '/'include inferred data.

Within AASK V4.0, 879 passengers (46% of passengers within the database) reported both their starting location and exit with which they exited the aircraft (see Table 6). If inferred information is included this number increases to 1,441 passengers (75% of passengers within the database). Of these, only 291/503 passengers (15%/26%) did not use their nearest serviceable exit (see Table 6).

This data suggests that 85% of passengers who report their exit usage make use of their nearest available exit (see Table 6). This figure represents a significant increase over that previously reported (70% tended to use their nearest serviceable exit based on analysis produced using data available in AASK V3.0[3,4].

Of the 291/503 passengers that did not use their nearest exit, 190/268 passengers supplied reasons for their actions. These reasons are summarised in Table 7. As can be seen, the passengers appeared to have a rational reason for selecting the exit they used to evacuate the aircraft. While by no means complete, this analysis suggests that an overwhelming 89% of those passengers reporting their exit usage, either used or had a rational reason not to use their nearest exit. (If the passengers with inferred data are included this figure becomes 84%). The remaining 11%/16% did not supply any reason for not using their nearest exit, however, this is not to say that they did not have a reason for their actions.

This analysis suggests that contrary to popular belief (and experience in buildings), passengers in emergency evacuation situations are likely to utilise their nearest exit. However, it must be noted that this analysis only considers those passengers who participated in interviews, who provided sufficient information and who survived the accident. Unfortunately, no information is available on those passengers who survived the incident but did not participate in the interview process or those passengers who perished. The increase in the numbers of passengers tending to utilise their nearest exit may be a result of better aircraft design in which the exits are more noticeable or the increasing tendency for crew to point out to passengers during the pre-flight safety briefing that the nearest exit may be behind the passenger or a combination of both.

Table 8
Direction of travel and distance travelled (seat rows) for passengers, where starting locations and exit usage is known or inferred. Note values after the '/' include pax where exit use and/or seat location is inferred

Direction	# Passengers	Travelled min. distance?	# Passengers	Mean distance
Forward	530/866	Yes	339/540	4·4/4·5
	No	191/326	11·3/ 12·4	
Aft	300/511	Yes	200/334	5·1/4·9
	No	100/177	10·7/11·3	
Exit Row	49/64	Yes	49/64	0

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3.2.2 Distance and direction traveled by survivors during egress

As has already been noted, it is a common held belief that passengers have a tendency to move forwards towards the front of the aircraft. This belief is often justified by stating that as passengers face towards the front of the aircraft this biases the passengers' choice of travel direction. As premium passenger cabin layouts in modern aircraft configurations increasingly have a mixture of forward and rear facing seats, this belief, if shown to be true could have serious repercussions for aircraft evacuation as considerable congestion and confusion may result from numerous contra flows resulting from passengers facing towards the front and rear of the aircraft. It is thus important to consider the direction travelled by the passengers when evacuating.

This analysis is based on passenger accounts that clearly state the direction in which they travelled or which can be firmly determined based on seating location and exit used. However, in some cases either the seat location and/or exit used is not clearly stated by the passenger. In most of these cases, the missing information can be inferred from other information such as other passenger accounts. Both results are presented, values appearing before the '/'are for those passengers who provide all the necessary information and values appearing after the '/' include inferred data.

Shown in Table 8 is the direction of travel for the 879/1,441 passengers for which we know the direction of travel. The results suggest that 60%/60% travelled forward, 34%/35% travelled towards the rear while the remainder were situated within an exit row. These results may suggest that passengers have a propensity for travelling forward.

However, of those passengers choosing to travel forward, 64%/62% have selected their nearest exit, while for those choosing to travel aft, 67%/65% have selected their nearest exit. The results suggest the reason so many passengers actually travelled forward is that their nearest exit was in front of them, rather than behind them. Thus the overriding ambition of the passengers is to exit via their nearest exit, rather than to travel forward. In addition, this further suggests that direction of travel and exit selection is based on a rational decision, at least for the survivors.

The mean distance travelled (in terms of seat rows) by survivors in evacuating is 6·5/7·0 seat rows. This compares with 6·1/6·3 seat rows found in earlier studies using AASK V3.0[3,4]. Furthermore, those passengers who select their nearest exit – excluding those in exit rows – travel on average approximately 4·7/4·7 seat rows regardless if they travel forward or aft, while those who do not travel towards their nearest exit travel at least two times as far.

It is interesting to compare these values with data generated in a study conducted by Snow *et al*[10] in 1970. This was one of the first systematic studies into human behaviour associated with aircraft evacuations. The study was based on the investigation of three fatal crashes involving: a DC-8 on 11 July 1961 with 114 passengers of which 17 died, a B727 on 11 November 1965 with 85 passengers of which 43 died, and a B707 on 23 November 1964 with 62 passengers of which 45 passengers and five crew died. All three incidents involved fire. The mean travel distance for survivors determined by Snow et al in his sample of three accidents was 4·1 seat rows. It should be noted that the accidents investigated by Snow et al were severe accidents involving fire in which a large number of passengers perished. As can be seen, the more recent analysis suggests that survivors are travelling almost 60% further compared with the earlier study. This difference suggests that passengers have a better chance of escaping a plane crash today then they did 30 years ago. However, the difference between the average distance travelled by survivors in the two studies could be due to a number of other factors such as the small number of accidents in the Snow sample, the gradual increase in aircraft size since the earlier Snow study, improvements to survivability characteristics of aircraft since the Snow study, the severity of the accident conditions in the Snow study compared to the conditions found in the AASK database, etc.

This type of analysis provides essential insight for both the development and application of computer models that attempt to simulate aircraft evacuation (see for example[11,12]). In developing passenger behaviour models for evacuation simulations, it is essential to understand that passengers are capable of making rational decisions when it comes to exit selection during certain types of emergency evacuation situation. In addition, when specifying the nature of the scenario to be simulated, it may be necessary to specify the nature of the passenger behaviour expected[11,12]. Thus it is essential to know that the majority of passengers attempt to utilise their nearest exit. Most importantly however, this type of analysis is extremely valuable in aiding our understanding of the behaviour of people in real accidents as opposed to behaviour observed in controlled experiments or certification trials.

3.2.3 Comparison of AASK and 90 second trial exit usage

AASK V4.0 was used to analyse evacuation data arising from 90-second certification trials. AASK was used to determine the distance travelled by passengers in the trials to their exit point and to determine whether or not passengers made use of their nearest exit. Trial data involving 5,530 passengers from a total of 18 aircraft was used, 12 of which were wide-bodied and six of which were narrow-bodied[13] aircraft.

The AASK analysis of this data suggests that on average 76% of passengers in certification trials make use of their nearest exit. This is compared with 85% of passengers (see Section 3.2.1) who used their nearest exit (which goes up to 89% of passengers who made use of their nearest exit or had a good reason for not using their nearest exit) in accidents. Only in two of the 18 certification trials does the number of passengers using their nearest exit exceed the value achieved in accident situations.

While in certification trials, the majority of passengers utilise their nearest exit, as noted in real accidents, the number of passengers utilising their nearest exit is significantly less (a 12% difference) than that observed in real accidents. In certification trials, cabin crew attempt to direct passengers towards the optimal exit in order to achieve a minimum evacuation time for the aircraft. In aircraft evacuation situations, it may not be very efficient to allow passengers to utilise their nearest exit, especially if there is a significant difference in exit flow rate capacity or exit performance and so cabin crew are trained to redirect passengers towards their most efficient exit (which may not be their nearest exit).

This is especially the case in aircraft with three exit zones (i.e. smaller aircraft) which have Type III exits (i.e. small hatch type exits) normally located in the central part of the aircraft over the wing. This type of exit is quite small and awkward to use and as a result it has a low flow rate compared to other larger floor level exits. As this type of exit is normally located near the centre of the aircraft (i.e. away from the front or rear end) it is surrounded by passengers and as a result is the nearest exit for the majority of the passengers on board. Thus if passengers are drawn to their nearest exit we can expect these centrally located exits to attract many passengers – more so than can efficiently utilise the exit. In terms of certification trials this could be disastrous as too many passengers would be attracted to the exit, prolonging evacuation times. As a result crew management procedures have been developed to direct passengers away from these exits. However, while the procedures may work in certification conditions do they work in actual accidents? AASK was used to investigate this issue by examining incidents involving aircraft with three exit zones and comparing this with certification performance.

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Table 9

Exit usage in terms of percentage of passengers using each generalised exit position (in planned or unplanned emergency evacuations). Information in brackets identifies exit type.

Accident reference	Pax Loading	Fwd (%)	Mid (%)	Aft (%)
(7)	39·0%	44· (I)	50·0 (III)	5·3 (I)
(43)	93·6%	19·2 (I)	61·5 (III)	19·2 (I)
(59)	96·6%	39·5 (I)	37·2 (III)	23·3 (I)
(80)	79·5%	23·6 (I)	58·3 (III)	18·1 (I)
(87)	78·1%	17·3 (I)	48·3 (III)	34·5 (I)
(90)	31·7%	27·8 (I)	16·7 (III)	55·6 (I)
(95)	85·2%	38·9 (I)	27·7 (III)	33·3 (I)
(96)	102·0%	6·3 (I)	11·3 (III)	82·5 (I)
Mean	75·8%	27·2	38·8	34·0

This analysis was first performed using AASK V3.0[4]. Here we repeat the analysis with the larger data set found in AASK V4.0. Of the accidents in AASK, eight accidents with three exit zones were found to be suitable for analysis (see Table 9). The selection criteria restricted the selection of accidents to planned or unplanned emergency evacuations and required that at least one exit in each exit zone was available during the evacuation. The results from the analysis were normalised so that the percentages shown represent the percentage of the total passengers where exit usage is known for each aircraft. It is important to note that with the exception of accident 7, no passenger fatalities were reported in these accidents. There were two fatalities in accident 7. These passengers were killed by crash trauma while still seated. Emergency personnel extricated five other passengers via a rupture. In all the other cases, passengers self-evacuated via exits.

This analysis shows that unlike the behaviour noted in certification trials (see Table 10) on average, the majority of passengers tend to utilise the central Type III exits. However, this trend has reduced when compared to the analysis undertaken using AASK V3.0[4], with only 38·8% of passengers utilising the centre exit compared with 49·6% in the earlier study. In the V3.0 analysis, the analysis was restricted to only three suitable aircraft, while in this study, the number of aircraft has increased to eight.

However on closer examination, not all the accidents included in this analysis are appropriate and so should be discarded from the analysis. Accident Ref. 7 had a passenger loading of only 39% while accident Ref. 90 had a passenger loading of only 31% of which less than half provided exiting information. These aircraft should be discarded due to the low numbers of passengers for which we have exit usage as they do not provide an appropriate basis for comparison with certification conditions (it should be noted that accident 7 was included in the previous study). Accident reference 95 should be discarded from this analysis because it included many passengers who while intending to use the mid Type III exit were forced to relocate to forward and aft exits due to passengers on the wing backing up to the exit. Accident reference 96 should also be discarded because it was a passenger-initiated unplanned emergency evacuation in which the flight crew halted and ordered a deplaning via the rear Tailcone exit.

Table 10

Generalised passenger exit usage for aircraft with three exit pairs in 90-second certification trials

Aircraft	Fwd %	Mid %	Aft %
1	40	20	40
2	27	37	36
Mean (%)	33·5	28·5	38

Table 11

Exit usage in terms of percentage of passengers using each generalised exit position during higher loaded, authorised evacuations with minimal exit redirection

Accident reference Appendix B Reference	Pax Loading	Fwd (%)	Mid (%)	Aft (%)
(43)	93·6%	19·2 (I)	61·5 (III)	19·2 (I)
(59)	96·6%	39·5 (I)	37·2 (III)	23·3 (I)
(80)	79·5%	23·6 (I)	58·3 (III)	18·1 (I)
(87)	78·1%	17·3 (I)	48·3 (III)	34·5 (I)
Mean	87·0%	24·9 (I)	51·3 (III)	23·8 (I)

Several other possible candidate aircraft were excluded from the above analysis. This was due to the circumstances of the incidents. In one case all passengers exited from the Tailcone exit, in another incident, one of the exits was jammed and was only made available late in the accident sequence, while in a third incident one of the available exits was not used due to smoke.

When these accidents are removed from the analysis, a different picture emerges (see Table 11). The trend to utilise the central exits is shown to be much stronger in real accidents than in the certification trial. The average number of people using the centre Type III exits has increased to 51·3% (see Table 11) compared to 28·5% (see Table 10) observed in certification trials. However, it is important to note that results presented in Table 11 only refer to four accidents. This analysis makes use of three accidents that were not available in the earlier study and discards one of the earlier accepted cases due to the small number of passengers involved.

In actual accidents, there appears to be a biased trend for exit usage in the midsections (i.e. the nearest exit for the majority of passengers) of the aircraft. Yet in the certification trials, the mean load on each exit pair is far more even and furthermore, in one aircraft fewer passengers use the midsection exits, the reverse of that seen in actual accidents.

The most probable reason for this lies in the behaviour of the passengers. Essentially, in real accident situations passengers have a higher motivation to escape than they do in experiments or in certification trials and tend to do so by what they perceive to be the most direct method – their nearest exit.

Cabin crew procedures developed from and used in evacuation experiments[14-16] and certification trials work quite well and achieve a well-balanced evacuation with most of the exits working in an efficient 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

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environmental conditions – and attempt to use 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 – given that all the exits have similar flow capabilities. It is possible that while passengers are aware of the location of their nearest exit, they are not 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. This is an area requiring further investigation utilising the historical record, controlled experimentation and passenger surveys. The finding concerning exit usage may have implications for the pre-flight safety briefing and cabin crew passenger management procedures and suggests that formulating cabin crew procedures on the basis of certification experience or controlled experimental conditions may be misleading in terms of their actual effectiveness.

4.0 CONCLUSIONS

In this paper we have attempted to address several of the misconceptions and myths concerning passenger evacuation behaviour through analysis of accident data using the AASK V4.0 database. These safety issues are associated with passenger exiting behaviour and exit configurations experienced during survivable crashes. In addressing these misconceptions we have also examined issues concerning the exit selection used in aircraft evacuation certification.

This analysis suggests that contrary to popular belief, passengers in emergency evacuation situations are likely to utilise their nearest exit. Indeed, the data suggests that 85% of passengers who report their exit usage make use of their nearest available exit (based on accounts from 879 passengers). Of the 291 passengers that did not use their nearest exit, 190 passengers supplied rational reasons for their actions. Furthermore, 879 passengers provided information concerning their direction of travel during evacuation and this data suggests that 60% of passengers travelled forward. However, of those passengers choosing to travel forward, 64% selected their nearest exit, while for those choosing to travel towards the aft, 67% selected their nearest exit. This result suggests that the reason so many passengers actually travelled forward is that their nearest exit was in front of them, rather than behind them.

These two findings – based on a considerable amount of data – suggest that even under emergency evacuation situations, passengers are capable of making rational decisions (based on the information available to them and their knowledge of the aircraft), at least as far as direction of travel and exit selection is concerned. These findings support the view that passengers do not become mindless automata when faced with emergency situations. This is important not only to our understanding of evacuation behaviour, but also to the development of computer models that attempt to simulate aircraft evacuation. It is also of fundamental importance in specifying the nature of representative aircraft evacuation scenarios which need to be modelled as part of a design or certification analysis.

The evacuation certification trial is the aviation industries benchmark of aircraft evacuation performance, and rightly or wrongly, is considered by the travelling public and safety professionals alike as the ultimate kite-mark of evacuation safety. However, for the benchmark to be effective it should serve as an indicator of safety, and to do so the benchmark should be as representative of reality as practical. While it is acknowledged that in the interests of safety it is not desirable or possible to make the evacuation certification trial closely resemble real accident situations, it is possible and indeed essential that the exit availability resemble as closely as possible challenging exit configurations typically found in accident scenarios. While it is true that no two accidents are alike, it is possible to investigate statistical data and identify both frequently occurring and challenging exit combinations that could be used in certification.

It is suggested that the certification practice of using half the available exits predominately down one side of the aircraft, regardless of size or type of aircraft is neither statistically relevant nor challenging. 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. In addition, the data 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. Furthermore, the accident analysis suggests and that over half (55%) of the accidents investigated involve a cabin section in which no exits were available.

Based on the accident data, a suite of more representative and challenging exit combinations for aircraft with three exit pairs and four exit pairs – while maintaining the 50% availability condition – has been suggested. A suitable set of such cases could be selected and used in the evacuation certification process. To efficiently examine such an extended set of evacuation certification cases, it is suggested that a combination of a full-scale evacuation trial and computer simulation be used.

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