An analysis of passenger performance on stairs and upper deck slides during evacuation trials: A report from the VERRES project

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ABSTRACT
This paper reports on research work undertaken for the European Commission funded study GMA2/2000/32039 Very Large Transport Aircraft (VLTA) Emergency Requirements Research Evacuation Study (VERRES). A particular focus of VERRES was on evacuation issues and several large-scale evacuation trials were conducted in the CRANFIELD simulator. This paper addresses part of the research undertaken for Work Package 3 by the University of Greenwich with a focus on the analysis of the data concerning passenger use of stairs and passenger exit hesitation time analysis for upper deck slides.

1 Introduction

This paper reports on research work undertaken for the European Commission funded study GMA2/2000/32039 Very Large Transport Aircraft (VLTA) Emergency Requirements Research Evacuation Study (VERRES). The VERRES consortium was made up of University of Greenwich, Cranfield University, The UK CAA, EADS Airbus, Virgin Atlantic and Sofreavia with ETF (SNPNC) and the JAA as observers. The purpose of VERRES was to investigate a number of issues relating to post-accident survivability of future large aircraft. A particular focus was on evacuation issues and several large-scale evacuation trials were conducted in the CRANFIELD simulator. This paper addresses part of the research undertaken for Work Package 3 by FSEG of the University of Greenwich with a focus on the analysis of the data concerning passenger use of stairs and passenger exit hesitation time analysis for upper deck slides. This paper only represents a summary of the findings. The full report can be found on the FSEG web pages at: http://fseg.gre.ac.uk/fire/VERRES_Project.html.

The trials were conducted over two days, the first taking place on the 25th January and the second on the 1st February 2003. The trials consisted of a series of four separate tests to be conducted on each of the two days. On each day a fresh cohort of test subjects would be utilised for each of the four tests. In this way two data points would be derived for each of the four tests. The tests were primarily intended to investigate the behaviour and performance of passengers utilising the main staircase. In addition, as an upper deck exit with slide was to be used during the trials, passenger exit hesitation times could also be usefully collected for the upper deck slide. As each cohort of volunteers would undertake four different trials, the ordering of the trials was designed to limit the learning influence on the outcome of the results

The trials were intended to explore various aspects of aircraft evacuation in which passengers made use of the main stairs linking the upper and lower deck. In particular the following aspects were highlighted by the consortium for investigation and were to be part of the University of Greenwich analysis. Other aspects of the evacuation were investigated by other members of the consortium.

1) Given a free choice (i.e. without direct intervention of Cabin Crew (CC)), how many passengers on the upper deck would elect to use the stairs to evacuate via the exits on the lower deck. The analysis would involve not only the numbers of passengers but also consider the circumstances and motivations influencing the decision to use the stairs.
2) Note the behaviour of passengers utilising the staircase.
3) Measure flow rates achieved by passengers using the stairs in both the upward and downward directions.
4) Measure the population densities on the staircase.
5) Measure the frequency of passengers utilising the hand rails (HR).
6) Explore the efficiency of staircase usage with zero or two CC managing the staircase flow.

Unfortunately, the trials did not proceed as anticipated. This means that not all of the objectives highlighted above can be satisfied. In summary, the main difficulties associated with these trials preventing the intended data analysis are as follows:

1) CC did not behave as originally expected. For example, in the first trial were free choice was intended, crew at the forward exits on the upper deck directed passengers to use the stairs and exit via the lower deck exits. This meant that it was not possible to (a) measure the propensity of passengers to elect to use the staircase and (b) it was not possible to estimate the passenger stair efficiency and flow rates without crew directing them downstairs. In other trials, crew directed passengers down the stairs when the trial was intended to measure the flow rates and stair efficiencies for passengers travelling upstairs (from the lower deck to the upper deck). It was apparent that in all the trials, crew played some role in managing the passenger flow on the stairs. It should be noted that CC were not given any special instructions as to how to control passengers on stairs and this type of behaviour is not a normal part of their training.
2) The camera angle for cameras intended to show the passenger stair behaviour on the first day trials were such that three separate cameras would need to be used to investigate passenger performance and behaviour on the stairs. Furthermore, even using these three cameras, a central portion of the stair was missing from view. While this difficulty was corrected for the second day’s trials, this meant that much of the video footage collected on the first day was either extremely difficult to analyse or not appropriate for analysis.
3) While the upper deck slide is considerably different to that expected to be used in actual VLTA such as the A380, the passenger exit hesitation times are of interest in aiding our understanding of passenger behaviour.
4) As these were the first trials to make use of the upper deck slides, the Cranfield crew that staffed the exit exhibited great caution and as such the majority of crew behaviour at the upper deck exits can be described as extremely non-assertive. This crew behaviour significantly biases the behaviour and hence performance of the passengers. It is thus not clear if the resultant passenger behaviour is a result of the sill height and slide length or the lack of assertiveness of the crew.

Given the actual behaviour that occurred during the experiments and based on the video footage provided the following data could be collected:

1. Average stair flow rates, i.e. flow rates that include periods of non-flow and/or obstructed flow, etc.
2. HR usage was determined using camera 13 and was consequently only calculated for Day 2.
3. Stair data was measured for both the left and right lanes (when looking up the stairs). Combination data could be derived from the Left and Right data as desired.
4. It was also possible to measure passenger exit hesitation times and generate a distribution of these, including identification of participants who sat at the exit.

2 Staircase performance

As already described in the introduction, the trials did not proceed as intended and this had an impact on the nature of the data that could be analysed. Throughout the trials, lower deck CC invariably dealt with lower deck participants first and those descending the stairs only when free. In both trials in which participants were intended to travel UPSTAIRS, trails participants initially descended stairs.

2.1 Behaviour on Stairs

Several types of participant action where noted on the stairs that will have implications for flow rates. These behaviours occurred within the staircase ***lanes*** defined by the free space between the HRs. The staircase in the Cranfield simulator consists of two distinct lanes.

2.1.1 Definition of frequently used descriptive terms

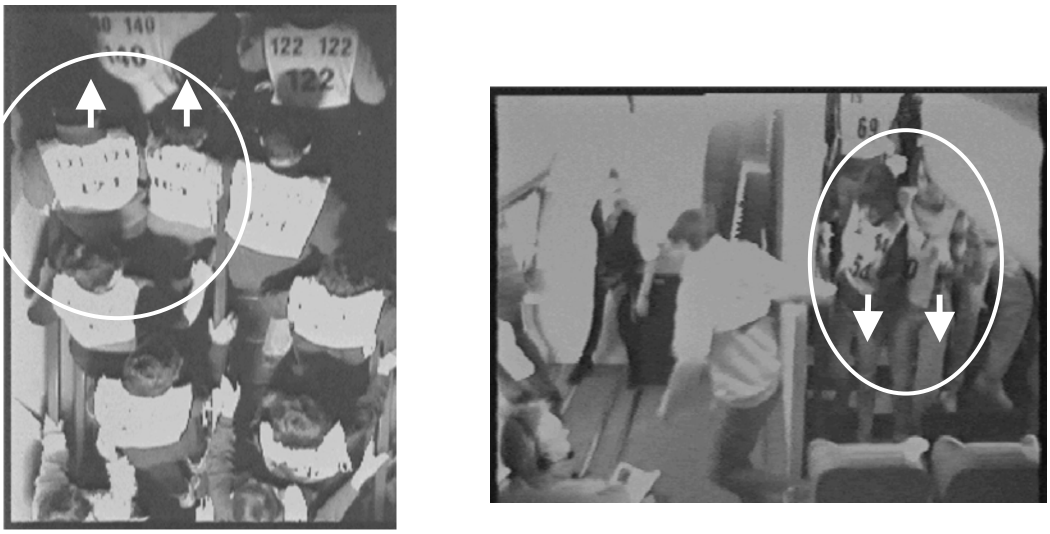
For clarity the staircase is defined as follows:

- The stair consisted of two distinct passenger lanes separated by a central HR.
- The width of the left lane (as measured from the centre of each HR) was 76.8 cms.
- The width of the right lane (as measured from the centre of each HR) was 75.8 cms.
- The width of the left lane (as measured from outermost portion of the HRs) was 73 cms.
- The width of the right lane (as measured from outermost portion of the HRs) was 72 cms
- The effective width of the left lane (allowing for 9 cms from each HR) was 58.8 m.
- The effective width of the left lane (allowing for 9 cms from each HR) was 57.8 m.
- The riser height was 17.8 m.
- The tread depth was 26 cms.
- There were 16 stairs from bottom to top (excluding the floor of each deck).
- Using camera 13, 11 of the 16 stairs were visible.
- There were 11 visible steps from camera 13.

Terms frequently used to describe the behaviour of the participants in this document will now be defined. HR use was characterised by participant holding or touching; (a) both hand rails, (b) only the side hand rail or (c) only the centre hand rail. `Use' was taken to mean any contact at any point in the camera shot from which measures were being taken. Many participants used the side HR to swing around to the exit during DOWN stairs movement. Some participants used a 2 handed grip, probably due to CC exhortation to hasten .

The term ‘Single file’ in this report refers to participants filing down / up the stairs in a single line i.e. one person per lane. In single file, free flow conditions and unhurried, less urgent conditions e.g. Trial 1.1 participants tried to maintain personal space between others. When flow was more urgent and congested, particularly in upstairs flows, close staggering / dual usage and occasionally overtaking occurred. The term ‘vaulting’ refers to participants who put all their body weight on their arms holding side and centre HRs, and then jump across several treads in one action. This only occurred during free flow conditions and may possibly occur with greater frequency during more ‘urgent’ evacuations involving passenger motivation.

‘Overtaking’ refers to a participant passing a slower participate located within the same lane. ‘Dual usage’ refers to a flow condition in which two participants move side-by-side for a period of time. This behaviour was witnessed during upwards (Figure 1(a)) and downwards stair movement (Figure 1(b)).



(a) (b)

Figure 1: Examples of Dual usage of a tread by participants

‘Dual flow’ refers to consecutive dual usage by more than one pair of participants. Again this occurred during both upwards and downwards movement. ‘Close staggering’ refers to flow which that was almost dual flow but without participants sharing the same tread. In this flow condition participants bunched together to the point of being packed / dual flow. Close staggering occurred during upwards and downwards movement.

2.1.2 Description of stair behaviours

On occasions participants were witnessed conflicting for space on the stairs. This usually occurred on the Upper and Lower deck landings whilst attempting to access the stairs. The situation was typically resolved by a participant stopping to let the other go ahead, or alternatively both used the stairs and a dual flow condition occurred.

As the CC did not which exits were to be made available, the trials on Day 1 Trial 3 and Day 2 Trial 2 were characterised by confusion on the part of the CC relating to the direction of stair use, i.e. UP or DOWN. This confusion typically prevailed for the first 16-17 seconds of these evacuations. In these trials participants at first attempted to descend the stairs. After 16-17 seconds had elapsed the flow turned and went in the intended direction of the experimental design. The initial periods of these trials were however subjected to a large degree of disorganisation on the stairs. Two examples can be seen in (Figure 2(a) and (Figure 2(b)).

Another behaviour that was noted was that at the start of some trials (i.e. Day 2 Trial 1) Upper deck participants had to queue on the stairs while lower deck participants evacuated (Figure 3). Whilst at the start of others (i.e. Day 1 Trial 4) some Upper deck participants disobeyed the CC that was attempting to block the use of the stair use.

(a) (b)

Figure 2: Disorganisation and resulting confluences on stairs
NOTE: the direction of travel according the experimental design was upwards.

During Day 2 Trial 2 the experimental design dictated that passengers should descend the stairs to evacuate via lower deck exits as none of the upper deck exits were available. During the early stages of this evacuation the CC at the stairs on the upper deck deliberately stopped passengers from using the stairs. This action was taken as the CC was waiting to see if any of the upper deck exits were operable CC (see Figure 4). During this period the CC appeared to be advocating the use of Upper Forward exits. Despite this, some participants were observed to disobey the CC and use the stairs (see Figure 4).

Figure 3: Participants queue DOWN right lane of stairs

Figure 4: Two participants disobeying CC (in centre with back to camera, telling participants to go forward) during DOWN stairs movement

The modal class of behaviour from those described was free flowing / single file movement. The second most typically flow condition was close staggering. Close staggering was usually coupled with higher densities on the stairs. In one of the downwards and both upwards movement trails, densities were higher and the flow was characterised as being dual usage

2.2 Stair population densities

Stair population densities could not be determined from the trials on Day 1 due to camera positioning and so only densities associated with Day 2 are presented here. The density on the stairs was measured using Camera 13 and calculated for the visible portion of the stairs only. The video footage was stopped every two seconds and the number of visible participants recorded. From this the density was calculated using the effective width [1] across the number of visible treads. To aid the discussion some hypothetical densities based on various stair behaviours can be seen in Table 1.

The stair densities as a function of time are displayed in Figure 5 to Figure 8. From these figures it is clear that the stair densities in the UPWARD direction is greater than that in the DOWNWARD direction and that maximum stair density recorded approached 5 passengers/metre^2. This was recorded during Day 2 Trial 2 and involved passengers moving upwards. In this trial the flow condition was characterised as being dual / dual staggered. Note that it is thought that the high density observed on Day 2 Trial 2 did not result from the disorganisation at the start of the trial (recall that initially passengers descended the stairs) as the highest densities occur once the flow has begun moving upwards.

Lower densities occurred in all of the DOWNWARDS movement trials performed on Day 2. These trials typically generated densities between 2.5 and 3.5 passengers/metre^2. These densities are broadly equivalent to having one passenger located every other tread, i.e. a single file flow.

Table 1: Hypothetical densities based on imposed packing densities

	Number of passengers		**Density (passengers/metre^2)**	
	Left lane	**Right lane**	**Left lane**	**Right lane**
1 passenger per tread	11	11	6.5	6.7
1 passenger every other tread	5.5	5.5	3.3	3.3
2 passengers per tread	22	22	13.1	13.3
2 passengers every other tread	11	11	6.5	6.7

While average individual stair speeds were not measured, it is hypothesised that the average upward travel speed of the participants is slightly less than the average downwards travel speed leading to a greater degree of bunching in the UPWARDS direction. This hypothesis is supported by evidence from the building industry, where the average stair speed in the UPWARD direction is generally accepted as being lower than the DOWNWARD speed. Another possible explanation for the difference in the observed packing densities could involve the nature of the discharge from the stairs in both cases. In situations with an UPWARD movement, the upper discharge from the stairs consists of two passenger aisles leading forward. In the DOWNWARDS movement trials, the discharge from the stairs can be fed by four aisles, (2 moving forwards and 2 moving aft wards). In the UPWARDS case there is greater potential for a bottleneck or slower discharge resulting in the higher observed densities.

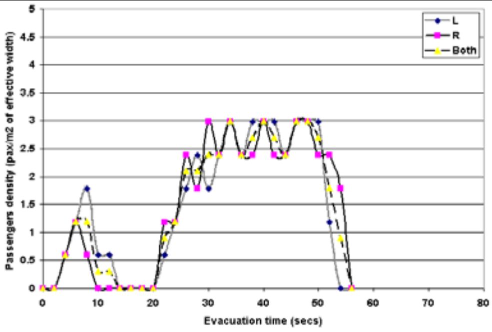


Figure 5: Density in visible portion of stairway during Trial 2.1 (DOWNWARDS TRAVEL)

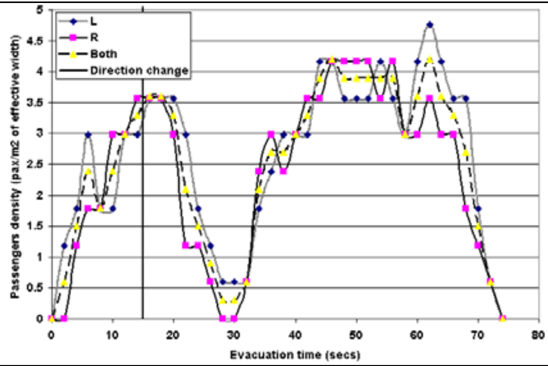


Figure 6: Density in visible portion of stairway during Trial 2.2 (DOWNWARDS and then UPWARDS TRAVEL)

It is also worth noting that the maximum density of 5 passengers/metre^2 is less than what would be expected if we had achieved one passenger per tread or two passengers every other tread (6 passengers/metre^2) and greater than if we had one passenger every other treed (3.3 passengers/metre^2). Thus, while the packing densities are high, they are not as high as could be achieved.

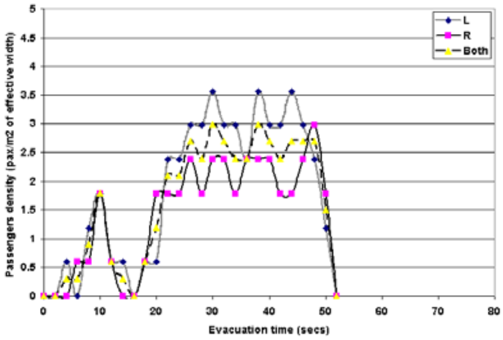


Figure 7: Density in visible portion of stairway during Trial 2.3 (UPWARDS TRAVEL)

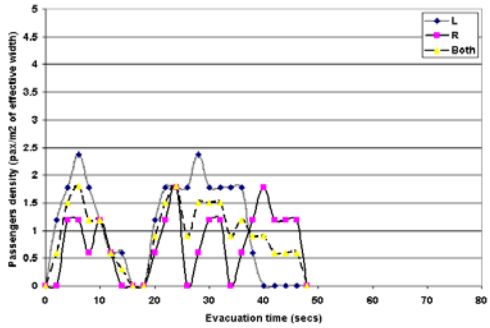


Figure 8: Density in visible portion of stairway during Trial 2.4 (DOWNWARDS TRAVEL)

2.3 Stair flow rates

2.3.1 Calculation of Stair flow rates

During the first pass at video analysis it became apparent that the central HR effectively created two separate staircases, with no participant ever crossing the central HR. The decision was made to analyse the left lane and right lane separately and then to combine the data. Average flow rates (AFR) – measured in paxs/minute - were calculated for the total period of passenger usage - this may include periods of no-flow (i.e. 'dry-ups') and periods of blocked discharge. During day 1 cameras 2, 4 and 12 were used. These measurements are extremely difficult and subject to error due to the use of several different cameras. Also, some important information is not recorded by these cameras. ***Thus, data from day 1 should not be considered very reliable.*** Trials for the second day were analysed using camera 13. Flow termination was determined at the visible point of discharge, i.e. the top of the stairs when ascending, and the bottom when descending. Similarly flow inception was determined using the point of flow initiation, depending upon the direction of travel this was the upper or lower most visible tread.

In detail, the first stage was to calculate Stair Use time. In Day 1 Trials cameras 2, 4 and 12 were used. For DOWN trails (1, 2 and 4) Stair Use time commenced with the time at which the first participant placed a foot on the first USED tread at the top of the stairs. `Used' covers the situation where a participant vaults more than one tread at a time. Stair Use time ended when the last participant placed a foot on the lower deck landing. Again this is to include those participants who leap the last few treads. The start of the UP trial (Day 1 Trial 3) was characterised by unintended descent by Upper deck participants, who then turned to ascend the stairs.

Discounting these Upper deck participants and measuring only Lower deck participants correctly ascending was the ideal. However no break in flow occurred to enable a reliable commencement of the UP measure to be made of Stair Use time. For the UP commencement marker, the first participants on the stairs to visibly turn to face UP were used. The same end point as DOWN was used but was measured on the upper not lower deck landing.

In Day 2 Trials camera 13 was used. For DOWN stairs conditions this commenced with the time at which the first participant began to enter the camera 13 shot and ended when the last participant disappeared from the camera 13 shot. This procedure was used for Day 2 Trials 1, 3 and 4. The 'first participant' in the UP stairs trial (D2T2) was deemed to be the first lower deck participant to appear following a break in stair use, following the unintended descent of Upper deck participants at the start of the trial, after they had retreated upstairs and disappeared from view. Stair Use time commenced with the time at which the first participant began to enter the camera 13 shot (lowest point visible on stairs) and ended when the last participant placed a foot on the Upper landing, which is visible in the camera 13 shot.

Stair Use time reflects periods of non-use of the stairs following the first participant, periods of waiting and queuing on the stairs, periods of free flow and periods of dense flow and congestion. Average flow rate was calculated by dividing Stair Use time into the number of participants who used the stairs, then multiplying by 60 gives a persons per minute flow rate, for both lanes then in combination. For the 2 UP conditions only those moving as intended were used in Stair Use and AFR calculations.

2.3.2 Stair flow rates

The average stair flow rates measured in the trials is presented in Table 2. As can be seen from these results, the mean flow rate in the UPWARD direction is greater than the mean flow rate in the DOWNWARDS direction. The average stair flow rate (per unit width) is a function of the average packing density and the average travel speed. For a given width stair, the stair flow rate may be increased by either increasing the stair flow rate or increasing the average travel speed. The higher flow rates when travelling UPWARDS are thought to originate from the higher packing densities that were witnessed on the stairs during these trials. It is suggested that while the average UPWARDS travel speed has been hypothesised to be less than the average DOWNWARDS travel speed, the increase in packing density compensates for this reduction, resulting in a greater flow rate.

The flow rates presented here are less than what may be expected to be achieved in emergency situations. Two reasons for this concern the calculation technique adopted and the nature of the trials. With regards the calculation technique, as an average flow rate was calculated, periods of non-flow were included in the flow rate calculations. This will result in the calculated flow rate being less than the actual achieved flow rate during periods of passenger flow. With regards to the trial conditions, it has already been noted in Section 2.2 that the stair packing densities were less than what could be expected. A possible explanation for this relates to the procedures adopted in the trial. The level of participant urgency was low for these trials and this could have resulted in the low levels of packing densities. In most trials participants were unhurried with gaps of one or more treads between them. In others, particularly those ascending the stairs, higher densities were apparent. CC activity on the lower deck may also have effected stair flow rates.

Another aspect that could influence stair flow rates concern the physical layout of the aircraft. When considering the evacuation efficiency of aircraft design, much can be learned about the potential performance of the aircraft layout by considering the aircraft as an escape system made up of a series of sub-components. These sub-components have a supply and discharge capability that must be balanced in order to achieve an efficient evacuation performance. Thus, the physical layout of the stairs, the cabin layout in the immediate vicinity of the stairs, the approach to the stairs finally the exits must be considered as an entire system. Each component will influence the performance of the system as a whole.

Table 2: Average stair flow rates for all trials

		Left lane		Right lane		Combined	
Trial	**Direction**	**Flow rate (pax/minute)**	**Users**	**Flow Rate (pax/minute)**	**Users**	**Flow rate (pax/minute)**	**Users**
1.1 *	DOWN	45.1	24	36.8	28	68.3	52
1.2 *	DOWN	45.6	39	53.2	46	97.7	85
1.3 *	UP #	63.4	56	60.6	58	119.2	114
1.4 *	DOWN	50.0	42	51.1	42	108.4	84
2.1 $	DOWN	48.2	41	49.4	44	95.1	85
2.2 $	UP ##	68.3	47	64.1	44	132.2	91
2.3 $	DOWN	54.8	44	52.2	41	105.2	85
2.4 $	DOWN	40.4	26	30.3	23	62.3	49
MEAN	**DOWN**	47.4	36.0	45.5	37.3	89.5	73.3
MEAN	**UP**	65.9	51.5	62.4	51.0	125.7	102.5

* Cameras 2, 4 and 12 used
$ Camera 13 used
# flow measure includes participants undertaking incorrect procedure
flow measured from point at which correct procedure occurred

2.3.3 Comparison of Stair flow rates with building evacuations

The unit flow rate capacity for a standard stair as specified in the UK Building Code [2] is 80 people/metre/minute. This equates to 1.33 people/metre/second. The unit flow rates measured in these trials together with the equivalent value as specified in the building regulations are displayed in Table 3. From Table 3 it is apparent the DOWNWARDS flow rates that were generated during the trials are broadly equivalent to those expressed in building regulations. However, for UPWARDS movement the flow rates generated by the trials are 35% higher than those prescribed in building regulations. It should however be noted that the UK Building Code does not specify a unique value for stair ascent. It is assumed that stair movement is in the DOWNWARDS direction.

Table 3: Flow rates expressed per unit of effective width

		Flow rate (passengers/metre of effective width/second)		Flow rate (passengers/metre/ second
		Left Lane	Right Lane	Building codes
1.1 *	DOWN	1.28	1.06	1.33
1.2 *	DOWN	1.29	1.53	1.33
1.3 *	UP#	1.80	1.75	1.33
1.4 *	DOWN	1.42	1.47	1.33
2.1 $	DOWN	1.37	1.42	1.33
2.2 $	UP##	1.94	1.85	1.33
2.3 $	DOWN	1.55	1.51	1.33
2.4 $	DOWN	1.15	0.87	1.33
Mean	DOWN	1.34	1.31	1.33
Mean	UP	1.87	1.80	1.33

* Cameras 2, 4 and 12 used
$ Camera 13 used
# flow measure includes participants undertaking incorrect procedure
flow measured from point at which correct procedure occurred

2.4 Stair Hand Rail usage

Determining HR usage was very difficult for day 1 trials due to the poor camera angles. HR usage was therefore only estimated for the day 2 trials using camera 13. HR use was categorised as either, ‘side-only’, ‘middle-only’, ‘both’ or ‘none’ (see Table 4). The term ‘Side-only’ represents passengers that ONLY used the HR located on the left or right hand side of the stairs. ‘Middle-only’ represents passengers that ONLY used the central HR. ‘Both’ represents passengers that used BOTH the side and central HR. Finally, ‘None’ represents passengers that did not use either HR. For the purposes of this analysis use is defined as a passenger making any visible contact with a HR. This may represent a light touch or the use of the HR to propel oneself using both arms. In addition use may occur at any point along the length of the HR and for any contact duration.

Table 4: Day 2 participant’s HR use, determined from camera 13

Trial	Direction	Side only	Middle only	Both	None
2.1	DOWN	10/85 (12%)	7/85 (8%)	68/85 (80%)	0/85 (0%)
2.2+	DOWN	34/112 (30%)	34/112 (30%)	44/112 (39%)	0/112 (0%)
2.3	UP	12/85 (14%)	3/85 (4%)	69/85 (81%)	1/85 (1%)
2.4	DOWN	3/49 (6%)	0/49 (0%)	45/49 (92%)	1/49 (2%)

+Could not be determined for one passenger via camera 13

It is clear from these trials that the majority of passengers made use of the HRs in some form. The majority of passengers either made use of only the central HR or used both the central and side HRs. It would be interesting to note from participant questionnaires if the central HR was cited as providing assistance during the evacuation.

3 Passenger Exit Delay Time distributions

3.1 General considerations

Only one exit was used that had a slide attached, this was the Upper right number 1 exit. Evacuation via the Upper exit and slide was only undertaken in Trials 1.1, 1.3, 2.2 and 2.4. The sill height for these experiments was 8 metres and the slide length was 16 metres. The exit is a standard dual lane Type A exit measuring 42 inches in width and 72 inches in height. The slide is also dual lane. Exit delay times were recorded from a video machine measuring 25 frames per second. Each participant's number of frames multiplied by 0.04 (one frame = 0.04 s) gives that participant's exit delay time in 100ths of seconds.

3.2 Extraction technique

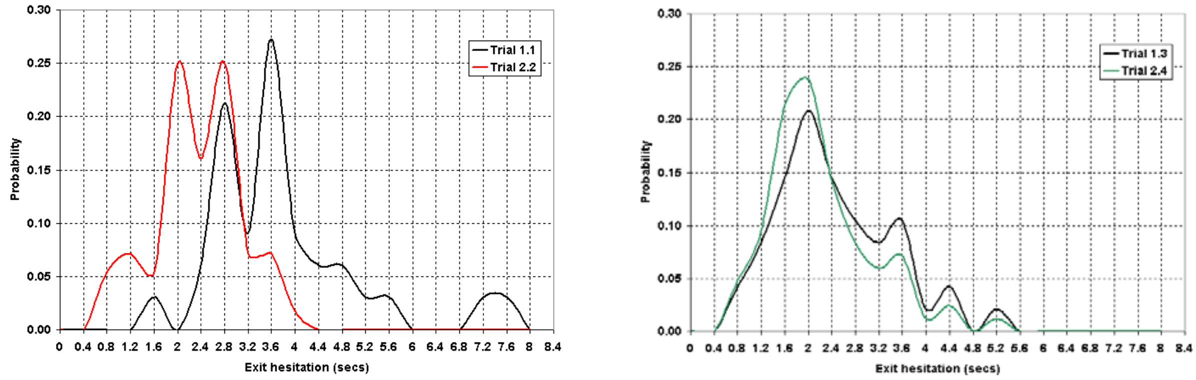
The Passenger Exit Delay Time is a combination of passenger exit hesitation time and passenger exit negotiation time. Hesitation refers to participants' reluctance to quickly vacate the exit for whatever reason and negotiation is the physical act of using the exit. Passenger Exit Delay Time is the time difference between two events. The time at which the participant breaks contact with exit system minus the time at which the participant starts his/her last steps to the exit door sill when the exit is free to use. In other words the period of time expended physically moving through the exit plus time expended hesitating when he/she *could* have moved if the exit was free. 'Starts Last Steps to Sill' is defined as the beginning of the approach to the door sill with the intention of exiting, rather than shuffling forward in a queue. If the participant 'goes' immediately after the previous participant no hesitation occurs and only negotiation time is measured. 'Exit free to use' is defined as the time from the moment the previous participant has broken contact with the exit system sufficiently enough for the next participant to step up and commence exit negotiation. 'Breaks contact with exit system' is the time at which the participant has effectively passed through the exit, which usually means letting go of the last exit sill foothold when through the door, or the last foothold on the thickness of the top of the slide. This assumes the participant jumps, leaps, hops or vaults from the exit (usually the case). Some participants sit at the exit before descending the slide. Here 'buttock hold' is used instead of foothold as the exit negotiation time end marker i.e. exit contact is broken when the participant can be seen to have disengaged his/her seat from the exit sill base or the thickness of the top of the slide, as appropriate.

The assertiveness of the CC at the exit is of paramount importance to the degree of participant hesitation displayed at the exit. The purpose of CC 'assertiveness' is to expedite passenger flow and minimise passenger hesitation at the exit, assuming an emergency evacuation or other time-critical event e.g. 90 second certification trial. Here, assertive CC are taken to be crew who displayed a vocal and physical assertiveness during the majority of the participant flow through their exit. Vocal assertiveness is taken to mean crew members who continuously yelled clear instructions to the participants and physical assertiveness is represented by CC who made physical contact with the participants during their egress, in particular pushing passengers out of the exit. Unassertive CC crew are those who fail to display either vocal or physical assertiveness for the majority of the evacuation.

3.3 Converting the data to exit delay distributions

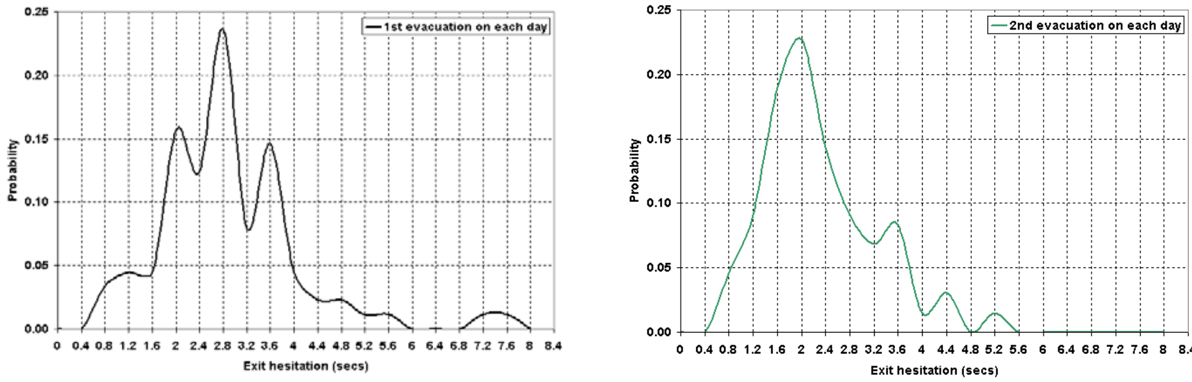
As all four sets of data refer to unassertive cabin crew, the intention was to combine these curves to produce a single smoothed probability distribution representing the distribution of expected passenger exit hesitation times.

The data was smoothed (using a bin size of 0.4 seconds) and the resulting curves indicated significant differences between the first evacuations undertaken on each day (see Figure 9(a)) and the second evacuations undertaken on each day (see Figure 9(b)). The first and second trials on each day were then combined (see Figure 10).



(a) (b)

Figure 9: Exit Hesitation Probabilities from (a) the first trials on days 1 and 2, and (b) the second trials on both days 1 and 2



(a) (b)

Figure 10: Combined Exit Hesitation Probabilities from (a) the first trials on days 1 and 2, and (b) the second trials on both days 1 and 2

Overlaying the curves for the first and second trials on each day (see Figure 11) indicates that the second trials on each day are offset to the left, i.e. generated faster evacuation times. This finding is substantiated by examination of the means that were generated (see Table 5).

Table 5: Summary of raw Passenger Exit Hesitation Times (secs)

	Hesitation (secs)					
	Trial 1.1	Trial 1.3	Trial 2.2	Trial 2.4	Trials 1.1 and 2.2 combined	Trials 1.3 and 2.4 combined
Min	1.6	0.7	0.6	0.8	1.6	0.7
Mean	3.6	2.2	2.0	1.7	3.6	2.2
Max	7.4	5.2	3.4	3.4	7.4	5.2
Standard deviation	1.25	1.05	0.69	0.58	1.25	1.05

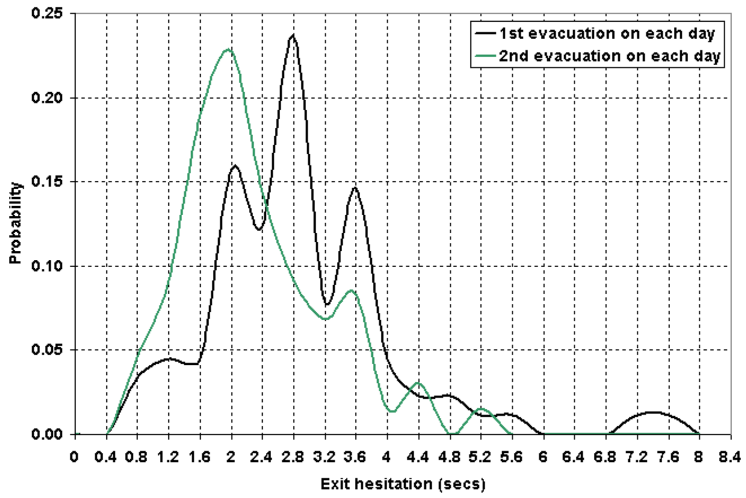


Figure 11: Combined Exit Hesitation Probabilities from the first trials on days 1 and 2 and the second trials on both days 1 and 2

Based on this analysis the following conclusions are made,

1. The first trial undertaken was particularly slow. This could be due to the extreme caution with which the CC approached the first trial. Indeed the first trial generated both the longest minimum times and the longest maximum times. This suggests that both the jumpers and the sitters were quite slow on this day.

2. The first trials undertaken on each day generated longer hesitation times than those generated by the second trials on each day. These differences are thought to originate from,
   a) the safety concerns of the CC leading to extremely unassertive behaviour, especially in the first trials that were undertaken on each day, and
   b) relative increases to both passenger and crew confidence in the second trials of each day.

These results can be compared with the data generated by FSEG from the analysis of passenger exit hesitation time behaviour at main deck Type-A exits with assertive cabin crew.

FSEG have analysed the exit hesitation time distribution produced from a large number of Certification Trial evacuations for a range of exit types. In particular, FSEG have analysed data from 11 previous certification tests involving Type-A exits with assertive cabin crew. The aircraft from which these exits were drawn included Boeing, Airbus and Douglas. It is also worth noting that three of the aircraft failed to meet the FAR part 25.803 certification requirements. In total, passenger exit delay time data from 20 exits representing some 2078 passengers was used to determine the passenger exit distribution. For each exit meeting the selection criteria (i.e. Type-A, main deck, assertive crew) a frequency distribution curve of passenger exit delay time can be generated. The shape of these distributions are remarkably similar, resembling an exponential/poisson distribution that peaks at the low end of the delay time distribution and tails off towards the higher end of the distribution. This suggests that the majority of the passengers display a short delay time (associated with a rapid jump onto the slide) while a sizeable number of passengers have a relatively long delay time (associated with sitters). On the whole, the slowest passengers exit delay times are associated with personal attributes of being elderly and being female. From this data we note that the minimum delay time is approximately 0.2 seconds and the maximum delay time is 4.7 seconds. The typical distribution of delay times for main deck Type-A exits with assertive crew is depicted in Figure 12. The shape of the curve for unassertive crew is similar to that shown in Figure 12 with the fastest times being unaffected but with more passengers displaying the slower times.

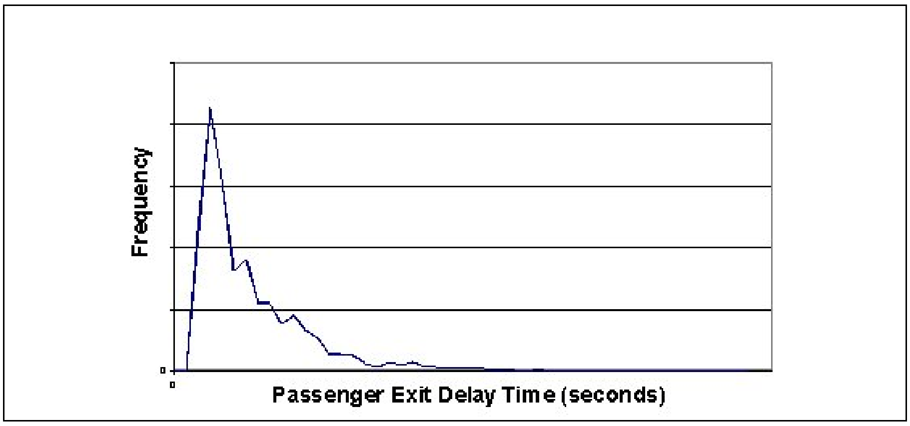


Figure 12: Passenger Exit Delay Time distribution for main deck Type-A exits with assertive crew.

The shape of the passenger exit hesitation time distribution generated from the second trials conducted on days 1 and 2 resemble Figure 12. However, the mean exit hesitation times generated by the first trials on each day are approximately 6 times longer than those typically found for Type-A exits with assertive cabin crew. The mean of the second trials on each day are approximately 4 times longer than those found for Type-A with assertive cabin crew.

3.4 Participant Average Exit Flow Rates

Participant average exit flow rates were measured by dividing flow time into the number of participants per trial. This is then multiplied by 60 to give participant per minute rate. ‘Flow time’ commenced when the first participant to exit stepped up to the exit door sill and commenced his/her exit hesitation. It finished when the last participant broke final foot contact with the exit system or thick edge of top of slide, as appropriate. These flow rates include any periods of dry-up in exit flow.

Results in Table 6 confirm the point made in Section **Error! Reference source not found.** and the means presented in Table 5. Participant exit delay time diminishes progressively through the trials. It should be re-iterated that the reason for this is not clear, but it was not through any assertive intervention by CC. whilst the AFR in Trial 2.4 is double that in Trial 1.1 the figure presented is considerably slower than would occur in a 90 second certification trials using assertive CC, which average 120 passengers/minute.

Table 6: Participant average exit flow rates

Trial	Participants	Average flow rate (passengers/minute)
1.1	33	31.13
1.3	48	43.70
2.2	56	44.97
2.4	36	63.34

4 Conclusions

While the trials did not proceed in the controlled manner that was originally planned, much has been learned from theses trials.

It is clear from these trials that crew can exert an influence on the performance of passenger stair usage. Passenger behaviour in utilising the staircase is both rich and complex and warrants further investigation. These trials support the view that for crew to consistently make appropriate or optimal redirection command decisions that include the possibility of using the stairs as part of the evacuation route, they must have sufficient situational awareness. Equally, passengers can only make appropriate or optimal redirection decisions if they too have sufficient situational awareness. This situational awareness may need to extend between decks.

Passengers were also noted to make heavy use of the central handrail while both descending and ascending the stairs. The presence of the central HR effectively created two staircases. By effectively separating the crowding on the stairs, reducing passenger-passenger conflicts and providing an additional means of passenger stability, it is postulated that the stair flow rates may be positively influence through the presence of the central HR. Flow rates in the UPWARDS direction were found to be greater than flow rates in the DOWNWARDS direction. This was thought to be due to the packing densities on the stairs which is a function of the motivation of the passengers, the travel speeds of the passengers and the feed and discharge characteristics of the staircase and surrounding geometry. It was also noted that the average unit flow rate in the DOWNWARDS direction was equivalent to that specified in the UK Building Regulations. Clearly, most of the parameters can be influenced by both crew procedures and cabin layout.

Concerning the passenger exit hesitation times for the higher sill height, the trials produced inconclusive results. While the measured exit flow rates are lower and the passenger exit delay times are longer than would be expected for a normal Type-A exit, it is clear that the extreme unassertiveness of the cabin crew positioned at the exits and the lack of motivation of the passengers exerted a strong influence on the data produced. The reaction of the passengers in these trials was to be expected as the trials were not performed under competitive conditions and the reaction of the cabin crew could also be understood as safety concerns were paramount given that these were the first trials of their type to be conducted at Cranfield.

Finally, due to the small number of data points provided by these trials, there is insufficient data upon which to claim statistical significance for any of the observations.

Clearly, much more work is required in order to generate essential data to improve our understanding of passenger performance, passenger-crew interaction and passenger-structure interaction within VLTA configurations.

5 References

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