VERRES CONSORTIUM

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VLTA EMERGENCY REQUIREMENTS RESEARCH EVACUATION STUDY

Work Package 3

Report 3.2. Analysis of Verres evacuation trials

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GLOSSARY

A/c	Aircraft
AIRBUS	AIRBUS Deutschland
CC	Cabin Crew
CON	Contribution Report
CU	Cranfield University
D	Deliverable
$Dn_1.n_2$	**"D"** means day, $\mathbf{n_1}$: day number, $\mathbf{n_2}$: session number
DG TREN	Directorate General Transport & Energy
ETF	ETF/SNPNC
FC	Free Choice (experimental scenario)
GD	Going Down (experimental scenario)
Gp	Passenger Group
GUp	Going Up (experimental scenario)
HR	Hand rails
JAA	Joint Aviation Authority
ND	Not Defined
NOSC	Experimental session without Stair Crew (NO Stair Crew)
Pax	Passengers
SC	Stair Crew
SOF	Sofréavia
SRG	CAA/SRG
UOG	University of Greenwich
VAA	Virgin Atlantic Airways
VERRES	VLTA Emergency Requirements Research Evacuation Study
VLTA	Very Large Transport Aircraft
WP	Work-Package

EXECUTIVE SUMMARY

This is the report for Task 3.2 within Work Package 3 of the VERRES project. It discusses findings from evacuation trials from a double deck aircraft cabin simulator. The trials were designed and implemented by members of the Verres consortium and undertaken within the Human Factors Group at Cranfield University.

As a starting point for the development of the experimental design, a discussion was held with all consortium members. From this discussion a number of potential research areas were noted and were classified into two categories – either high or low priority within the specification of the Verres project. Cranfield University, with the assistance of the University of Greenwich, used the ideas generated during this discussion to propose to the Verres consortium, an experimental design that ensured methodological rigour. This design was presented in version 1 of the report for work package 3, Task 3.1. After further discussion, the Verres consortium identified a large number of potential variables of interest, and it soon became evident that it would be difficult to limit the number of independent variables and insufficient test evacuations were available to obtain adequate replications of each test condition. As the consortium partners were unable to agree a test programme, it was finally agreed that the evacuation trials would not be conducted as an experiment. Instead, the evacuation trials would take the form of a series of evacuation demonstrations, which could then be used to explore possibilities for future research. As a result, there were no independent variables to be manipulated within the tests.

The final programme that was agreed was to use the eight trials available to explore passenger movement in three types of situation. The first when there was a free choice between available exits on both decks (the free choice condition). The second type of situation was where passengers on the lower deck were required to move to the upper deck, to the only available exits (the moving upstairs condition). The third situation was where passengers on the upper deck were required to move to the lower deck, to the only available exits (the moving downstairs condition).

The test facility was the large cabin evacuation simulator located at Cranfield University in the UK. The facility is constructed over two decks in a modular fashion, such that key configurational variables can be manipulated according to specific research aims. For this programme, the facility was modified to provide key physical features of a generic wide-bodied cabin with two decks.

Two groups of 168 passengers were recruited via either the volunteer database held within the Human Factors Group at Cranfield University or local advertising, and were required to participate in a single session involving four evacuation trials. Due to concern for participant safety, participation was restricted to those between twenty and fifty years of age. All participants were required to complete a medical questionnaire and receive a brief medical before being permitted to give their informed consent to take part in the trials. In addition, participants were asked to provide demographic information for research purposes.

Participants were divided into two groups, and each group was seated on either the upper or the lower deck for each evacuation trial. Seats were allocated according to a pre-defined seating plan on a random basis, with the exceptions that no participant was allocated to the same seat on the same deck twice and participants would sit twice on the upper deck and twice on the lower deck.

All evacuations were video recorded using infra-red cameras. Each participant was allocated a volunteer number, this was documented on a bib wore by the participant for all four evacuation trials. This enabled each participant to be identified on the video footage. The video footage was time coded in order to extract participant movement and evacuation times.

In this report the experimental methodology of the trials is described and is followed by the analyses conducted by three of the Verres partners - Cranfield University, University of Greenwich and Sofréavia. It is noted that each partner has used a different approach and has conducted their analysis independently, reaching their own conclusions. In the final section the main conclusions from each organisation are brought together. The Cranfield University researchers analysis was focussed on passenger evacuation times and data obtained from the Cranfield University passenger post evacuation questionnaire. Researchers from the University of Greenwich have analysed data primarily concerning the passenger use of the stairs and passenger exit hesitation time analysis for the upper deck slide. The Sofréavia analysis investigated cabin crew performance and utilised a human behaviour approach that focused on the operators' work, i.e. the cabin crew's work as evacuation manager. This analysis has used data collected from interviews with the cabin crew and passenger data obtained from the Sofréavia post evacuation questionnaire.

The planned test programme was completed and no evacuations were halted. Data were therefore obtained for all eight demonstration evacuations. In total, 336 individuals participated in the evacuation demonstrations. It is believed that the trials produced passenger behaviour representative of non-competitive evacuations and the crew behaved in a manner that might be expected under a set of simulated operational conditions in which no additional training concerning the use of stairs for evacuation was provided. Valuable information was gathered on the management of passengers on the stairs by cabin crew.

Although a number of pilot trials had been conducted, the experimental trials did not proceed in the controlled manner that was originally planned, however much has been learnt from these trials. 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 documented within the report.

In the event, the cabin crew behaved in a number of ways that differentiated from that which had been expected. . This meant it was not possible to measure the propensity of passengers to freely elect to use the staircase and to estimate impact of crew influence on passenger stair efficiency and flow rates. It was apparent that in all the trials, crew played some role in managing the passenger flow on the stairs.

It must be remembered that all crew (except those located at UR1) were line cabin crew who were trained in specific operator emergency procedures, commands and gestures as appropriate, with the aim of reducing the overall evacuation time of the aircraft. Ethically it could be argued that if the cabin crew were trained in behaviours that conflicted with their normal procedures, this could be potentially detrimental to their later performance in a genuine emergency situation. Although cabin crew knowledge and experience is crucial to our understanding of aircraft emergency evacuation, the Verres trials have demonstrated that in exploratory research where specific crew commands and behaviours are fundamental to the experimental design, in particular where these are not identical to those implemented by the operator, the use of researchers trained as cabin crew should be carefully considered. It is acknowledged that ultimately line cabin crew should be used within the experimental testing programme.

Unfortunately, the Cranfield University analysis was limited to descriptive analysis only on the passenger evacuation times, as inferential analyses of the evacuation data could not be conducted, as insufficient data was available to conduct comparisons across conditions. However within the free choice evacuations, there did appear to be differences in evacuation rates between the two demonstrations, with lower mean evacuation times, faster evacuation rates, and lower overall exit evacuation times evident on the last trial of the programme. However, this may simply be a function of the cabin crew, who by this time would have gained significant additional experience in passenger management and evacuation situations.

Within the conditions involving ascending the stairs, there did appear to be marked differences in evacuation rates between UR1 and UL1. The UR1 exit involved passengers evacuating down a slide whereas UL1 was out onto a platform. This difference in time through UR1 is most likely a function of the caution exercised by cabin crew at the UR1 exit. The evacuation slide used in these trials had not been used in any previous research, and hence passenger safety was considered of primary importance in the use of this escape means. Finally, within the evacuations involving descent of the stairs, the mean evacuation times, evacuation rates and overall exit evacuation times do appear to be broadly similar across the evacuation trials conducted.

The Cranfield University contribution also includes analyses on the data provided on the Cranfield University post evacuation questionnaire by condition. Again, this is descriptive data as it was not possible to conduct inferential analysis of this data across the different experimental conditions.

The University of Greenwich analysis reviewed passenger stair usage and the influence of the sill height from the upper deck. It was demonstrated from these trials that the cabin crew can exert an influence on the performance of passenger stair usage. The data on passenger behaviours 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. Situational awareness between decks should be the subject of further investigation.

Passengers were also noted to make heavy use of the central handrail while both descending and ascending the stairs. The presence of the central handrail 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 handrail. 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 increased 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 caution 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.

The analysis carried out by Sofréavia followed a French cognitive psychology approach using a model known as "Keeping control of the situation" (Amalberti 1996, Amalberti & Al. 2000). This approach is human behaviour oriented, and focuses on the operators' work, i.e. the cabin crew's work as evacuation manager. Thus, the interest was on the individual's objectives of actions, their decision making process, their situation awareness building and the communication strategies evolving in the evacuation trials, through the use of interviews with the line cabin crew after each evacuation trial. The Sofréavia analysis has suggested the cabin crew's objectives were to control the passenger flow, to anticipate the variations and to optimise the use of the exits. The negative aspects mentioned by the cabin crew refer to a lack of situation awareness, an inappropriate action, and the achievement of an undesirable state (missed objective) and the positive aspects refer to the ability to carry out appropriate action, ability to enrich the situation awareness, or the achievement of an objective.

A number of case studies have been highlighted within the analyses that have suggested that the cabin crew behaviours was logical and efficient, even when they decided to adapt the procedure. Due to the adaptations, solutions were found, and control of the situation was kept. The cabin crew also need to be aware of the status of the staircase as it perceived to be a strategic element in keeping control of the evacuation, similar in respect to the crew need for information concerning the status of the exits and aisles. It is proposed that procedures, aircraft cabin design and communication means should be carefully considered to ensure the cabin crew know what is occurring at all the strategic elements throughout the evacuation.

The Verres evacuation trials have identified a number of areas where future research needs to be conducted to generate essential data to improve our understanding of passenger performance, cabin crew performance, passenger-crew interaction and passenger-structure interaction within very large transport aircraft configurations. The next step should be to form clearly identifiable research objectives and to develop detailed research programmes combining partial experimental evacuation testing including statistically reliable results, evacuation computer modelling and qualitative analysis, in an attempt to address the complex issues relating to the safe evacuation of very large transport aircraft.

1. INTRODUCTION

1.1. Background

The VERRES programme is an European Commission/DG Tren funded project to examine some of the evacuation issues relevant to evacuation from next generation very large transport aircraft. The consortium includes Sofréavia, CAA/SRG, JAA, Airbus, University of Greenwich, Cranfield University, Virgin Atlantic Airways and ETF-SNPNC.

The VERRES Technical Annex details the proposal for the VERRES study. The study was initiated as 'the development of Very Large Transport Aircraft (VLTA) is of utmost importance to face the forecast increase in air traffic. The VLTA is a challenge for aircraft manufacturers and the certification authorities for emergency evacuation in case of major incident/accident or survivable crash. Indeed, the transition to more than two aisles and full double deck with a significant number of passengers to deal with may raise concerns. This poses problems not only for industry, which is looking for a rapid return on RTD investment, but also for the certification authorities who are faced with the approval of a product within a very short time scale. The VERRES project will investigate the problem for different scenarios' (p1 VERRES_TAO2_2.doc).

The Technical Annex notes that 'this study is general in nature and will provide information for the future generation of very large transport aircraft and it is intended that some of the recommendations may have immediate applicability to aircraft of this size that are shortly to be developed in Europe and elsewhere' (p1 VERRES_TAO2_2.doc).

Three major domains are studied within the project: the configurational aspects, the use of analysis supported by relevant small-scale evacuation tests and evacuation modelling software and the human aspects via cabin crew co-ordination and training and the mental representation layout of the aircraft for the passenger.

1.2. Regulatory requirements

The regulatory authorities need to be confident when certifying a new aircraft, or making changes to an existing configuration, that all passengers can be evacuated quickly and safely in the event of an emergency. It is a regulatory requirement that a Full Scale Evacuation Demonstration (FSED) is conducted, where it must be shown that all passengers can evacuate the aircraft within 90 seconds, using only half of the available exits (FAR/JAR 25, Appendix J). Although aircraft may be certified on this basis, evidence from accidents has shown that the demonstration does not always predict what might actually occur in a given situation. For example, in a life threatening emergency, passengers may use radically different behavioural strategies to evacuate than may be evidenced in a certification drill.

1.3. Factors influencing evacuation efficiency

Snow, Carroll and Allgood (1970) suggested that a number of factors influence passenger survival in the event of an emergency evacuation. They placed these factors into four categories – procedural, environmental, biobehavioural and configurational. Procedural factors relate to the regulatory and training practices governing the evacuation situation. This may include the level of experience and training of the crew, and the standard operating procedures of the airline. The environmental factors include elements inside and outside the aircraft that may influence the evacuation. Examples include the presence of smoke or fire, and the weather conditions outside the aircraft. Biobehavioural factors are the factors relating to the passengers themselves, and include sex, age, physical state and level of motivation. Perhaps the most critical factors influencing passenger survival are the configurational variables. These relate to the physical features and layout of the cabin, and include aisle width, seating density and the number and location of exits.

1.4. Experimental cabin safety research

Since 1985, the Human Factors Group has become the focus for European cabin safety research. The expertise and experience which has been developed in factors influencing safety and survival is such that, since 1993, research programmes have received support from the Federal Aviation Administration, the Civil Aviation Authority, and Transport Canada. In addition to support from the regulatory authorities, research sponsored by manufacturers, operators and suppliers is also regularly undertaken.

Early research involved the use of a Trident airframe parked on the university airfield. This has now been superseded by two cabin simulators, a Boeing 737 and a large cabin evacuation simulator. Both research facilities are equipped with control systems for manipulating experimental variables such as smoke, lighting, sound and so on. A range of infra-red sensitive and thermal imaging cameras located internally and/or externally allow data to be collected in a range of conditions, including in darkness and in smoke.

One of the difficulties associated with conducting research into the survival of aircraft accidents is the introduction of sufficient realism, without putting participants at serious risk of physical of psychological harm. The Cranfield approach has been to maximise fidelity, by using realistic cabin simulators, trained and uniformed members of cabin crew, safety cards and passenger safety demonstrations. Members of the public who are recruited to take part in emergency evacuations are given a pre-flight safety briefing, they hear the sounds of engine noises, and are finally briefed to evacuate the aircraft.

Although the Cranfield methodology can be potentially hazardous for volunteers, over 7,000 members of the public have taken part without sustaining any serious injuries. This level of safety has been achieved by having clearly defined selection criteria, detailed medicals and briefings, and clearly defined safety procedures and organisational reviews. All research undertaken within the Group is subjected to independent scrutiny by the Human Factors Group Ethics Committee. It is also recognised that, in view of the possibility of litigation, experiments of this kind may be more practicable in the UK than elsewhere.

2. METHOD - CRANFIELD UNIVERSITY

2.1. Test facility

The test facility was the large cabin evacuation simulator located at Cranfield University in the UK. This facility was commissioned and funded by the Civil Aviation Authority of the United Kingdom, and was opened by HRH The Duke of Kent in July 2001. The facility is constructed over two decks in a modular fashion, such that key configurational variables can be manipulated according to specific research aims. The aisles, seats, monuments, the staircase linking the decks, and the exit size and location have all been designed and fitted such that they can be moved or relocated as required. For this programme, the facility was modified to provide key physical features of a generic wide bodied cabin over two decks. Both decks were used in the current study.

2.2. Cabin configuration

The lower deck of the cabin seated up to 172 participants. Seats within the cabin were set at a 31" pitch, equivalent to a vertical projection of 5 inches. Three exits were fitted on the lower deck, one forward on the port side of the cabin (Lower Left 1, or LL1). An exit pair was also located midway down the cabin at the base of the staircase, one exit on the port and one on the starboard sides. These exits were designated Lower Left 2 and Lower Right 2 (LL2 and LR2 respectively). All lower deck exits conformed to the dimensions of Type A exits, being 42" wide by 72" high. Platforms were available outside all lower deck exits for participants to evacuate. The sill height of the lower deck platform was 5 metres above ground level.

On the upper deck, 88 seats were available, also at 31" pitch. Two exits were fitted to the upper deck, one forward on the port side (Upper Left 1, or UL1), and one forward on the starboard side (Upper Right 1, or UR1). All upper deck exits conformed to the dimensions of Type A exits, being 42" wide by 72" high. UL1 had a platform outside for evacuating passengers, at 8 metres above ground level. UR1 was fitted with a dual-lane evacuation slide, again 8 metres above ground. The slide was 16 metres long and was capable of carrying upwards of 140 passengers per minute (70 per lane, in accordance with the FAA Emergency Evacuation Slides Technical Order (FAA, 1999).

Diagrams showing the configurations of the lower and upper deck cabins are provided in Appendix A.

2.3. Test participants

Up to 168 test participants were recruited for each test day. Participants were permitted to take part in a single test session only. Participants were members of the public who were recruited using either the volunteer database held within the Human Factors Group at Cranfield University or local advertising. The database holds contact details of people who have responded to local and regional advertising, and have thereby expressed an interest in participating in aviation safety research.

To minimise the risk of injury, participants were required to be aged between 20 and 50, and relatively fit. Participants who had experienced any of the following conditions were excluded from taking part:

Heart disease, high blood pressure, fainting or blackouts, diabetes, epilepsy or fits, deafness, chronic back pain, ankle swelling, depression, anxiety, other nervous/psychiatric disorders, fear of enclosed spaces, fear of heights, fear of flying, brittle bones, asthma, bronchitis, breathlessness, chest trouble, lumbago sciatica, or any other serious illness. Volunteers who were pregnant, or who thought they might be pregnant, were also excluded from participating, as were participants who had recently undergone surgery or who were receiving medical treatment. All participants were required to weigh no more than around 15 stones (95.25 kg).

Participants were sent a letter advising them of appropriate clothing to wear for the trials, and were also provided with details of the time and location of their chosen test session, along with a map. Copies of the pre-trial correspondence are provided in Appendix B. A member of the research team was added to the participant complement on each trial session to act as a "stooge" passenger. This person, participant 100, always occupied the 1J seat on the upper deck, and his task was to protect the UR1 cabin crew while they made this exit available.

2.4. Experimental design

As a starting point for the development of the experimental design, a discussion was held with all consortium members. From this discussion a number of potential research areas were noted and were classified into two categories – either high or low priority within the specification of the Verres project. Cranfield University, with the assistance of the University of Greenwich, used the ideas generated during this discussion to propose to the Verres consortium, an experimental design that ensured methodological rigour. When proposing this design, the data requirements as stated within the work package 3 management plan were considered. Within the management plan, developed by the work package leader and agreed by the partners contributing towards the work package, it is stated that the data analysis of the experimentation will be divided into three sets of analytical work: statistical data, quantitative analysis and qualitative analysis. This design was presented in version 1 of the report for work package 3, Task 3.1.

The design of an experiment is directly related to the confidence that may be placed in the results. In any study intended to assess evacuation issues, when a robust research design is employed, the regulators may be confident that the results are purely due to the factors that were included and controlled within the study. If this is not the case, then the results may be erroneous, and may not be interpreted with confidence. This is because the experimental findings are then subject to interpretation by other factors, such as chance, learning and practise, or a confounding variable. Although the experimentation resources within the Verres project only permitted two days of testing, each with four trials, the design in version 1 allowed each condition to be tested twice, with counterbalancing present as far as possible in an attempt to control for effects of practice and learning. It was anticipated that this design would provide data amendable to inferential statistical analyses, although it was noted that the results would be preliminary findings. It is noted that Cranfield University and the University of Greenwich have extensive experience in the field of aircraft evacuation research and when presenting the design proposed in version 1, were drawing on existing knowledge and understanding. This was done as it was felt that the issues raised by the Verres project, built on existing knowledge of passenger behaviour during aircraft evacuation but with novel interior features – i.e. height of upper deck and an internal staircase. It is noted that other partners within the consortium, although having experience in other fields, were not experienced in conducting experimental evacuation tests.

The Verres consortium identified a large number of potential variables of interest, and it soon became evident that it would be difficult to limit the number of independent variables and insufficient test evacuations were available to obtain adequate replications of each test condition. As the consortium partners were unable to agree a test programme, it was finally agreed that the evacuation trials would not be conducted as an experiment. Instead, the evacuation trials would take the form of a series of evacuation demonstrations, which could then be used to explore possibilities for future research. As a result, there were no independent variables to be manipulated within the tests.

The final programme that was agreed was to use the eight trials available to explore passenger movement in three types of situation. The first when there was a free choice between available exits on both decks (the free choice condition). The second type of situation was where passengers on the lower deck were required to move to the upper deck, to the only available exits (the moving upstairs condition). The third situation was where passengers on the upper deck were required to move to the lower deck, to the only available exits (the moving downstairs condition).

Within the analysis conducted by Cranfield University, the dependent variable for each of these tests was the time taken for each participant to place their first foot over the exit threshold. The dependent variable measure was obtained from video footage taken outside each exit. The footage was obtained using monochrome cameras and broadcast quality Super VHS recorders. Supplementary information would be collected from passenger post evacuation questionnaires.

2.5. Trial order

Given that the trials were a series of evacuation demonstrations, it was decided to prioritise the situations that were perceived as more critical. Hence, within the eight tests, two were free choice situations. There were also two tests of the moving upwards scenario. However, for the moving downwards scenario, there were four tests. Also of interest was the presence or absence of additional cabin crew at the staircase, but this was considered to only be relevant for conditions in which participants had no free choice about where they moved to available exits. Hence, one of the moving upwards tests had two additional cabin crew, and two of the moving downwards test had two additional cabin crew. Where additional crew were available at the staircase, one was located at the top of the staircase on the upper deck, and one at the bottom of the staircase on the lower deck. Given the limited number of tests available, and the fact that the evacuations were for demonstration purposes only, no attempt at counterbalancing was made.

The University of Greenwich had expressed a preference for data obtained from naïve participants on the staircase. Given the lack of counterbalancing, the only manner in which such data could be obtained was to divide the passenger load into two groups. This ensured that a quantity of data was obtained from naïve participants moving both up and down the stairs. The order of each of the evacuation trials over both test days is provided in Table 1.

Trial	25 January 2003	1 February 2003
1	**Free choice** No additional crew at staircase Available exits UR1, LL2 and LR2, Group A seated on upper deck Group B seated on lower deck	**Moving Downwards** Additional crew at staircase Available exits LL2 and LR2 Group A seated on upper deck Group B seated on lower deck
2	**Moving Downwards** No additional crew at staircase Available exits LL2 and LR2 Group A seated on lower deck Group B seated on upper deck	**Moving Upwards** No additional crew at staircase Available exits UL1 and UR1 Group A seated on upper deck Group B seated on lower deck
3	**Moving Upwards** Additional crew at staircase Available exits UL1 and UR1 Group A seated on lower deck Group B seated on upper deck	**Moving Downwards** No additional crew at staircase Available exits LL2 and LR2 Group A seated on upper deck Group B seated on lower deck
4	**Moving Downwards** Additional crew at staircase Available exits LL2 and LR2 Group A seated on upper deck Group B seated on lower deck	**Free Choice** No additional crew at staircase Available exits UR1, LL2 and LR2 Group A seated on lower deck Group B seated on upper deck

Table 1: Evacuation trials on 25 January 2003 and 1 February 2003

2.6. Procedure

On arrival at the test session, volunteers were issued with a bib detailing their volunteer number for the test session. In addition, each participant was provided with a clipboard of information. The first document on the clipboard was the volunteer information sheet, a copy of which is provided in Appendix C. The volunteer information sheet included the insurance and health and safety provisions for the research, and explained the issues of data confidentiality.

The height and weight of all participants was measured and documented by members of the research team. Participants were also required to complete a medical questionnaire, which was checked and signed by one of three nurses. A doctor was also available in the event that a nurse had a query concerning any given individual's fitness to participate. Participants were also required to sign a consent declaration to indicate that they had understood the information provided, and were giving full and informed consent to participate in the trials. A copy of this form is provided in Appendix D.

Participants then received a briefing from Professor Helen Muir, detailing the general nature of the research, and providing instructions for the four evacuations of the session. Although no bonuses were payable, the briefing emphasised the need for participants to move as they would in a genuine emergency situation. The briefing also included details of the procedure for stopping an evacuation trial in the event of participant injury or an emergency. Appendix E contains a transcript of the briefing provided on 25 January 2003.

On completion of the briefing, participants boarded the aircraft cabin using the external staircases, to ensure participants did not use the internal staircase prior to the evacuation trials. Participants had been divided into two groups, and each group was seated on either the upper or the lower deck for each evacuation trial. Seats were allocated according to a pre-defined seating plan on a random basis, with the exceptions that no participant was allocated to the same seat on the same deck twice and participants would sit twice on the upper deck and twice on the lower deck. Seating plans can be found in Appendix F.

On boarding, lights within the cabin were at take-off and landing levels, these levels are documented in Appendix G. It is noted that additional lighting was used at the staircase for safety purposes; this light remained on throughout the evacuation trials. Participants were seated by the cabin crew, there were 10 members of cabin crew in total. Four were located at exits on the lower deck, two at the staircase (one at the top of the staircase and one at the bottom of the staircase) when appropriate and four on the upper deck, with two crew at each exit. The cabin crew on the lower deck, staircase and at UL1 were line crew or trainers supplied by Virgin Atlantic Airways. For safety purposes, the crew located at UR1 were two members of the research team trained and dressed as cabin crew due to the evacuation slide. Participants received a typical pre-flight briefing and safety demonstration. A transcript of the safety briefing is provided in Appendix H. Passenger information cards were produced to illustrate the location of the exits, the operation of the seat belts, and the use of oxygen masks. A copy of the passenger safety card is provided in Appendix I. On completion of the safety briefing, cabin crew moved to their allocated seats, and lights within the cabin were dimmed to night levels.

On completion of the safety briefing, participants were played one of four pre-recorded evacuation scenarios. The scenarios were all different, so that passengers would be unable to anticipate precisely the call to evacuate the cabin. Transcriptions of the evacuation scenarios are available in Appendix J. Each scenario included a signal at approximately 10 seconds after the call to evacuate. This whistle was intended to communicate to cabin crew the estimated slide deployment time. Using such a signal meant that all stewards outside the exits would know when to signal to the crew the exit availability. It was decided that cabin crew (except those at UR1) would not know in advance if exit was available or unavailable, instead stewards located outside the exits would signal to the cabin crew once the whistle had sounded.

It is noted that the commands used during the trials were those used by Virgin Atlantic Airways in order to reduce any potential confusion for the line cabin crew, as to introduce commands outside their normal procedures could have been detrimental to their later performance in a genuine emergency situation. On the call “Emergency stations”, cabin crew commanded passengers to brace, using the commands “heads down, feet back” Initially this was shouted twice and then repeated at five second intervals, until the call to evacuate (which was the Captain’s voice shouting to passengers to “Evacuate, evacuate, evacuate”). At that point, the lights within the cabin were reduced to emergency levels (these are documented in Appendix G). The crew immediately opened their exit and stood in front of the exit - to prevent passengers from evacuating, calling passengers towards them using the commands “Open seat belts and get out”, “Leave everything behind” and “Come this way”. The cabin crew continued to shout these commands to passengers until the whistle, when cabin crew actions were then dependent on the exits to be used on any given trial.

On the whistle signal, cabin crew at available exits immediately stood aside in the assist space, and began calling to passengers to evacuate. This was done using commands such as “Go!” “Stay on your feet”, “Keep moving”, and “Form two lines”. Cabin crew used physical gestures and assistance as appropriate.

On the whistle signal, cabin crew at unavailable exits remained directly in front of their exit and informed passengers that the exit was blocked and to find another exit. This was done using commands such as "Exit blocked", and "Go that way". Cabin crew used physical gestures and assistance as appropriate.

Stewards were located immediately outside each exit, in order that evacuating passengers could be moved swiftly away. Blockages outside the exit could have slowed the evacuation rate had this not been the case.

The trial was deemed complete when all passengers had evacuated the cabin. Passengers were then required to complete two post-evacuation questionnaires, one designed by Cranfield University and the other by Sofréavia, detailing their experience of the evacuation. A copy of the Cranfield University questionnaires is provided in Appendix K and a copy of the Sofréavia questionnaire is provided in Appendix P. The Sofréavia team also completed individual interviews with all line crew after each evacuation trial, detailing their experiences, transcripts of these interviews can be found in Appendix Q. When all volunteers had completed the questionnaires, they boarded the cabin for the next evacuation, sitting in the seat randomly allocated to them for that trial.

When the session was complete, volunteers were debriefed by Professor Muir. They were paid £25 for attending the session, and were also provided with contact details should they experience any psychological or physical problems as a result of participation in the trials (see Appendix L).

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3.1. Completed trials

No evacuations were halted, and data were therefore obtained for all eight demonstration evacuations. In total, 336 individuals participated in the evacuation demonstrations. One participant withdrew after the first trial on 25 January 2003 (Participant 27). No injuries were sustained throughout the testing programme.

It was the original intention to investigate the potential influence of additional cabin crew located at the top and bottom of the staircase on passenger evacuation, when exits on one deck were unavailable and passengers on that deck have to travel via the internal staircase to the alternative deck. It was also intended within the free choice trials, to investigate the number of passengers on the upper deck who decided to use the internal staircase to evacuate via lower deck exits, rather than the upper deck slide as upper left 1 (onto a platform) was not available. In order for these issues to be reviewed, the research design manipulated the presence or absence of cabin crew at the internal staircase, and it was assumed that cabin crew stationed at exits on both the upper and lower deck would remain at their exit throughout the evacuation. It was also assumed that during the free choice trials, the exit used by upper deck passengers (UR1 or the internal staircase) would be based on a decision made by the passenger rather than due to cabin crew directions.

In the event of the trials, the cabin crew behaved in a number of ways different to those assumed by some members of the consortium. During free choice trials, it was observed on the videos a cabin crew member at the unavailable UL1 exit, verbally and physically re-directed passengers towards the staircase as opposed to UR1. Once the crew member had space to move out of the assist space, they moved around the upper deck redirecting passengers who were both in the aisles and queuing for the upper deck slide. It is understood that the crew member felt able to leave the door as there was a second member of crew protecting the door. Therefore data was not available on the number of upper deck passengers who chose to move to the lower deck to evacuate.

A second example of crew behaviour that was not originally expected was crew from both the upper and lower decks moving from their assist space during an evacuation towards the staircase. Crew at LL2 and LR2, whilst passengers were still evacuating, were observed moving out of the assist space, across the aisle and positioning themselves at the end of the base of the staircase, where they were able to see passengers descending the staircase and manage the crowd in a manner they felt more appropriate. The crew perceived the need for crowd control to be necessary to ensure an efficient evacuation. It is noted that the crew members only left their assist space once their immediate area (i.e. the lower deck) was clear. As the evacuations were onto platforms as oppose to slides, it is noted that this may have altered the behaviour of the cabin crew. This was also observed on the upper deck, where one crew member from UL1 remained at the exit and the other crew member moved around the deck (including the top of the staircase) issuing commands to passengers. It is noted that the majority of door crew movement towards the staircase occurred when there were no additional crew present at the staircase. This crew movement had the effect of making it difficult to investigate the effect of additional staircase crew on passenger flow rates, as during most evacuations cabin crew played some part in passenger behaviour at the internal staircase.

It is possible that the crew member at UL1 exhibited these behaviours as there were two members of cabin crew at UL1 due to the safety requirement of having two members of crew at UR1 as the other member of crew located at UL1, remained at the exit throughout the evacuation. It is anticipated that the qualitative analysis of interviews conducted with cabin crew after each trial by the Sofréavia team will provide some insight into these behaviours. It must be remembered that all crew (except those located at upper right 1) were line crew who are trained in specific operator emergency procedures, commands and gestures as appropriate, with the aim of reducing the overall evacuation time of the aircraft. Ethically it could be questioned if behaviours were introduced to the cabin crew that conflicted with their normal procedures, as it could have been detrimental to their later performance in a genuine emergency situation. Although cabin crew knowledge and experience is crucial to our understanding of aircraft emergency evacuation, the Verres trials have demonstrated that in research where specific crew commands and behaviours are fundamental to the experimental design, in particular where these are not identical to those implemented by the operator, the use of researchers trained as cabin crew should be carefully considered.

3.2. Sample details

The final sample included 336 individuals, of whom 190 were male (56.5%) and 146 were female (43.5%). The recruiting requirements specified that participants had to be between the ages of 20 and 50. In the event, at the time of testing, participants' ages ranged from 19 to 68. Participants falling outside the specified limits were able to take part only following consultation with the medical practitioner. The average age of participants at the time of testing was 31 years, with a standard deviation of 9 years.

In terms of flying experience, most participants had travelled by air previously, since only four people (1.2%) had never previously flown. Another 47 participants (14.0%) had made between 1 and 3 return trips, while 52 (15.5%) had made between 4 and 7 return trips. The majority of people had made eight or more return trips (233 participants, 69.3% of the sample). However, only six individuals reported having undertaking a genuine emergency evacuation (1.8%).

In terms of handedness, 287 participants (85.4%) reported themselves as being right-handed, 28 (11.3%) reported themselves as being left handed, and 10 (3.0%) claimed to be ambidextrous. There was one person who did not provide an answer to this question (0.3% of the sample). For corrected vision, 147 participants did not report having corrected vision (43.8%). 37 participants reported correcting their vision for close work (11.0%), 100 reported correcting their vision for distance tasks (29.8%), and 50 participants (14.9%) reported corrected vision for both close and distance work. Two people did not answer this question (0.6%) of the sample.

3.3. Data preparation

For the evacuation data, the video footage for each demonstration was dated and time-coded from the call to evacuate. The call to evacuate was the command from the captain to "Evacuate, evacuate, evacuate!" The length of this command meant that with the second, third and fourth trials of each session, participants were able to anticipate the command, and sometimes left their seats before the final call. However, this command is the one adopted by Virgin Atlantic Airways, and given that the cabin crew were mainly operational crew, it was decided that it was preferable to use commands that would be familiar to them. This was because, as line crew, to introduce commands outside their normal procedures could have been detrimental to their later performance in a genuine emergency situation.

The data were extracted from the time-coded footage. A person was deemed to have evacuated when they placed their first foot over the exit threshold. Hence, none of the evacuation times for the UR1 exit include the time taken to negotiate the evacuation chute. It is hoped that this strategy will have made the times obtained from different exits more comparable, although evacuation times onto platforms and slides are known not to be directly equivalent. These data were then analysed using the Statistical Package for the Social Sciences (SPSS) to produce the results reported here. All raw evacuation times, along with seating locations and the exit used to evacuate, are provided in Appendix M.

For the post evacuation questionnaire data, the quantitative data were entered onto SPSS, in order that statistical analyses could be conducted. The quantitative data were then analysed, and the findings are reported here as supporting information. The qualitative data were sorted and typed into a separate document, issued as a data supplement (Wilson, Muir & Jolly, 2003). No further analyses of the qualitative data are reported here.

3.4. Data analyses

The analyses conducted related primarily to the different evacuation scenarios tested. The first scenario was the free choice condition, and the test programme included two demonstrations under this condition. The free-choice scenario did not include any tests with additional crew at the internal staircase. The second situation to be examined was the situation where passengers moved upwards to reach available exits on the upper deck. Again, two demonstrations were conducted in this condition, one with additional crew at the internal staircase, and one without. The final situation explored was where passengers moved downwards, and four demonstrations were conducted under this condition. Two were conducted where additional cabin crew were available at the internal staircase, and two were conducted without additional crew. The evacuation and quantitative questionnaire results that follow are provided for each scenario in turn.

3.4.1. Free choice evacuations

Summary statistics for the free choice evacuations are provided in Table 2 below.

Free choice evacuations	N	**Slide deployment (seconds)***	**Mean evacuation time (seconds)**	**Evacuation rate (passengers per minute)†**	**Overall exit evacuation time (seconds)§**
25 January 2003 **Trial 1**					
UR1	33	10.7	42.4	25.4	75.6
LL2	62	10.7	31.2	56.7	64.5
LR2	74	10.7	33.4	63.3	69.2
1 February 2003 **Trial 4**					
UR1	36	10.7	29.9	46.4	45.3
LL2	65	10.7	22.9	92.3	41.6
LR2	68	10.7	25.3	79.4	50.6

* The slide deployment time was taken from the call to evacuate, to the signal to stewards that the available exits were to be opened.

† Calculated using the formula n-1/time.

§ The overall exit evacuation time was taken from the call to evacuate to the first foot of the last participant over the exit thresh old.

Table 2: Summary statistics for free choice evacuations

Unfortunately, inferential analyses of these evacuation data cannot be conducted, since insufficient data are available to conduct comparisons with the other conditions. However, there do appear to be differences in evacuation rates between the two demonstrations, with lower mean evacuation times, faster evacuation rates, and lower overall exit evacuation times evident on the last trial of the programme. This may simply be a function of the cabin crew, who by this time would have gained significant additional experience in passenger management and evacuation situations.

Analysis of the post evacuation questionnaire data also provided information on passenger perceptions of these free choice evacuations. Participants were asked to rate the difficulty of moving out of their seat to reach an aisle on a seven point scale, where one was very easy and seven was very difficult. For participants seated on the upper deck, ratings provided ranged from 1 to 7, with a mean rating of 2.2. For participants seated on the lower deck, ratings ranged from 1 to 5, with a mean of 1.8.

Participants were also asked to rate the difficulty they experienced in finding an open door (i.e. an available exit) on the same seven point scale, where one was very easy and seven was very difficult. For participants on the upper deck, the ratings ranged from 1 to 7, with a mean rating of 2.4. For participants on the lower deck ratings ranged from 1 to 6, with a mean rating of 1.9. These ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

The post evacuation questionnaire also asked participants to rate the difficulty of moving towards an open door (i.e. an available exit). The seven point scale ranged from one, which was very easy, to seven, which was very difficult. On the upper deck, participants rated this difficulty using the range of scores from 1 to 7, with a mean perceived difficulty rating of 3.2. On the lower deck, again scores ranged from 1 to 7, with a mean score of 2.2. These ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

With regards to actually moving through the exit, again participants rated this difficulty on a seven point scale, where one was very easy and seven was very difficult. For participants seated on the upper deck, the ratings provided ranged from 1 to 7, with a mean rating of 2.0. For participants seated on the lower deck, ratings ranged from 1 to 7, with a mean rating of 1.7. These ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Participants were also asked to choose from several options the single most important factor in choosing an exit to evacuate through. The options were that the exit used was chosen because it was the nearest available exit, because it was the door that participants had entered or boarded by, that cabin crew directions had influenced their exit choice, that it was the door with the shortest queue, that it was the first exit they passed, the only one they could see, that they followed other people to the exit, that they knew about the exit from the safety briefing or safety card, or any other reason. The results, split according to whether passengers were seated on the upper or lower deck, are provided below in Table 3.

Reason given	**Upper deck** (N = 165)	**Lower deck** (N=165)
It was the nearest available door	56 (33.9%)	104 (63.0%)
I entered/boarded using the door	0 (0%)	1 (0.6%)
Cabin crew directed me to the door	76 (40.6%)	30 (18.2%)
It was the door with the shortest queue	20 (12.1%)	8 (4.8%)
It was the first available door I passed	6 (3.6%)	6 (3.6%)
It was the only door I could see	1 (0.6%)	4 (2.4%)
I followed the passengers in front	7 (4.2%)	5 (3.0%)
I knew about the door from the safety briefing/card	6 (3.6%)	5 (3.0%)
Other	2 (1.2%)	2 (1.2%)

Table 3: Free-choice evacuation responses for choice of door

The post evacuation questionnaire also questioned passengers about whether they had used the internal staircase and/or the slide. Of the 166 passengers seated on the upper deck who gave a response, 69 said that they had not used the internal staircase, and 97 said that they had. Of the 168 passengers who were seated on the lower deck who gave a response, 165 said that they had not used the internal staircase, compared to 3 who said that they had used it. For the slide, of 167 upper deck participants who answered the question, 101 said that they had not used the slide in the free choice evacuations, while 66 said that they had. Of the 168 lower deck participants who answered the question, none had used the slide.

The post evacuation questionnaires also asked participants to rate the extent to which their awareness of the cabin layout had assisted in their evacuation. The ratings were provided on a seven point scale, where one was very helpful and seven was not at all helpful. The mean rating for participants on the upper deck was 2.6, with a range from 1 to 7. For participants on the lower deck, the mean rating was 2.3, also with a range between 1 and 7. It must however be noted that upper deck participants may have been somewhat confused by the safety demonstration, in which cabin crew were required to point out three pairs of upper deck exits, two of which did not exist, however the safety card detailed only the front pair of exits that were present on the deck. Slight confusion may have also occurred on the lower deck, as the safety briefing and card detailed three pairs of exits at the front, in the centre and at the rear of the deck, however there were no exits or cabin crew at the rear of the cabin. This confusion is evident from the comments provided on the post evacuation questionnaires, and that this is more likely to have been the case where the free choice trial was the first of the session (25 January, 2003). Also, these statistics do not take account of any movement between decks.

Finally, participants were also asked to rate on a seven point scale the extent to which the cabin crew instructions assisted in their evacuation, where one was not at all helpful and seven was very helpful. For upper deck participants, the mean rating was 2.3 with a range of 1 to 7. For lower deck participants, the mean rating was 2.5 with a range of 1 to 7. Again, these ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit, and ratings may also have been influenced by the absence or presence of cabin crew on the internal staircase.

3.4.2. Moving upwards evacuations

Summary statistics for the moving upwards evacuations are provided in Table 4 below.

Moving upwards evacuations	N	Slide deployment (seconds)*	Mean evacuation time (seconds)	Evacuation rate (passengers per minute)†	Overall exit evacuation time (seconds)§
1 February 2003 Trial 2 No additional crew					
UL1	112	10.7	43.9	78.9	84.4
UR1	57	10.7	47.5	38.8	86.5
25 January 2003 Trial 3 Additional crew					
UL1	119	10.7	45.3	91.1	77.7
UR1	49	10.7	45.4	36.8	78.2

* The slide deployment time was taken from the call to evacuate, to the signal to stewards that the available exits were to be opened.

† Calculated using the formula n-1/t.

§ The overall exit evacuation time was taken from the call to evacuate to the first foot of the last participant over the threshold.

Table 4: Summary statistics for moving upwards evacuations

Unfortunately, inferential analyses of these evacuation data cannot be conducted, since insufficient data are available to conduct comparisons within this condition, or between the other conditions. However, there do appear to be marked differences in evacuation rates between UR1 and UL1, which is most likely a function of the caution exercised by cabin crew at the UR1 exit. The evacuation slide used in these trials had not been used in any previous research, and hence passenger safety was considered of primary importance in the use of this escape means.

Analysis of the post evacuation questionnaire data also provided information on passenger perceptions of the moving upwards evacuations. One moving upwards evacuation was conducted without additional cabin crew at the internal staircase, and one was conducted with additional cabin crew at the internal staircase. Participants were asked to rate the difficulty of moving out of their seat to reach an aisle on a seven point scale, where one was very easy and seven was very difficult. Table 5 shows the results for this question.

Moving upwards evacuations	Upper deck participants			Lower deck participants		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
No additional crew	2.0	1	6	2.0	1	7
Additional crew	2.3	1	6	2.0	1	6

Table 5: Summary statistics for moving upwards evacuations

The post evacuation questionnaire also asked participants to rate the difficulty of finding an open door (i.e. an available exit). The seven point scale ranged from one, which was very easy, to seven, which was very difficult. Summary results are provided in Table 6 below, although it must be noted that these ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	Upper deck participants			Lower deck participants		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
No additional crew	2.8	1	7	5.4	1	7
Additional crew	3.3	1	7	5.3	1	7

Table 6: Moving upwards evacuation ratings for difficulty of finding an open door

With regards to actually moving towards an open exit, again participants rated this difficulty on a seven point scale, where one was very easy and seven was very difficult. For participants seated on both the upper and lower decks, descriptive statistics are provided in Table 7. These statistics do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	Upper deck participants			Lower deck participants		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
No additional crew	3.2	1	7	5.1	1	7
Additional crew	3.6	1	7	5.4	1	7

Table 7: Moving upwards evacuation ratings for difficulty of moving towards an open exit

With regards to moving through an open exit, again participants rated this difficulty on a seven point scale, where one was very easy and seven was very difficult. For participants seated on both the upper and lower decks, descriptive statistics are provided in Table 8. These statistics do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	Upper deck participants			Lower deck participants		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
No additional crew	1.8	1	5	2.3	1	7
Additional crew	2.0	1	6	2.3	1	6

Table 8: Moving upwards evacuation ratings for difficulty of moving through an available exit

As with the free choice evacuation, participants in the moving upwards evacuations were also asked to choose from several options the single most important factor which influenced their choice of an available exit. The options were that the exit used was chosen because it was the nearest available exit, because it was the door that participants had entered or boarded by, that cabin crew directions had influenced their exit choice, that it was the door with the shortest queue, that it was the first exit they passed, the only one they could see, that they followed other people to the exit, that they knew about the exit from the safety briefing of safety card, or any other reason. The results, split according to whether passengers were seated on the upper or lower deck, are provided below in Table 9.

Reason given	**Upper deck**		**Lower deck**	
	No additional crew (N = 84)	Additional crew (N = 83)	No additional crew (N = 82)	Additional crew (N = 80)
It was the nearest available door	47 (56.0%)	28 (33.7%)	8 (9.8%)	7 (8.8%)
I entered/boarded using the door	3 (3.6%)	1 (1.2%)	0 (0%)	0 (0%)
Cabin crew directed me to the door	11 (13.1%)	34 (41.0%)	47 (57.3%)	53 (66.3%)
It was the door with the shortest queue	10 (11.9%)	8 (9.6%)	6 (7.3%)	4 (5.0%)
It was the first available door I passed	2 (2.4%)	5 (6.0%)	7 (8.5%)	3 (3.8%)
It was the only door I could see	1 (1.2%)	3 (3.6%)	0 (0%)	1 (1.3%)
I followed the passengers in front	3 (3.6%)	2 (2.4%)	6 (7.3%)	6 (7.5%)
I knew about the door from the safety briefing/card	3 (3.6%)	2 (2.4%)	1 (1.2%)	1 (1.3%)
Other	4 (4.8%)	0 (0%)	7 (8.5%)	5 (6.3%)

Table 9: Moving upwards evacuation responses for choice of door

The post evacuation questionnaire also questioned passengers about whether they had used the internal staircase and/or the slide. Of the 167 passengers seated on the upper deck, 118 said that they had not used the internal staircase, and 49 said that they had. Of the 167 passengers who were seated on the lower deck, 4 said that they had used the internal staircase, compared to 163 who said that they had not used it. For the slide, of 168 upper deck participants, 111 said that they had not used the slide in the moving upwards evacuations, while 57 said that they had. Of the 166 lower deck participants who answered the question, 47 reported using the slide.

The post evacuation questionnaires also asked participants to rate the extent to which their awareness of the cabin layout had assisted in their evacuation. The ratings were provided on a seven point scale, where one was very helpful and seven was not at all helpful. The results are shown below in Table 10. These ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	**Upper deck participants**			**Lower deck participants**		
	Mean	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
No additional crew	2.9	1	7	3.3	1	7
Additional crew	2.7	1	7	3.0	1	7

Table 10: Moving upwards evacuation ratings for extent to which awareness of cabin layout assisted in evacuating

Finally, participants were also asked to rate on a seven point scale the extent to which the cabin crew instructions assisted in their evacuation, where one was not at all helpful and seven was very helpful. The results are shown in Table 11. Again, these ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	Upper deck participants			Lower deck participants		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
No additional crew	2.8	1	6	3.1	1	7
Additional crew	2.6	1	7	2.3	1	7

Table 11: Moving upwards evacuation ratings for extent to which cabin crew instructions assisted in evacuating

3.4.3. Moving downwards evacuations

Summary statistics for the moving downwards evacuations are provided in Table 12 below.

Moving upwards evacuations	N	Slide deployment (seconds)*	Mean evacuation time (seconds)	Evacuation rate (passengers per minute)†	Overall exit evacuation time (seconds)§
25 January 2003 **Trial 2** **No additional crew**					
LL2	80	10.7	28.3	83.0	57.1
LR2	88	10.7	29.4	92.9	56.2
1 February 2003 **Trial 3** **No additional crew**					
LL2	81	10.7	27.5	90.7	52.9
LR2	88	10.7	28.1	98.3	53.1
25 January 2003 **Trial 4** **Additional crew**					
LL2	81	10.7	28.8	90.2	53.2
LR2	87	10.7	28.2	99.0	52.1
1 February 2003 **Trial 1** **Additional crew**					
LL2	86	10.7	29.9	89.9	56.7
LR2	83	10.7	31.1	83.5	58.9

* The slide deployment time was taken from the call to evacuate, to the signal to stewards that the available exits were to be opened.

† Calculated using the formula n-1/t.

§ The overall exit evacuation time was taken from the call to evacuate to the first foot of the last participant over the threshold.

Table 12: Summary statistics for moving downwards evacuations

Unfortunately, inferential analyses of these evacuation data cannot be conducted, since insufficient data are available to conduct comparisons within this condition, or with the other conditions.

However, the mean evacuation times, evacuation rates and overall exit evacuation times do appear to be broadly similar over the different moving downwards tests.

Analysis of the post evacuation questionnaire data also provided information on passenger perceptions of the moving downwards evacuations. Two moving downwards evacuations were conducted without additional cabin crew at the internal staircase, and two were conducted with additional cabin crew at the internal staircase. Participants were asked to rate the difficulty of moving out of their seat to reach an aisle on a seven point scale, where one was very easy and seven was very difficult. Table 13 shows the results for this question.

Moving upwards evacuations	**Upper deck participants**			**Lower deck participants**		
	Mean	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
No additional crew	2.3	1	7	2.0	1	7
Additional crew	2.3	1	7	1.7	1	5

Table 13: Moving downwards evacuation ratings for difficulty of moving out of the seat

The post evacuation questionnaire also asked participants to rate the difficulty of finding an open door (i.e. an available exit). The seven point scale ranged from one, which was very easy, to seven, which was very difficult. Summary results are provided in Table 14 below, although it must be noted that these ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	**Upper deck participants**			**Lower deck participants**		
	Mean	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
No additional crew	3.8	1	7	2.1	1	7
Additional crew	4.1	1	7	2.0	1	7

Table 14: Moving downwards evacuation ratings for difficulty of finding an open door

With regards to actually moving towards an open exit, again participants rated this difficulty on a seven point scale, where one was very easy and seven was very difficult. For participants seated on both the upper and lower decks, descriptive statistics are provided in Table 15. These statistics do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	**Upper deck participants**			**Lower deck participants**		
	Mean	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
No additional crew	4.0	1	7	2.4	1	6
Additional crew	4.1	1	7	2.3	1	6

Table 15: Moving downwards evacuation ratings for difficulty of moving towards an open exit

With regards to moving through an open exit, again participants rated this difficulty on a seven point scale, where one was very easy and seven was very difficult. For participants seated on both the upper and lower decks, descriptive statistics are provided in Table 16. These statistics do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	Upper deck participants			Lower deck participants		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
No additional crew	2.1	1	7	1.9	1	7
Additional crew	1.9	1	6	1.8	1	7

Table 16: Moving downwards evacuation ratings for difficulty of moving through an available exit

As with the free choice and moving upwards evacuations, participants in the moving downwards evacuations were asked to choose, from several options, the single most important factor which influenced their choice of an available exit. The options were that the exit used was chosen because it was the nearest available exit, because it was the door that participants had entered or boarded by, that cabin crew directions had influenced their exit choice, that it was the door with the shortest queue, that it was the first exit they passed, the only one they could see, that they followed other people to the exit, that they knew about the exit from the safety briefing or safety card, or any other reason. The results, split according to whether passengers were seated on the upper or lower deck, are provided below in Table 17.

Reason given	Upper deck		Lower deck	
	No additional crew (N = 166)	Additional crew (N = 164)	No additional crew (N = 164)	Additional crew (N = 165)
It was the nearest available door	38 (22.9%)	28 (17.7%)	99 (60.4%)	101 (61.2%)
I entered/boarded using the door	0 (0%)	1 (0.6%)	1 (0.6%)	6 (3.6%)
Cabin crew directed me to the door	65 (39.2%)	100 (61%)	34 (20.7%)	32 (19.4%)
It was the door with the shortest queue	5 (3.0%)	4 (2.4%)	5 (3.0%)	3 (1.8%)
It was the first available door I passed	10 (6.0%)	5 (3.0%)	5 (3.0%)	5 (3.0%)
It was the only door I could see	4 (2.4%)	1 (0.6%)	1 (0.6%)	3 (1.8%)
I followed the passengers in front	19 (11.4%)	12 (7.3%)	9 (5.5%)	6 (3.6%)
I knew about the door from the safety briefing/card	15 (9.0%)	8 (4.9%)	6 (3.7%)	8 (4.8%)
Other	10 (6.0%)	5 (3.0%)	4 (2.4%)	1 (0.6%)

Table 17: Moving downwards evacuation responses for choice of door

The post evacuation questionnaire also questioned passengers about whether they had used the internal staircase and/or the slide. Of the 334 passengers seated on the upper deck, 4 said that they had not used the internal staircase, and 322 said that they had. Of the 334 passengers who were seated on the lower deck, 9 said that they had used the internal staircase, compared to 325 who said that they had not used it. For the slide, of 331 upper deck participants, 329 said that they had not used the slide in the moving downwards evacuations, while 2 claimed that they had. Of the 333 lower deck participants who answered the question, none claimed to have used the slide.

The post evacuation questionnaires also asked participants to rate the extent to which their awareness of the cabin layout had assisted in their evacuation. The ratings were provided on a seven point scale, where one was very helpful and seven was not at all helpful. The results are shown below in Table 18. These ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	**Upper deck participants**			**Lower deck participants**		
	Mean	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
No additional crew	2.6	1	7	2.3	1	7
Additional crew	2.8	1	7	2.5	1	7

Table 18: Moving downwards evacuation ratings for extent to which awareness of cabin layout assisted in evacuating

Finally, participants were also asked to rate on a seven point scale the extent to which the cabin crew instructions assisted in their evacuation, where one was not at all helpful and seven was very helpful. The results are shown in Table 19. Again, these ratings do not take account of any movement between decks. A number of participants may have been expected to move from the deck on which they were seated to a different deck to find an exit.

Moving upwards evacuations	**Upper deck participants**			**Lower deck participants**		
	Mean	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
No additional crew	3.1	1	7	2.4	1	7
Additional crew	2.6	1	7	2.5	1	7

Table 19: Moving downwards evacuation ratings for extent to which cabin crew instructions assisted in evacuating

4. RESULTS - UNIVERSITY OF GREENWICH

4.1. Introduction

From the perspective of the researchers from the University of Greenwich, 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 (see Table 20).

Day	Trial	Exits used	Participant direction on stairs	Crew with responsibility for stairs
1	1	UPPER DECK: **UR1** LOWER DECK: **LR2, LL2**	Free choice* (DOWN)	NO
1	2	UPPER DECK: **None** LOWER DECK: **LR2, LL2**	DOWN	NO
1	3	UPPER DECK: **UR1, UL1** LOWER DECK: **None**	UP	**YES**
1	4	UPPER DECK: **None** LOWER DECK: **LR2, LL2**	DOWN	**YES**
2	1	UPPER DECK: **None** LOWER DECK: **LR2, LL2**	DOWN	**YES**
2	2	UPPER DECK: **UR1, UL1** LOWER DECK: **None**	UP	NO
2	3	UPPER DECK: **None** LOWER DECK: **LR2, LL2**	DOWN	NO
2	4	UPPER DECK: **UR1** LOWER DECK: **LR2, LL2**	Free choice* (DOWN)	NO

*'Free choice' refers to Upper Deck participants who could egress via either the Upper Deck exit or the stairs then a Lower Deck exit.

Table 20: Planned test matrix for trials

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:

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 (see Table 21).

1) 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.

	Planned behaviour		**Actual behaviour (unanticipated behaviour underlined)**	
	Participant direction on stairs	**Crew with responsibility for stairs**	**Participant direction on stairs**	**Crew assumed responsibility for stairs**

Day 1 Trial 1	Free choice (DOWN)	NO	Free choice then **Crew directed DOWN**	**YES**
Day 1 Trial 2	DOWN	NO	DOWN	**YES**
Day 1 Trial 3	UP	YES	**DOWN then UP**	YES
Day 1 Trial 4	DOWN	YES	DOWN	YES
Day 2 Trial 1	DOWN	YES	DOWN	YES
Day 2 Trial 2	UP	NO	**DOWN then UP**	**YES**
Day 2 Trial 3	DOWN	NO	DOWN	**YES**
Day 2 Trial 4	Free choice (DOWN)	NO	Free choice then **Crew directed DOWN**	**YES**

Table 21: Planned and actual experimental goals

Given the actual behaviour that occurred during the experiments and based on using the video footage provided the following data could **NOT** be collected:

1. It was *not* possible to measure the average flow rates for the Day 1 trails from the above stairs angle, due to camera positioning (camera 13 was not in place on Day 1, see Table 22).
2. It was not possible to measure average flow rates for **ALL** participants during Day 1 Trial 3 and Day 2 Trial 2 due to the unexpected crew intervention. Recall that in these trials some upper deck participants initially descended the stairs, and that those downstairs did not initially go upstairs. In Day 2 Trial 2 flow rate calculations were begun ONLY once participants began using stairs in the desired direction (i.e. upwards).
3. It not possible to comment on any relationship between the performance of the stairs and CC performance, as there appear to be discrepancies between the agreed protocol and the manner in which the trials were conducted as evident on the video footage.
4. It is not possible to come to any firm conclusion regarding the nature of the passenger exit hesitation time distribution and its relationship to sill height as CC performance at the exits are extremely non-assertive.

The data that could be generated from the trials is summarised in Table 22.

	Collected Data		
	Exit hesitation delays	**Handrail use**	**Stair flow rates**
Day 1	YES	NO	YES
Day 2	YES	YES	YES

Table 22: Summary of data that could be extracted by UoG from the video footage

4.2. Staircase performance

The planned matrix of experimental trials is presented in Table 20. Error! Reference source not found.This shows the intended direction of participant stair movement and CC action per trial.

Trial	Participant Direction on Stairs	CC activity at top of stairs
Day 1 Trial 1	Four participants descend stairs before CC arrives. Most participants who then descend stairs were re-directed to them by CC.	Arrives at 36 s and directs participants downstairs then departs to re-direct participants downstairs from Forward Upper exit.
Day 1 Trial 2	Approx 20 participants voluntarily descend stairs before the majority realise only the stairs are available, or were redirected by CC, and turn away from the Upper exit queue to descend stairs.	No CC at stairs until last 7 participants. During evacuation CC verbally re-direct participants downstairs from Forward Upper cabin.
Day 1 Trial 3	Participant procedural confusion. Initially descend stairs causing chaos at base of stairs. Correct upstairs movement only due to intervention of Lower deck CC. 32 participants descended or were beginning to descend stairs before error corrected at 16 s	CC directed participants downstairs instead of forward to Upper exit. This was corrected when participants started to ascend stairs
Day 1 Trial 4	Seven participants ignore CC and correctly descend stairs before CC allows stair descent by all remaining participants	CC blocks participants from descending stairs. Attempts to send them to Upper exit. Then changes to encouraging stair descent.
Day 2 Trial 1	Eight participants ignore CC and descend stairs before CC allows stair descent by all remaining participants	CC blocks participants from descending stairs. Attempts to send them to Upper exit. Then changes to encouraging stair descent after a 13 s dry-up on the stairs
Day 2 Trial 2	Participant procedural confusion. Initially descend stairs causing chaos at base of stairs. Correct upstairs movement only due to intervention of Lower deck CC. 30 participants descended stairs before error corrected at 17 s	CC arrives at stairs after 37 s when all Upper Deck participants are out and correct flow from downstairs is occurring.
Day 2 Trial 3	Eleven participants voluntarily descend stairs before the majority realise only the stairs are available, or were redirected by CC, and turn away from the Upper exit queue to descend stairs	No CC at stairs until last 8 participants. During evacuation CC verbally re-direct participants from Forward Upper cabin to descend stairs
Day 2 Trial 4	Thirteen participants voluntarily descend stairs before others start to redirect to descend stairs from Upper exit queue. Redirection due to CC further back.	CC directs participants to descend stairs from further back. Arrives at stairs at 23 s and directs participants downstairs then departs to re-direct participants downstairs from Forward Upper exit.

Table 23: Summary description of participant and CC behaviour during trials

The actual participant stair movement and CC behaviour is presented in Table 21 and further in Table 23. 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.

4.3. 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 (see Figure 1 and Figure 2).

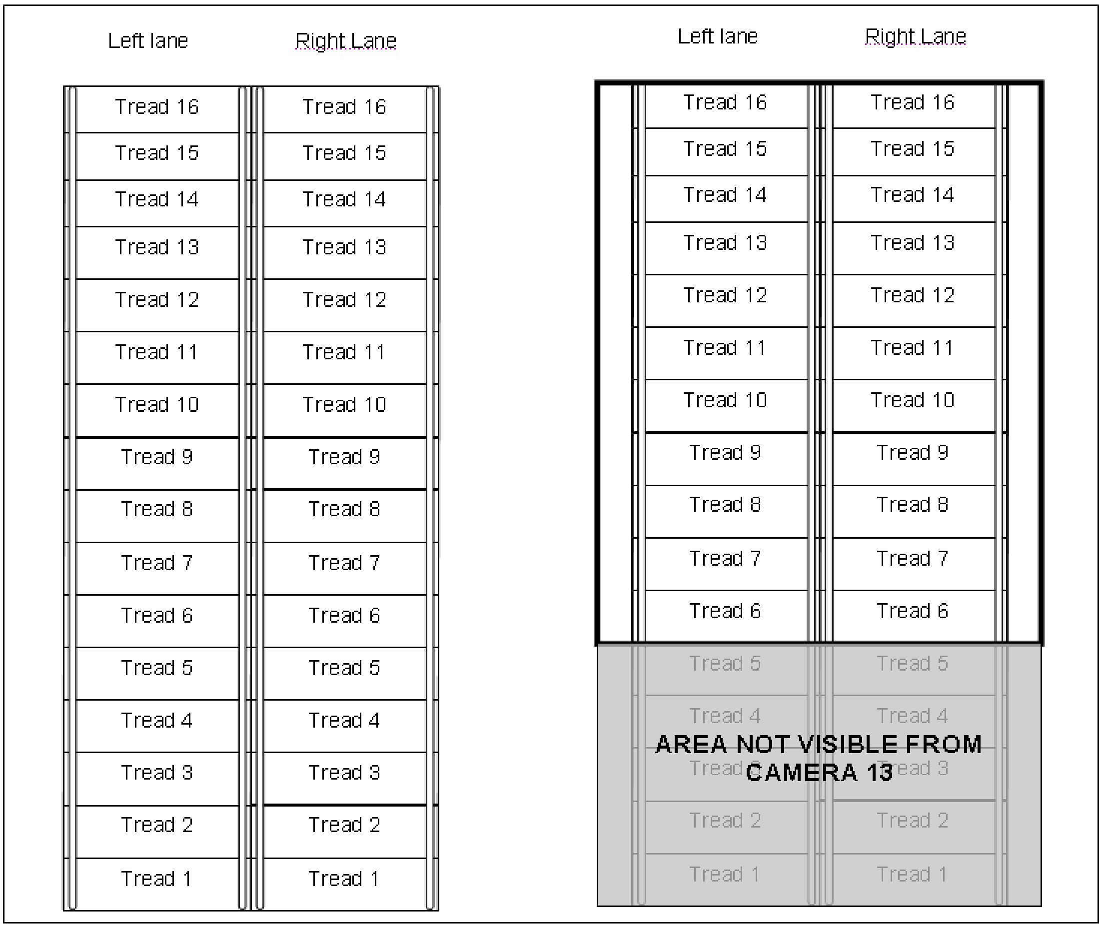


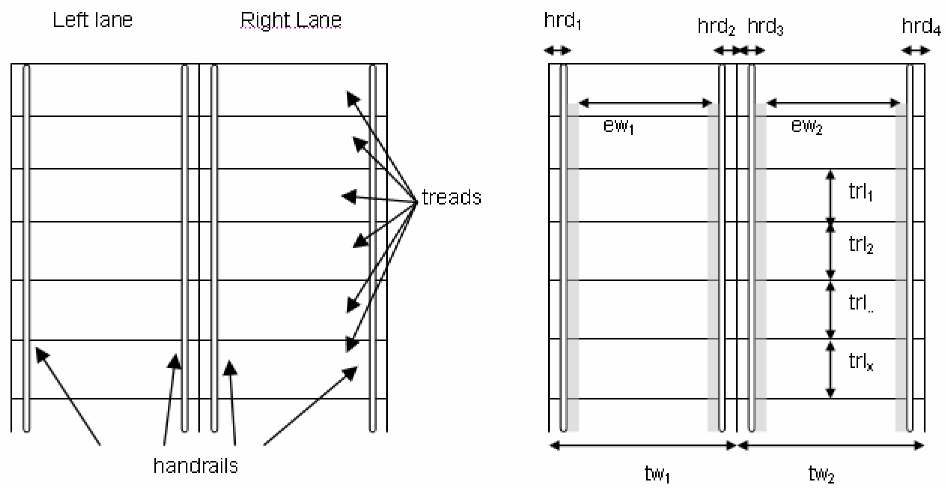
Figure 1: Description of stair configuration and portion of the staircase visible from camera 13

4.3.1. 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 (see Figure 2).
- There were 11 visible steps from camera 13.



hrd = Handrail distance as measured from wall to centre of the hand rail
tw = Total Width of the lane measured from barrier to barrier excluding handrails
ew = the effective operational width of the lane, calculated as, tw – hrd – sway factor+
trl = the length of the tread
total lane area = ew * (trl * number of risers)

+Sway factor allows 9 cms 'edge gap' from the centre of each handrail

hrd_1 = 9.8 cms tw_1 = 87.8 cms ew_1 = 58.8 cms (87.8 – 9.8 – 1.25 – 18)
hrd_2 = 1.25 cms tw_2 = 86.8 cms ew_2 = 57.8 cms (86.8 – 9.8 – 1.25 – 18)
hrd_3 = 1.25 cms
hrd_4 = 9.8 cms
number of visible risers from camera 13 = 11 trl = 26 cms

Left lane visible area = 168.2 cms^2 Right lane visible area = 165.3 cms^2
Left lane Effective width = 58.8 cms Right lane Effective width = 57.8 cms

Figure 2: Description of stair geometry

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 (Figure 3(a)). Some participants used a 2 handed grip, probably due to CC exhortation to hasten (Figure 3(b)).

(a) (b)

Figure 3: Participants using the side HR to swing around to an exit during DOWN stairs movement with (a) one handed and (b) 2 handed grips

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 (Figure 4(a) followed by Figure 4(b)). This only occurred during free flow conditions and may possibly occur with greater frequency during more 'urgent' evacuations involving passenger motivation.

(a) (b)

Figure 4: (a) Commencement and (b) the completion of a vault across several treads during DOWN stairs movement

'Overtaking' refers to a participant passing a slower participate located within the same lane (Figure 5(a) followed by Figure 5(b)).

(a) (b)

Figure 5: (a) Commencement of and (b) over-taking during DOWN stairs movement

'Dual usage' refers to a flow condition in which two participants move side-by-side for any period of time. This behaviour was witnessed during upwards (Figure 6(a)) and downwards stair movement (Figure 6(b)).

(a) (b)

(c) (d)

Figure 6: 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 (Figure 6 (c)) and downwards movement (Figure 6(d)).

'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 (Figure 7(a)) and downwards movement (Figure 7(b).

(a) (b)

Figure 7: Close staggered participant movement (a) up and (b) down the stairs

4.3.2. 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 had elapsed the flow turned and went in the intended direction of the experimental design (see Table 20). 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 8(a) and (Figure 8(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 9). 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 8: 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 10). 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 10).

Figure 9: Participants queue DOWN right lane of stairs

Figure 10: 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

A more detailed breakdown of the behaviour that occurred in these trials can be found in Appendix N.

4.4. 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 (see Figure 1 and Figure 2). 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 (Pauls 1995) across the number of visible treads (see Figure 2). To aid the discussion some hypothetical densities based on various stair behaviours can be seen in Table 24

The stair densities as a function of time are displayed in Figure 11 to Figure 14. 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 DOWNWARD 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.

	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

Table 24: Hypothetical densities based on imposed packing densities

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.

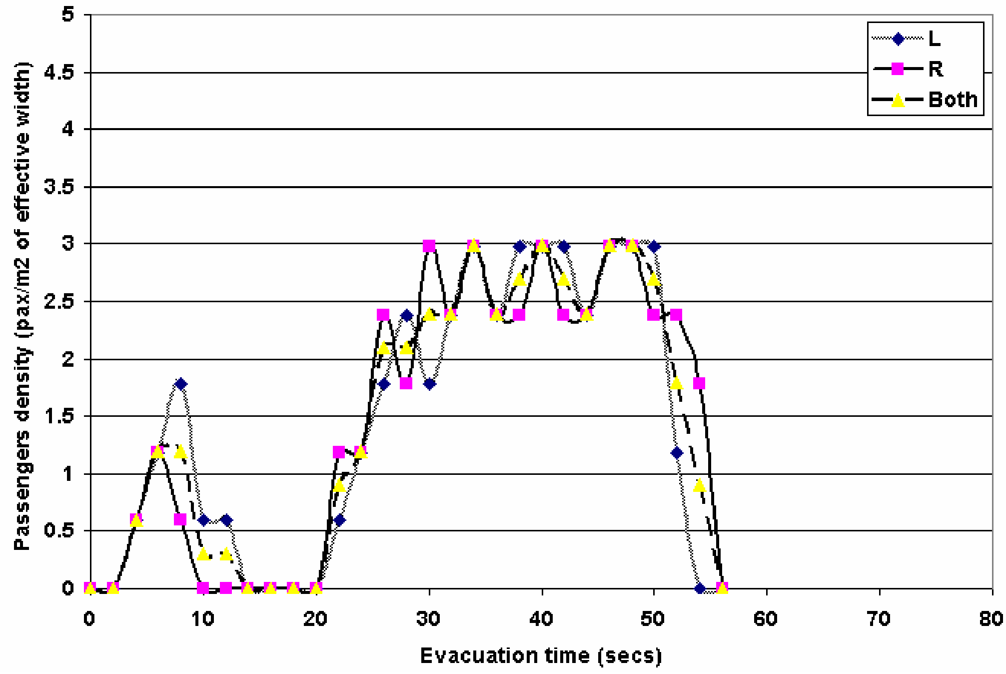


Figure 11: Density in visible portion of stairway during Trial 2.1 (DOWNWARDS TRAVEL)

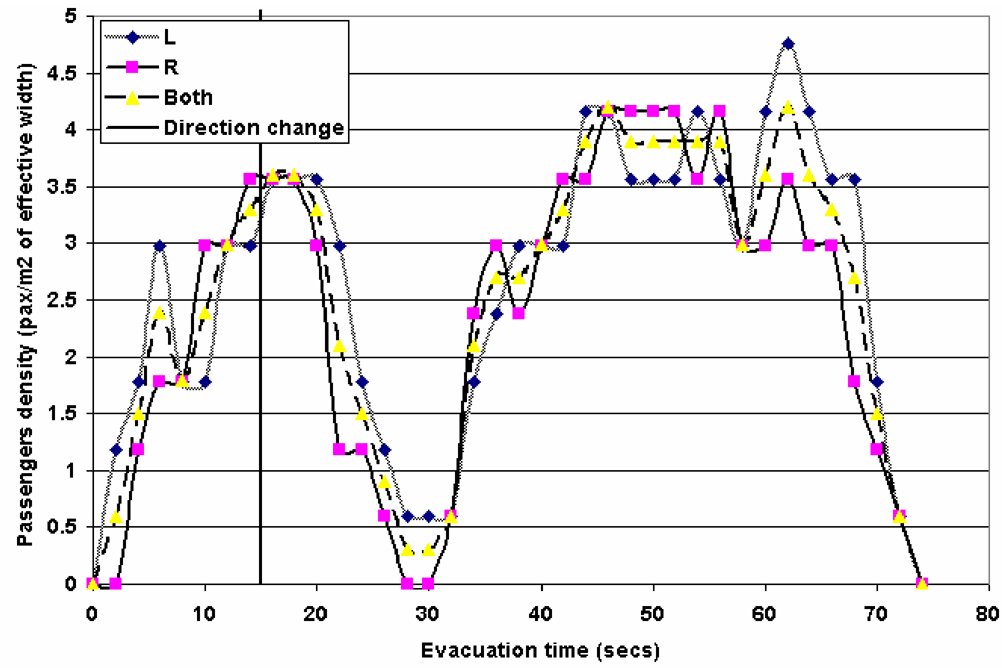


Figure 12: Density in visible portion of stairway during Trial 2.2 (DOWNWARDS and then UPWARDS TRAVEL)

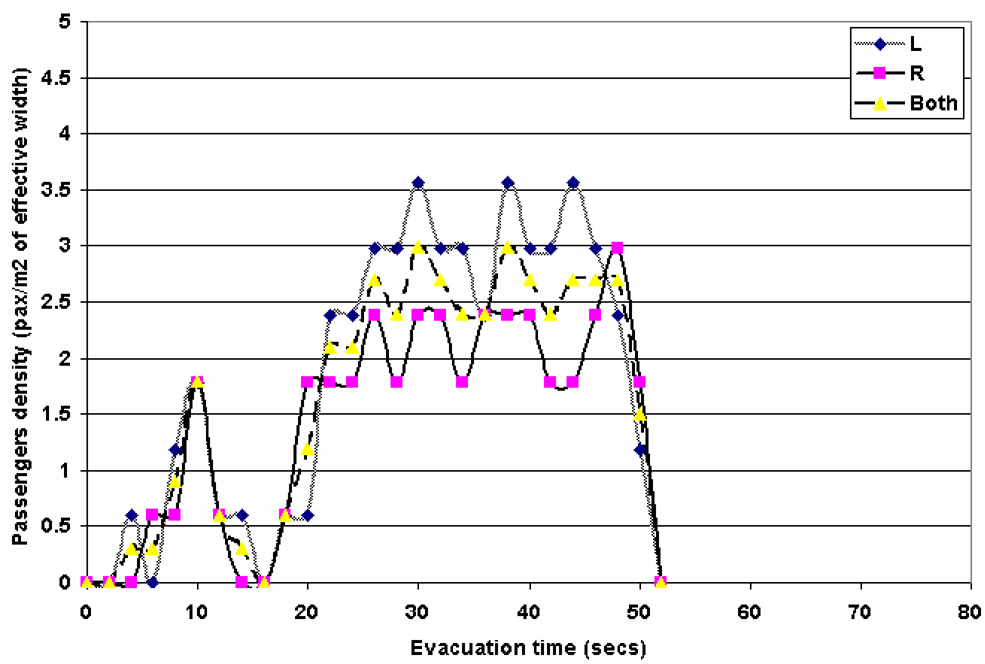


Figure 13: Density in visible portion of stairway during Trial 2.3 (UPWARDS TRAVEL)

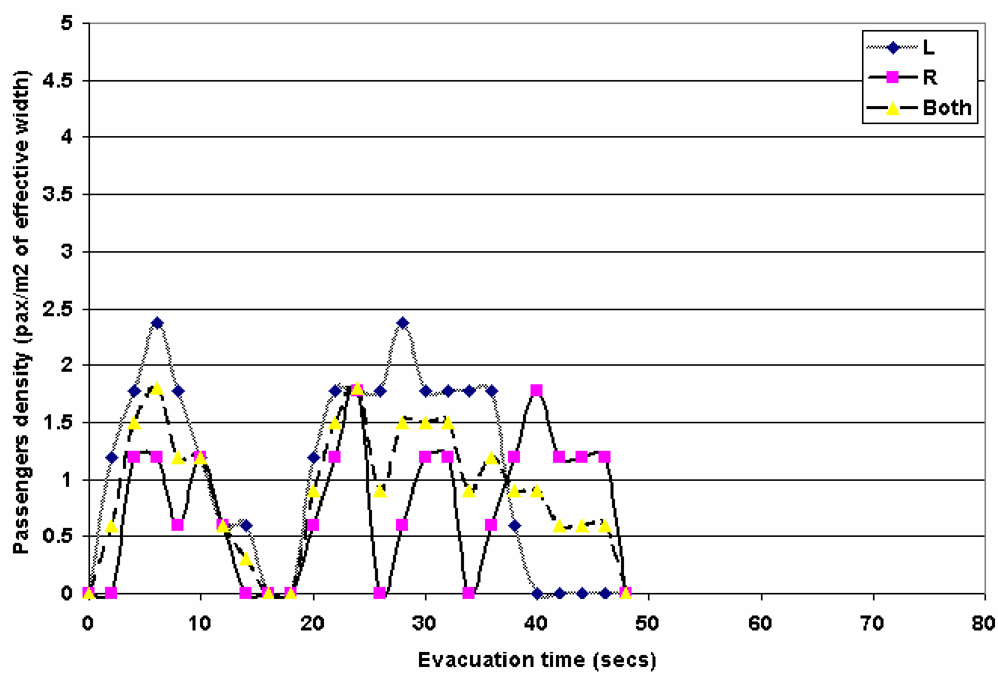


Figure 14: Density in visible portion of stairway during Trial 2.4 (DOWNWARDS TRAVEL)

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.

4.5. Stair flow rates

4.5.1. 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 (Figure 15(a)) 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 (Figure 15(b)). 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.

(a) (b)

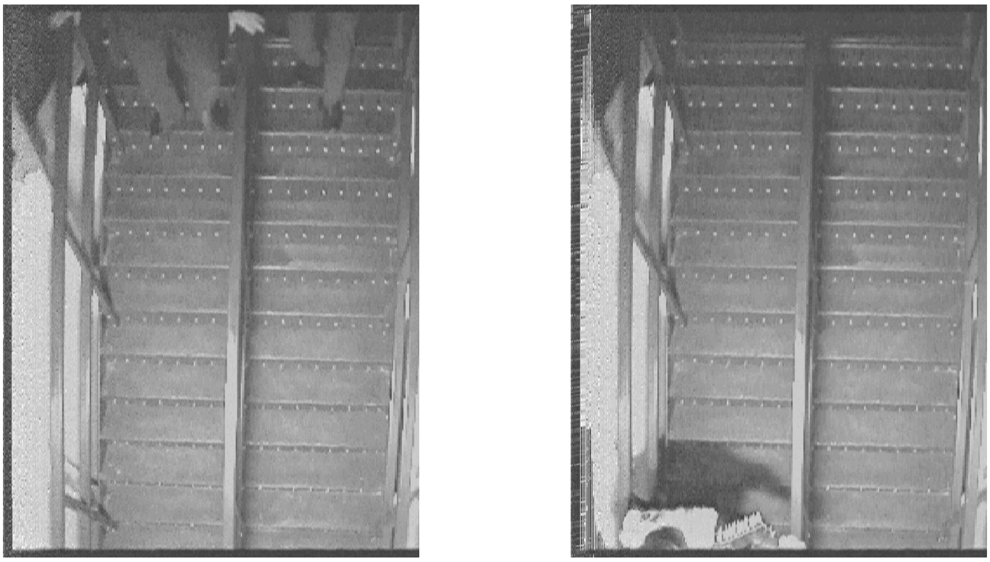
Figure 15: (a) commencement and (b) termination markers used for calculating stair flow rates on day 1 during DOWNWARDS movement

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 (Figure 16(a)). The same end point as DOWN was used but was measured on the upper not lower deck landing (Figure 16(b)).

(a) (b)

Figure 16: (a) commencement (in this example taken as first participant moving in correct direction) and (b) termination markers used for calculating stair flow rates on day 1 during DOWNWARDS movement

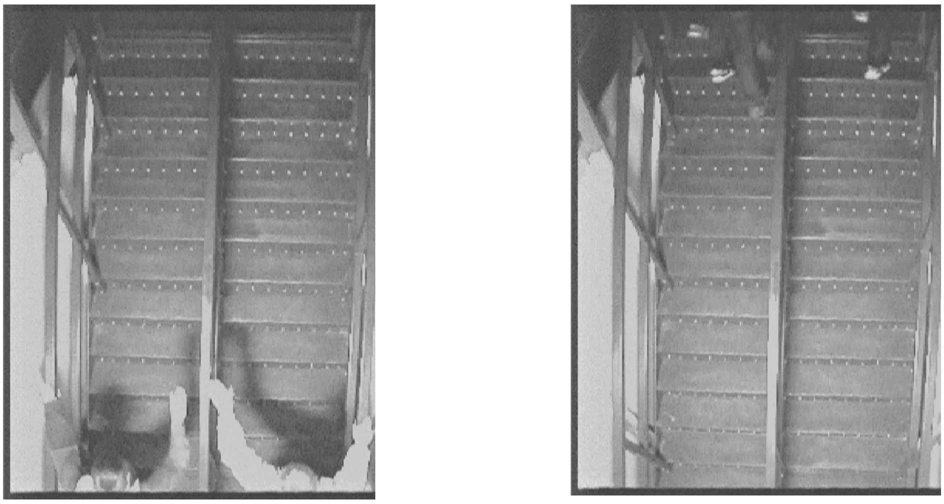
In Day 2 Trials camera 13 was used. For DOWN stairs conditions this commenced with the time at which the first participant began to enter the camera 13 shot and ended when the last participant disappeared from the camera 13 shot. Figure 17(a) and Figure 17(b) show the first and last participants in shot for illustrative purposes. In reality the moment the participant begins to enter and has disappeared from shot were used.



(a) (b)

Figure 17: (a) commencement and (b) termination markers used for calculating stair flow rates on day 2 during DOWNWARDS movement

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. Figure 18(a) and Figure 18(b) show the first and last participants in shot for illustrative purposes.



(a) (b)

Figure 18: (a) commencement and (b) termination markers used for calculating stair flow rates on day 2 during UPWARDS movement

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.

4.5.2. Stair flow rates

Before turning to an analysis of measured average stair flow rates, a brief discussion of behaviours that are relevant to the flow rate calculations is presented (see Section 4.3 for descriptions of participant behaviour). A more detailed description of passenger behaviour may be found in Appendix N.

Trial 1.1: Free Flow conditions. The trial commenced with a 22 seconds delay in participants beginning to use stairs. Flow was single file with no dual usage or over-taking. Flow was unhurried with no crowding, no over-taking, no dual flowing or close staggering.

Trial 1.2: Flow DOWN stairs. Participants queued in Left lane from 9-17 seconds due to congestion from lower deck participants at the lower deck exit. When free flow gathered momentum it was single file and unhurried with no crowding, no over-taking, no dual flowing or close staggering. In Right lane participant 130 stops on stairs and slows up flow behind even though there was room ahead of him to keep moving. This causes others behind him to stop altogether. Flow rate gathered momentum when main flow started. This correlated with CC downstairs facing the stairs and shouting orders and pushing participants.

Trial 1.3: Flow UP stairs. Participant procedures were confused. Upstairs participants went downstairs, turned and were joined by participants from downstairs sent up. Slow congested flow throughout. Correct upstairs flow started at 16 s into the trial and was high density throughout.

Trial 1.4: Flow DOWN stairs. Left lane flow was unhurried and single file with 2 or 3 incidences of close staggered flow. Only one CC who remained at the Assist Space (AS) throughout. Flow may have been slower due to this. Right lane movement is initially slow then at 18 seconds participant 52 descends stairs at crawl speed. He may have been injured or disabled and held other participants up behind him. When flow down stairs gathered momentum CC were positioned either side of the exit. Flow was unhurried and mostly single file, but some close staggered flow plus 4 seconds of dual flow occurred.

Trial 2.1: Flow DOWN stairs. Left lane, participants queued on stairs initially. Dual usage occurred at 45 seconds. Half a dozen participants over-took at the top of the stairs. Bunching and close staggering occurred in the middle of the stairs. Right lane, also some bunching and close staggering in middle of stairs and dual usage occurred at 45 seconds.

Trial 2.2: Flow UP stairs. Base of stairs was disorganised at the beginning of the trial with participants crossing each other on stairs, and descending then back tracking up the stairs. Correct upstairs flow started at 17 s into the trial and was high density throughout. Use of BOTH handrails coincided with less congestion during the main use phase (38-72 seconds in) and use of Centre or Side HR only coincided with peak congestion where flow was `staggered dual flow'.

Trial 2.3: DOWN. 10 -15 seconds into the trial participants had to wait/queue on stairs. Thereafter flow was unhurried and less urgent than other trails. The paradoxically high flow rate achieved in Table 25 reflects a near optimal combination of free flow and little dry up in flow compared to other trials.

Trial 2.4: Free Flow conditions. Left lane exhausts 9 seconds before right. This was due to Cabin Crew redirecting participants from the Upper deck exit queue to the stairs. Dry ups on both lanes due to Upper participants exit choice indecision. Flow was unhurried with no crowding, over-taking or dual flowing or close staggering.

The average stair flow rates measured in the trials is presented in Table 25. 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 4.4 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.

		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

Table 25: Average stair flow rates for all trials

4.5.3. Comparison of Stair flow rates with building evacuations

The unit flow rate capacity for a standard stair as specified in the UK Building Code (HMSO 1991) 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 26. From Table 26 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.

		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

Table 26: Flow rates expressed per unit of effective width

4.6. 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 27). 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.

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

Table 27: Day 2 participant's HR use, determined from 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.

4.7. Passenger Exit Delay Time distributions

4.8. 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.

4.9. 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.

4.10. Raw data and qualitative features

4.10.1. Trial 1.1

In Trial 1.1 two CC worked the exit and 33 participants evacuated. Participants appeared to wait for the previous participant to be some distance down or off the slide before they jumped. There were long intervals between participants ('long' in terms of the behaviour that was being measured). Data in Table 28 does not reflect inter-participant delays. Participant exit during this trial is thought to resemble a precautionary evacuation in which extreme care is taken with respect to minimising injuries. For the first 66 seconds the exit door was not fully open / fastened.

The FSEG team would classify the CC behaviour at the exit as significantly less than Unassertive. The CC during the trials neither physically or verbally expedited participant exit flow. Indeed, in several cases CC are seen to actively prevent participants from exiting. The CC did not appear to treat the trial as time critical, but more safety critical. 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.

1.56	3.68	3.88	3.24	2.72
3.52	2.96	3.52	3.52+	
3.56	3.36	2.88	7.36+	
3.4	2.4	3.64	6.88+	
2.6	2.52	4.6+	4.36+	
2.08	2.8	4.36	5.56	
3.4	2.68	3.12	4.68+	
2.72	3.48	2.6	5.2+	

+denotes sitter

Table 28: Raw exit delay times (s) extracted from trial 1.1

One CC was located in the AS either side of the exit. They called for participants to form two lines on approach to the Type A exit. But at the exit participants evacuated one at a time, cued by CC, who took turns at saying "go" once the CC thought a 'safe' amount of time had elapsed since the last evacuee had descended the slide. On several occasions CC stopped participants from evacuating too soon. In these cases the participants either jumped from the exit or sat and slid down the slide on their own initiative. CC did not push participants or throw them out. Only the longest 'sitters' appeared to receive any assistance from the CC. The only physical contact which CC undertook was to take hold of a participant's arm, step them up to the exit sill and pull them to one side so that two participants were at the sill, ready for CC to take turns at saying "go". However, it should be noted that this behaviour was the exception not the rule.

4.10.2. Trial 1.2

Not applicable. No evacuation slide used

4.10.3. Trial 1.3

In this trial 48 participants exited via the slide. As in Trial 1.1, the CC were classified as less than Unassertive. Participant behaviour in this trial appeared to be more motivated than in Trial 1.1 however, this was despite rather than because of CC activity.

1.28	1.2	2.6	1.52	1.64	2.84
2.68	3.08	2.88	2.56+	2.12	3.24
1.64+	2.36	1.08	1.68+	2.08+	2.24
2.4	5.16+	0.76	1.76	3.56+	1.4
2.92+	3.96+	1.68+	1.24	3.32+	1.76
2.64	1.36	1.2	2.04	1.96	1.6
4.36+	2.24	0.72	1.32	2.76	1.04
3.52+	1.88	2	3.48+	4.08	1.92

+denotes sitter

Table 29: Raw exit delay times (s) extracted from trial 1.3

4.10.4. Trial 1.4

Not applicable. No evacuation slide used

4.10.5. Trial 2.1

Not applicable. No evacuation slide used

4.10.6. Trial 2.2

In this tria l 56 participants made use of the slide. Again CC were less than Unassertive. At approximately 17 seconds into the trial the door partially closes, which temporarily impeded participants. Participants' behaviour in this trial appeared to be more motivated than in Trial 1.1, but this was despite rather than because of CC activity. CC appeared to tap participants on the shoulder, telling them when to go.

1.04	2.32+	1.08	2.56	2.6	3+	1.8
1.84	1.4+	1.96	1.92	1.72	2.52	2.8
0.8	2.48	1.92	2.44	3.16+	1.36	2.48+
0.64	2.52	2.2	0.8	2.44+	3.4+	2.16
2.44	2.64	2.36	2.4	2.4	3.8+	2.4
1.92	1.16	1.72	1.68	2	1.84	1.8
3.44	1.8	3.2	2.08	1.2+	3.36+	2.68+
2.52+	2.72	1.28	1.96	2.16	3.28	2.92

+denotes sitter

Table 30: Raw exit delay times (s) extracted from trial 2.3

4.10.7. Trial 2.3

Not applicable. No evacuation slide used

4.10.8. Trial 2.4

In this trial 36 participants made use of the slide. Similar to the other trials the CC were classified as being less than Unassertive during this trial. Participants in this trial appeared to display the highest levels of motivation, but again this was despite rather than because of CC activity. The reason for this participant motivation is not clear from the video evidence but it did not appear to be a reflection of CC instructions or assertiveness.

3.36+	1.28	1.36	2.12	1.6
3	2.76	1.72	1.48	2.44
1.24	1.72	1.4	2.12	1.4
1.72	1.12	1.44+	1.08	1.08+
1.2	2.36+	1.96	1.56	
1.76	0.8	1.36+	2	
1.64	2+	2.2	1.6	
1.72	2.28	1.68+	0.76	

+denotes sitter

Table 31: Raw exit delay times (s) extracted from trial 2.4

4.11. 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.

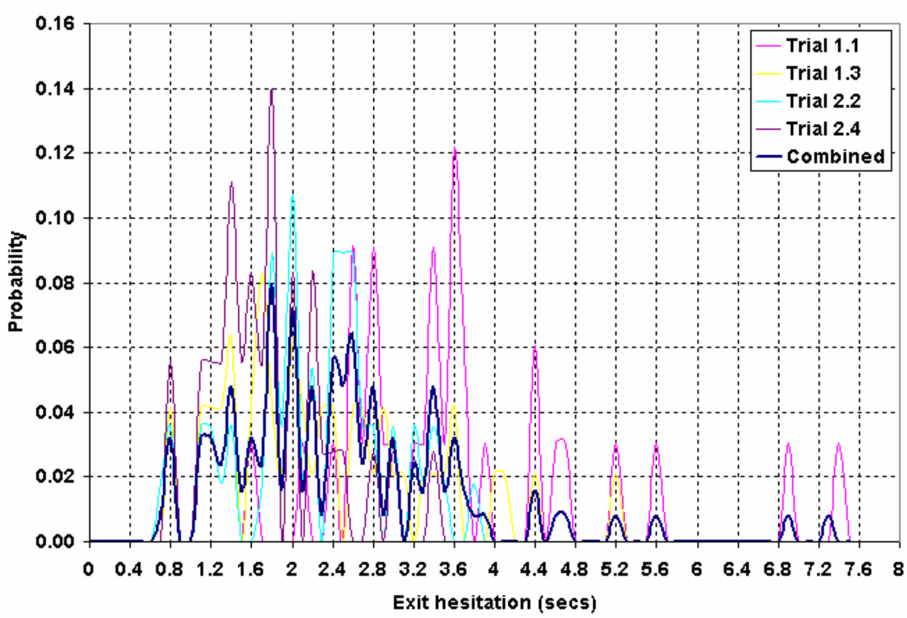
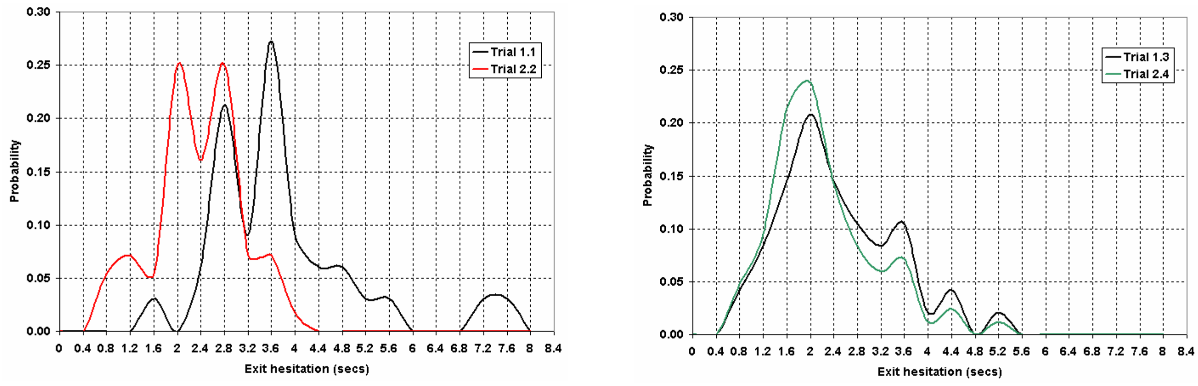


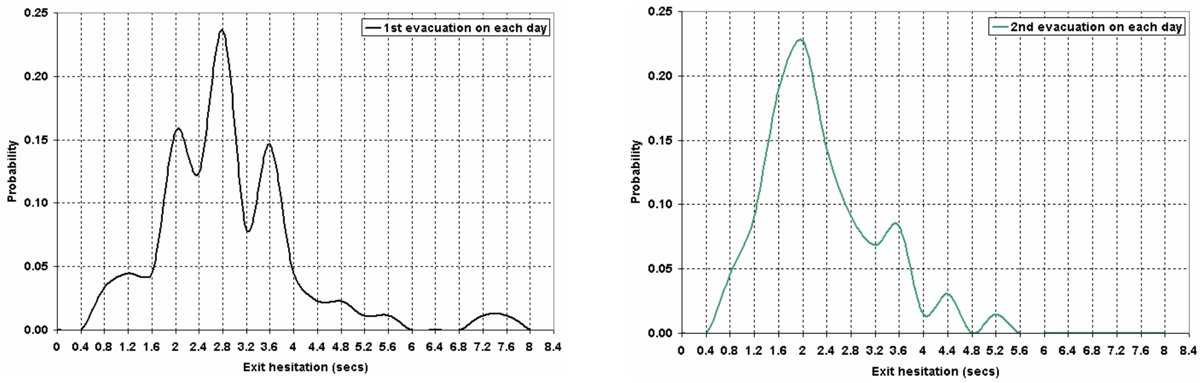
Figure 19: Uniform probability curves using a bin size of 0.1s

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 20(a)) and the second evacuations undertaken on each day (see Figure 20(b)). The first and second trials on each day were then combined (see Figure 21).



(a) (b)

Figure 20: 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 21: 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 22) 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 32).

	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

Table 32: Summary of raw Passenger Exit Hesitation Times (secs)

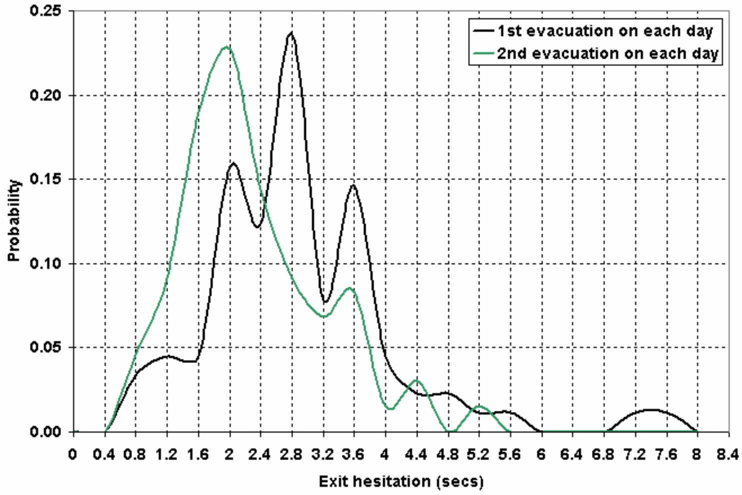


Figure 22: Combined Exit Hesitation Probabilities from the first trials on days 1 and 2 and the second trials on both days 1 and 2

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 23. The shape of the curve for unassertive crew is similar to that shown in Figure 23 with the fastest times being unaffected but with more passengers displaying the slower times.

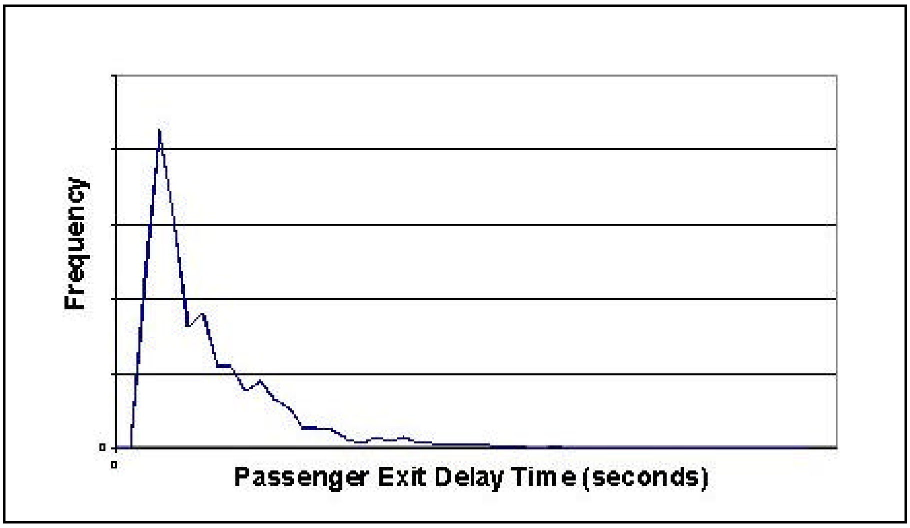


Figure 23: Passenger Exit Delay Time distribution for main deck Type-A exits with assertive crew

The shape of the passenger exit hesitation time distribution generated from the second trials conducted on days 1 and 2 resemble Figure 23. 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.

4.12. 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 33 confirm the point made in Section 4.10 and the means presented in Table 32. 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.

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

Table 33: Participant average exit flow rates

4.13. 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. RESULTS – SOFRÉAVIA

5.1. Introduction

This section of the report presents the Sofréavia contribution to the analysis of the VERRES experimental data. The elements presented in this report come from the observation and analysis of video data, CCs interviews, and passengers' questionnaires.

In this report, data gathered during the experiments are analysed from a behavioural point of view (and not measurable performance, time, duration…). In this perspective, our research objective is to find the elements took into account by individuals to make their decisions, built their situational awareness, follow or not follow a procedure, find a solution to solve a new issue.

In order to catch some elements to reach our objective we need to know different kind of information from the trial:

- the objectives of people's action,
- some elements of the decision making process,
- some elements concerning the situation awareness construction,
- explanation concerning communication strategies carried out during the trials.

Consequently, professional Cabin Crews are a precious source of reliable data because the way they cope with an evacuation is not comparable with trained researchers. Knowledge, experiences and culture impact on the evacuation management. They are essential elements to reach our research objective: understand how those who are in charge of it manage evacuation process.

This approach is complementary from the ones applied by the consortium partners, much more quantitative data oriented. The different objectives among the consortium members lead to find out some compromises during the test procedure building. That is the reason why test results appear to be difficult to analyse for everyone in the consortium and sometimes disappointing.

As a matter of fact, hypothesis defined at the beginning of our work in order to guide the different choice in the design the experiment procedure did not allow us to make use of the richness of the data.

Nevertheless, the test was a great opportunity to have a first look to a very new and innovative a/c cabin design.

In order to explore and understand the CCs work within a VLTA environment, and based on the interviews data, we decided to use the famous cognitive model "the control of the situation" (Amalberti.R & al. 1996, 2000), through 3 cases studies. The cases have been chosen because of the questionable facts they involved according to the VERRES consortium members. The use of cases studies allowed us to focus on very specific issues which occurred during the test and highlighted some specific aspect of the evacuation management.

This report is composed of the following structure:

- General description of the results from the three sources of data (CCs interviews, video, Passengers questionnaires)
- Presentation of the cognitive model: "the control of the situation"
- A cases studies chapter
- The last chapter deals with other interesting apart from the cases studies
- All the raw data are gathered in the Appendices R, S and T.

5.2. General description of the results

5.2.1. CCs Interviews data

The interview guide (*Appendix Q),* started with two very simple opened questions: “according to you what were the three main negative aspects of the trial” and “according to you, what were the three main positive aspects of the trial”.

A first reading of the interviews data allowed us to categorise the CCs answers as such:

The negatives aspects mentioned by CCs referred to:

- **A lack of situation awareness** concerning the usable exit, the use of the stairs, communication issues with other CCs, impossibility to predict flow variation
- **An inappropriate action**
- **Achievement of an undesirable state or no achievement of an objective**

The positive aspects mentioned by CCs referred to:

- Ability to carry out appropriate **action**
- Ability to catch an important information to enrich **the situation awareness**
- **Achievement of an objective**

Objectives: to control the flow, to anticipate the variation of passenger flow, to optimise the use of the exits.

Precise references of the interviews (*Appendix S*) are mentioned in the analysis of the case studies.

5.2.2. Video data

Tables 34 and 35 show the number of passengers seated next to the stairs (on lower and upper decks) who used the stairs before any indication from CCs (or against his/her intervention).

D1.1-FC	D1.2-GD-NOSC	D1.3-GUp-SC	D1.4-GD-SC
4	15	20	7

Table 34

D2.1-GD-SC	D2.2-GUp-SC	D2.3-GD-NOSC	D2.4-FC
10	29	11	13

Table 35

Results presented in these Tables and analytical reading of the timed descriptions of video *(Appendix S*) allowed us to make several statements:

Concerning the Crew behaviours

- In almost all sessions (*D1.2, D1.3, D1.4, D2.1, D2.2 and D2.4*), SC or door CCs acting as a SC (leaving their own door) stopped or encouraged the commencing passenger stair flow.
- In all the sessions without SC (*D1.1, D1.2, D2.2, D2.3 and D2.4*) as no cabin crew was managing the bottom of stairs and passengers were hesitating, the cabin crew behaved as a Stair Crew at the bottom of stairs on an ad hoc basis.

- The position of the cabin crew at top of stairs does not seem comfortable and safe. He must stand forward to prevent the pseudo-passengers to go down too early and he has nothing to prevent him from falling back.

Concerning the Passenger behaviours

- If we consider the amount of people in the above Table 34 and 35, the first thought would be that very few people use the stairs on their own.
- However, the number of passengers who were queuing at the upper deck is 80 in total among whom **32** were nearer from the staircase than the exit. Thus, if we compare the results of Table 34 and 35 with **32**, we have to admit that a large proportion of people in upper deck, able to see the stairs, did use them as an alternative.
- Learning curve, light in the stairs might have impacted the number of people using the stairs, but no information in that sense appears in the questionnaire data.
- The crowd masks the handrail and some pseudo- passengers are bouncing into it because they don't know there is a handrail. A pole, from the ceiling to the floor, at the end of the handrail would maybe improve the cabin crew position and would indicate the handrail to pseudo-passengers when the top of stair is crowded.

5.2.3. Passengers questionnaire data

In *Appendix T*, questionnaires data are presented in relation with the initial set of hypothesis used to guide us in the preparation work. Results obtained from the passengers answers do not allow us to conclude on precise statements (lot of questions were completed for the first trial of the day, and then there is often a big amount of "Not Defined" answers).

As a consequence, the assessment of the hypothesis could not be done through the questionnaire data analysis. Above all, the little amount of trials made does not allow obtaining representative results.

Nevertheless, passenger's data could help to confirm the analysis and interpretations made on the basis of the Interviews and video data. Some of the questionnaire results figures are referenced in the cases studies because they could bring some additional information.

A blank questionnaire is available in the *Appendix P* of this report.

5.2.4. Appraisal of the general description

Based on this 3 statements, and to allow us to go further in the comprehension of the CCs behaviours, we decided to use 3 cases studies taken from the trial events. The choice has been made according to the VERRES researchers main questions following the trials.

In order to help us in the analysis of the cases studies, we will use the cognitive model named "the control of the situation". This model is used in various industrial fields for HF training purpose, for several types of operators (pilots, aircraft manufacturers, nuclear power plant operators, maintenance operators, air traffic controller).

5.3. Managing the risk thanks to the control of the situation

In order to explain and describe in details the data collected during the VERRES trials, we would like to use the *"famous"* cognitive model named "Control of the situation model".

This model, built by French psychologists researchers (AMALBERTI, R. -1996 - and Al. *"La conduite des systèmes à risques"* Coll. Le travail Humain, Paris, Presses Universitaires de France, Amalberti, R. –2000-, *"La maîtrise des situations à risque"*. Psychologie Française) is used in several fields for pedagogical purpose or HMI designing working basis: French army, Airlines, Aircraft manufacturer, EDF, FRAMATOME (AREVA).

The model is based on two statements:

- The statement that our **main objective** when dealing with a *dynamic* situation is to **keep the control of the situation**
- The statement that the **management** of our **limited mental resources** is a primary condition to reach this objective.

"Mental resources" is an expression used to speak about the perception and information processing potentially usable at the same time by our brain (short term memory capacity, attention capacity, mental representation capacity). The mental resources limitation is a major constraint when using our knowledge in a dynamic situation (we are not able to carry out consciously two different complex tasks at the same time). Thus, mental resources have to be managed (shared and saved).

Mental resources are spent by two main categories of consumption: ***Actions management, Situation Awareness management***. Actually, one feeds the other: on one hand we need to understand sufficiently the situation in order to carry out the right action, and on the other hand the action provides us new information on the situation. The Figure 24 presents the way resources can be spent.

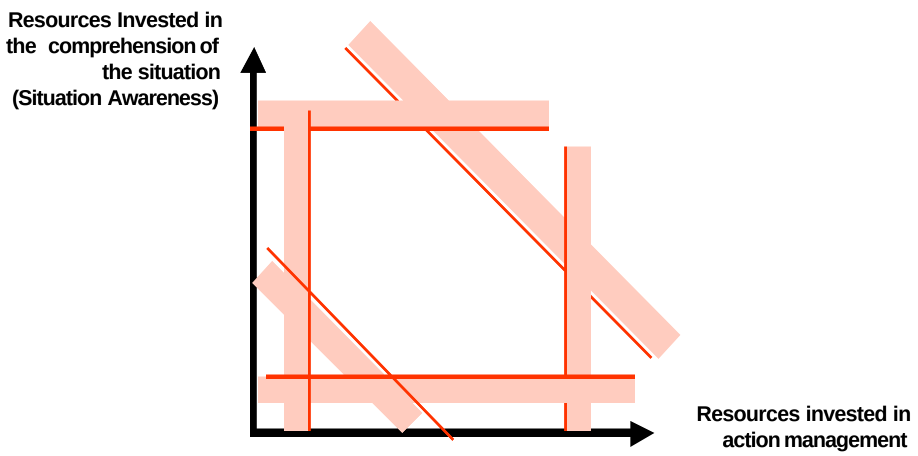


Figure 24

Because our mental resources are limited, some vertical and horizontal limitations are indicated on Figure 24. There is also a transversal limitation indication because we can't invest totally the resources in one of the domains, we need other mental resources to manage the memory, the perception, etc.

We have to indicate also minimum investment limitations because human being is obliged to invest a minimum amount of resources to be able to act or think.

Thus, we obtain a *"resource area"* (green in Figure 25) symbolising a room where the situation is kept in control by our cognitive system. The main objective of an operator is to stay in this area by managing the resources sharing. By doing this management, the operator is managing a **risk**: to loose the control of the situation.

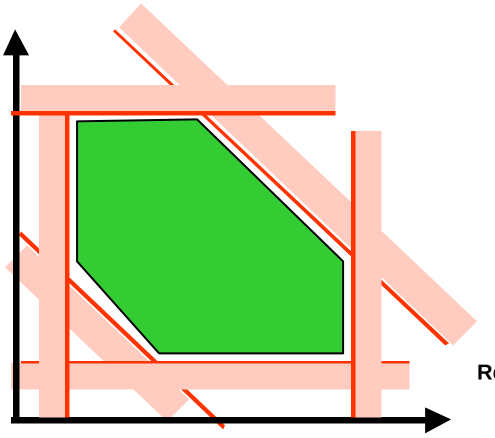


Figure 25

Let's recapitulate by showing in Figure 24 the whole model organised in 3 areas:

- a "**controlled area**" (green).
- The "**margin area**": We are working at the limit of the control. When we are near to loose the control of the situation, alarms occur from the situation. Take into account these alert signals is important for the operator to allow her/him to go back in the control area.
- The "**out of control area**": we are not longer able to manage the situation, events are independent from our actions.

What are the alarms for the CCs managing an emergency evacuation?

To answer this question we first have to state (thanks to observation of video and interviews data) several elements of the CCs task during an evacuation:

- **Objectives**: to control the flow, to anticipate the variation of passenger flow, to optimise the use of the exits.
- **Actions**: shouting, moving, having a gestural language to convince people to follow her/his indications
- **SA building**: being able to assess the flow state, to anticipate the flow variation, to infer the state of the other exits of the a/c.
- ➢ **Alarms**: non-anticipated flow variation (to much passengers – jam – no more passengers at the door), anarchical behaviour of the passengers.

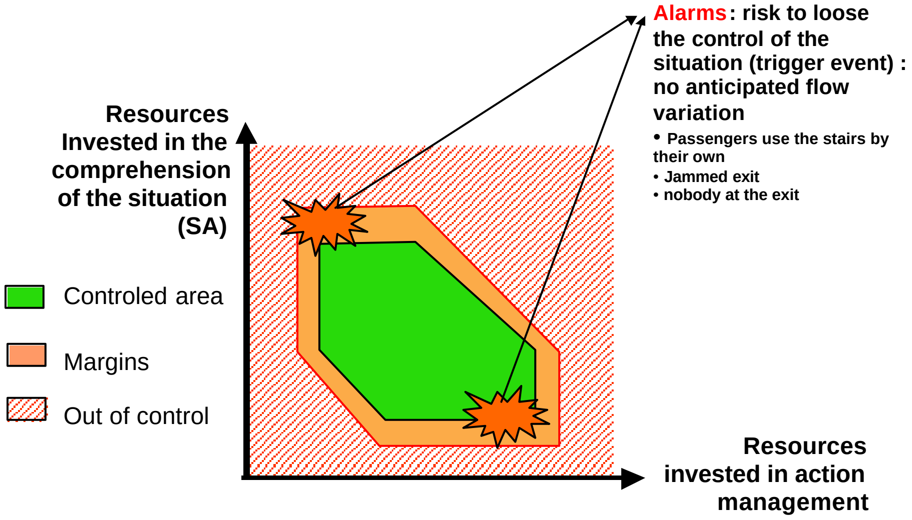

Alarms: risk to loose the control of the situation (trigger event) : no anticipated flow variation
• Passengers use the stairs by their own
• Jammed exit
• nobody at the exit
Resources Invested in the comprehension of the situation (SA)
Controled area
Margins
Out of control
Resources invested in action management

Figure 26

5.4. Application of the model to cases studies from the VERRES experiments

5.4.1. Case study n°1: Day One, 1st session, Free choice condition (D1.1. FC)

Objective of the trial: during this trial with no Stair Crew, the objective was to observe passengers using the stairs, and CCs managing passenger flow.

Doors status during this trial: UL1 was blocked during all the evacuation, UR1was opened. LL2 and LR2 were open during all the time. All other doors were blocked.

The main relevant data identified by researchers for this trial were (main questionable facts):

- On video
  - The spontaneous use of the stairs by 4 passengers before any intervention of the CCs.
  - The intervention of the UL1 CC in the management of the stairs, encouraging passengers to use the stairs
- CCs interviews directly concerned
  - UL1 interviews data (relevant data are referenced in the following analysis)
- On Passengers questionnaires

The answers of the passengers in group A (located at upper deck seats during this trial) are presented hereafter:

	Question 7: Did you use the stairs to evacuate the aircraft?	Question 8: Did you use the slide to evacuate the aircraft?
Yes	60 % (49/82)	37 % (31/83)
No	40 % (33/82)	63 % (52/83)

Table 36

The amount of people saying they have not used the slide to evacuate and the passengers saying that they used the stairs to evacuate is coherent (around 50 pax).

Among the passengers who said that they did not use the slide (Question 8), the following reasons where given:

Reasons for not using the slide to evacuate	
ND	52% (27/52)
CC directed me elsewhere	19% (10/52)
Too long queue at slide	23% (12/52)
Stairs seems nearest exit	6% (3/52)

Table 37

At minimum 15 passengers used the stairs on their own because there was a too long queue at UR1 exit ("too long queue at slide" and "stairs seemed nearest exit"). About 10 passengers specified that they were directed by the CC to use the stairs ("CC directed me elsewhere"). These two facts are confirmed by the video data (see *Appendix R- FC condition*).

Analysis of the situation management by the UL1 CC:

- Just after the 10' delay (slide inflation delay), UL1 realises that his door is blocked (**1st alarm**), with a big amount of passengers waiting at his door to exit (**A** location on the Figure 27)
- Then, first planned action is impossible (use the exit door). To be able to choose another action (solution), he has to enrich his situation awareness. Observing his environment, he is able to see a jam of passengers at UR1. It his **2nd alarm, B** location on the Figure 27).
    - * *Page 73 of the Appendix S, box A2 in the Table*
- Thus, he decides to go down stairs to check the availa bility of the lower exits. He takes a risk (no respect of the procedure) in order to gather information (enrich his situation awareness) which would allow him to carry out an appropriate action (**C** in Figure 27).
    - * *Page 73 of the Appendix S, box A3 in the Table*
- He becomes aware of the usability of the lower deck exits.
- As CC objective is to keep the control of the situation by optimising the passengers flow, he decides to enhance this solution (**D** in Figure 27): redirecting passengers downstairs
- Because the situation is very dynamic (time pressure) the decision chosen is not the best possible but the one which appears as sufficient at the moment, involving an immediate action (*Naturalistic Decision Making*).

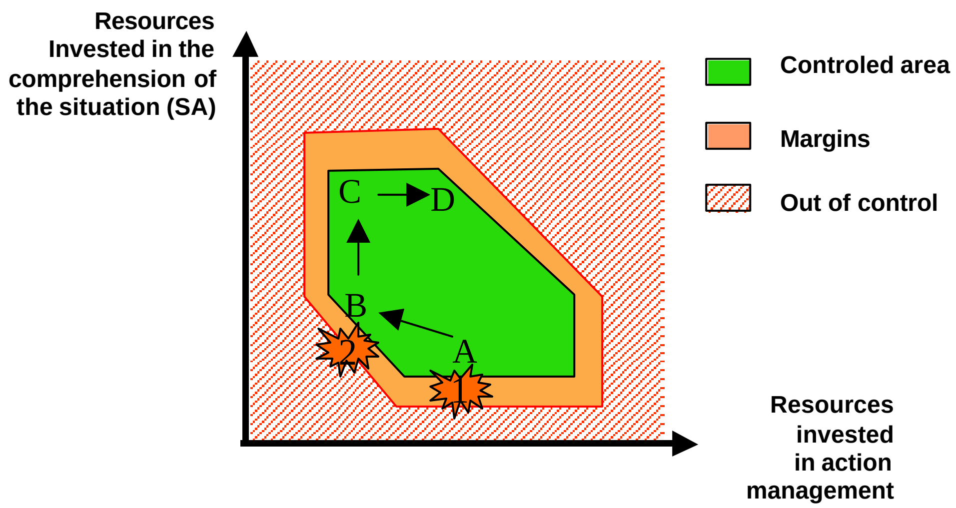


Figure 27

5.4.2. Appraisal of the 1st case study

- Few passengers did go down trying to evacuate faster.
- Without SC, the UL1 CC felt the need to have the SC position for a while, in order to enrich his situation awareness and make the right decision.
- From an operational point of view, SC in this scenario would have been useful to feed the CCs (door manager) with relevant information concerning the staircase flow and usability of other doors.

- According to the analysed scenario, SC would allow CCs to better manage their own limited mental resources by giving then fast information. Their mental resources could have been more invested in the management of action.

5.4.3. Case study n°2: Day one, 3rd session, Going up with Stair Crews (D1.3-Gup-SC)

The objective of this trial was to assess the way passengers use the stairs by going to the upper deck, to assess the role and usefulness of the Stair Crew, to assess the usability (difficulty of use) of the slide .

Doors status during the trial : All lower deck exits blocked during all the evacuation, UL1 and UR1 open.

The main relevant data identified by researchers for this trial were (main questionable facts):

- On video
  - The spontaneous use of the stairs by 20 passengers to go down the stairs before any intervention of the CCs.
  - The intervention of the Top SC in the management of the stairs: encouraging passengers to go down without knowing any thing about the exit status (before the 10 seconds delay)
  - The intervention of the Bottom SC in the management of the stairs: shouting to passengers to go upstairs when realising the lower exits were blocked.
  - Flow in staircases had to be reversed during the evacuation
- On CCs interviews
  - Top SC interviews (relevant data are referenced in the following analysis)
  - Bottom SC interviews (relevant data are referenced in the following analysis)
  - LR2 interviews (relevant data are referenced in the following analysis)
  - LL2 interviews (relevant data are referenced in the following analysis)
- On Passengers questionnaires

Answers for Question 7: Did you use the stairs to evacuate the aircraft? Please specify why you use or did not use them.

	Passengers : Gp A (seated on lower deck)	Passengers : Gp B (seated on upper deck)
Yes	96% (80/83)	29% (24/82)
No	4% (3/83)	71% (58/82)

Table 38

Among the Gp B passengers who said that they used the stairs (Question 7), the following reasons where given:

Reasons to have used the stairs for 24 passengers on Upper deck	
CC directed me to use the stairs	12,5% (3/24)
only possible way	4% (1/24)
Stairs seems fastest exit	71% (17/24)
YES- ND	12,5% (3/24)

Table 39

In this Going Up condition, all the passengers had to evacuate through the upper deck doors which presupposes that all the passengers seated on lower had to use the stairs to go upwards whereas the upper deck passengers (GpB) did not need to use the stairs to evacuate. However, Table 38 shows that 24 passengers used the stairs (of whom 20 used them on their own, see Table 39) to go first downwards and then upwards. This movement of upper deck passengers is also observed in video data (see *Appendix R-GUp condition*).

Analysis of the situation management by the TOP SC:

- The Top SC sees some passengers going down the stairs before he has a chance to interfere. It's the **1st alarm** (anarchical passenger behaviours) for him (**A** in the Figure 28), he has to decide about an action to recover (keep) the control of the situation
  - *Page 71 of the Appendix S of this report, box A2 in the Table*
- Being before the 10' delay i.e. before knowing the exit status, it is impossible to enrich the situation awareness. The Top SC decides to enhance the commencing flow by directing people in the staircase (error because of poor situation awareness). (**B** in the Figure 28)
- The upstream passenger flow commencing surprises the Top SC. It's the **2nd alarm**, a non-anticipated variation of passenger flow (error detection). He then realises that lower exits are blocked
  - *Page 71 of the Appendix S of this report, box A3 in the Table*
- Thanks to his enriched situation awareness (**C** in the Figure 28), the Top SC decides to enhance the upstream passengers flow, by shouting them to go forward (to UL1 and UR1 exits)
  - *Page 72 of the Appendix S of this report, box A1 in the Table*
  - *Page 72 of the Appendix S of this report, box A2 in the Table*

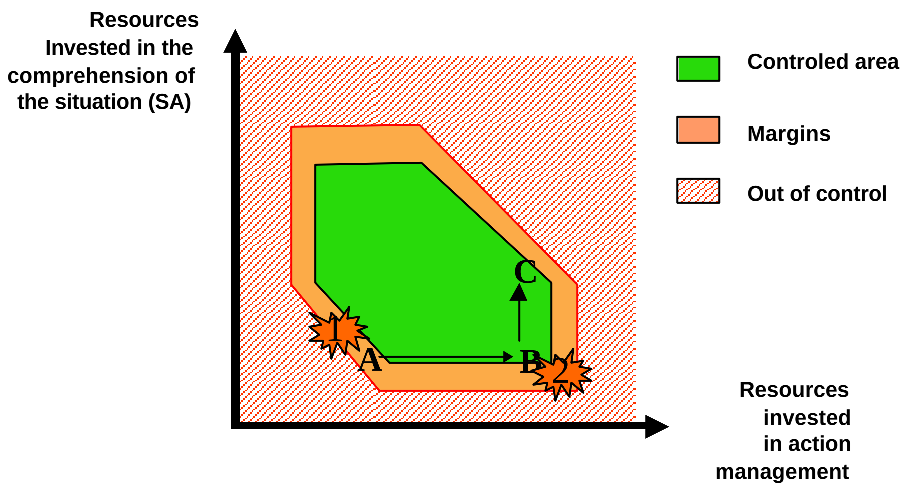


Figure 28

Analysis of the situation management by the BOTTOM SC:

- The Bottom SC sees some passengers going down the stairs but does not know which exit is available (it's the **first alarm**). All he knows is that LR2 exit is blocked (poor situation awareness). He decides to wait and see (**A** in the Figure 29).
  - *Page 71 of the Appendix S of this report, box B1 in the Table*

- After the 10' delay, the Bottom SC listens to other CCs to know about exit status (enrich the situation awareness) and hears "exit blocked". It is the **second alarm** for him.
  - *Page 71 of the Appendix S of this report, box B2 in the Table*

- He decides to redirect passengers upstairs by reversing the flow (**B** in the Figure 29).
  - *Page 71 of the Appendix S of this report, box B3 in the Table*

- By doing this, the Bottom SC achieves a good level of situation control and allows other CCs to do the same
  - *Page 70 of the Appendix S of this report, box A1 in the Table*
  - *Page 72 of the Appendix S of this report, box E1 in the Table*

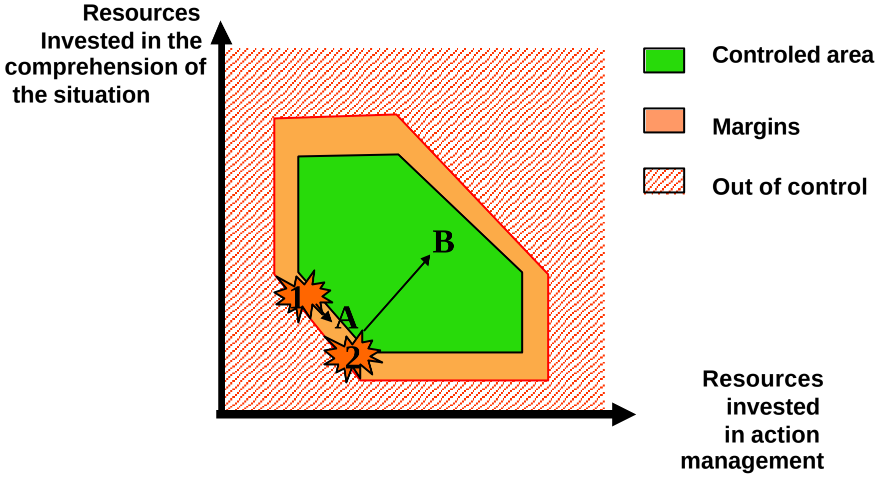


Figure 29

Analysis of the situation management by the LR2 CC:

- The **first alarm** for LR2 CC happens when realising that the exit is blocked, and when in the same time he/she has no idea where to send passengers (**A** on Figure 30)
    - *Page 67 of the Appendix S, box E1 in the Table*
- LR2 CC then decides to send passenger at the opposite door and to LR1 without knowing nothing about the exits status, just because of the habit and because she sees a gap to LR1. (**B** on Figure 30)
    - *Page 67 of the Appendix S, box E2 in the Table*
- LR2 CC realises that passengers comes back from LR1 and LL2 exits (**2nd alarm**).
- LR2 then decides to look and listen to the Bottom SC, and sends passengers upstairs (**C** on Figure 30)
    - *Page 68 of the Appendix S, box E1 in the Table*
    - *Page 68 of the Appendix S, box E2 in the Table*

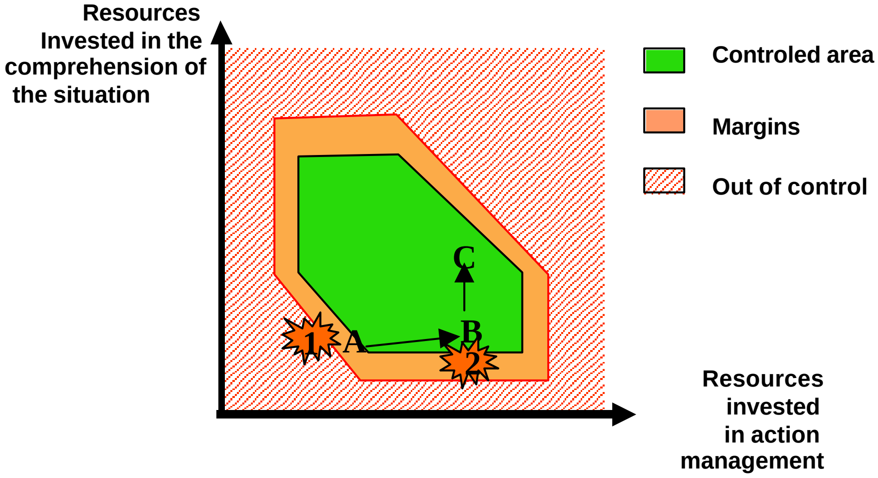


Figure 30

Analysis of the situation management by the LL2 CC:

- The **first alarm** for LL2 CC happens when realising that the exit is blocked, with no idea where sending passengers (**A** on Figure 31).
  - *Page 67 of the Appendix S, box F1 in the Table*
- LL2 CC decided to send passengers at the opposite door without knowing its status, but in the same time he decides to pay attention to the cabin status in order to build a good situation awareness (leaving the exit). By doing this, LL2 CC sees the crowd in the front of the cabin (assuming doors were blocked), and hears the Bottom SC sending passengers upstairs (**B** on Figure 31)
  - Page 67 of the Appendix S, box F2 in the Table
- LL2 CC decides to co-operate with Bottom SC in sending passengers upstairs (**C** on the Figure 31)
  - *Page 68 of the Appendix S, box F1 in the Table*

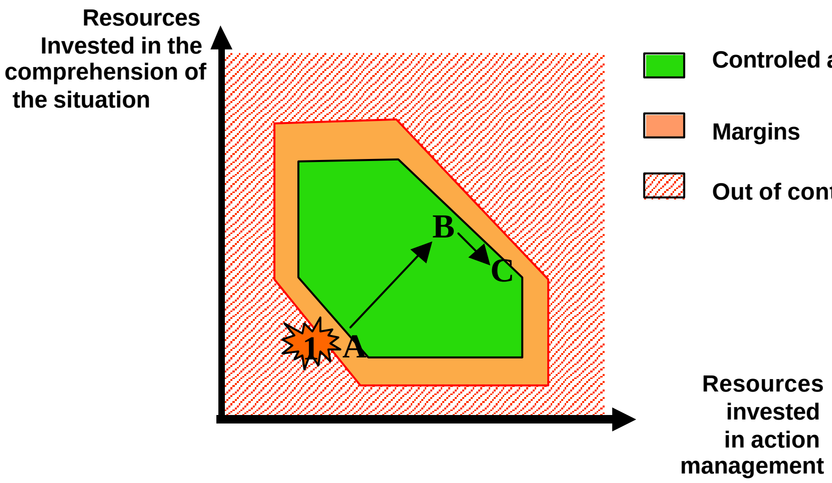


Figure 31

5.4.4. Appraisal of the second case study

- Few passengers did went down on their own to try to evacuate faster
- No passengers went up on their own to try to evacuate faster. SCs had to shout and push passengers to manage the upstream flow.
- In this scenario, Bottom SC was a very useful help for LR2 and LL2 CCs, facilitating the flow management.
- In this scenario, SC allows LR2 and LL2 CCs to save resources by giving them information on staircase passenger flow and other doors status.

5.4.5. Case study n°3: Day two, 2nd session, Going Up without Stair Crew (D2.2-GUp-NOSC)

The objective of this trial was to assess the way passengers use the stairs by going to the upper deck, to assess the performance of CCs without Stair Crew, to assess the usability (difficulty of use) of the slide.

Doors status in the trial: All lower deck exits blocked during all the evacuation, UL1 and UR1 open.

The main relevant data identified by researchers for this trial were (main questionable facts):

- On video
  - The spontaneous use of the stairs by 29 passengers to go down the stairs before any intervention of the CCs.
  - Crowding point at Bottom of stairs with flow coming from the front, rear, and upper deck before the 10” delay (slide inflation delay).
  - Decision of CCs to send the lower passengers at the rear of the cabin (doors closed)
  - People bumping, running around, people jumping above seats
  - Staircase is almost empty during few seconds
  - The intervention of the LR2 CC in the management of the stairs: encouraging passengers to go up (after the 10” delay to know the exit status).
  - The delayed intervention of the LL2 CC in the management of the stairs (compared to the LR2).
- On CCs interviews
  - LL2, LR2 interviews (relevant data are referenced in the following explanation)
- On Passengers questionnaires

Answers for Question 7: Did you use the stairs to evacuate the aircraft? Please specify why you use or did not use them.

	Passengers : Gp A (seated on upper deck)	Passengers : Gp B (seated on lower deck)
Yes	26% (21/82)	99% (81/82)
No	74% (61/82)	1% (1/82)

Table 40

21 passengers said that they used the stairs (they went downstairs then upstairs) but unfortunately they did not precise the reason of their behaviour (only one passenger said that it was the only possible way).

Analysis of the situation management by the LR2 CC:

- Just after the 10" delay (slide inflation delay), LR2 CC has a very poor situation awareness except that her door is blocked (**1st alarm**) and many passengers are waiting (**A** in the Figure 32).
    - *Page 69 of the Appendix S of this document, box C1 of the Table*

- LR2 CC needs to find a solution, situation becoming worth, people "scrambling» around and bumping into each other (**2nd alarm**). At this moment, she's almost out of control (**B** in the Figure 32).
    - *Page 69 of the Appendix S of this report, box C2 of the Table*

- LR2 CC decides to "leave her door to try to understand what was going on". She takes a risk (no respect of the procedure) in order to gather information (enrich her situation awareness) which would allow her to carry out an appropriate action (**C** in the Figure 32).

- LR2 CC enriches her situation awareness by seeing the "clear stairs"
    - *Page 70 of the Appendix S of this report, box C1 of the Table*

- Then she decides to order passengers to go upstairs (**D** in the Figure 32)

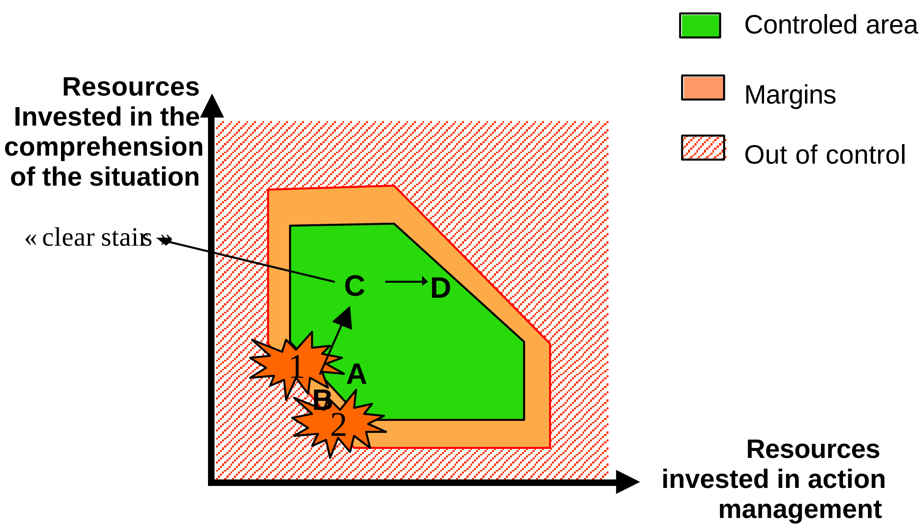


Figure 32

Analysis of the situation management by the LL2 CC:

- LL2 CC first decision, observing his own door blocked (**1st alarm, A** in the Figure 33), is to send passenger at the opposite door, without knowing nothing about other doors. He then acts with very poor situation awareness (**B** in the Figure 33).

  ∗ *Page 69 of the Appendix S of this report, box D1 of the Table*

- Passengers running down towards the rear of the lower deck cabin (**2nd alarm**), make LL2 CC aware of a commencing serious jam (exit blocked at the rear). He is at this moment almost out of control.

  ∗ *Page 69 of the Appendix S of this report, box D2 of the Table*

- LL2 CC decide to do nothing because he was unable to enrich his situation awareness (no visual clues, no Stair Crew) - (**C** in the Figure 33)

  ∗ *Page 69 of the Appendix S of this report, box D3 of the Table*

- After a while, LL2 CC ears/sees LR2 CC sending passengers upwards (**D** in the Figure 33)

  ∗ *Page 70 of the Appendix S of this report, box D2 of the Table*

- LL2 CC decides to do the same (**E** in the Figure 33), trusting her decision without any other information

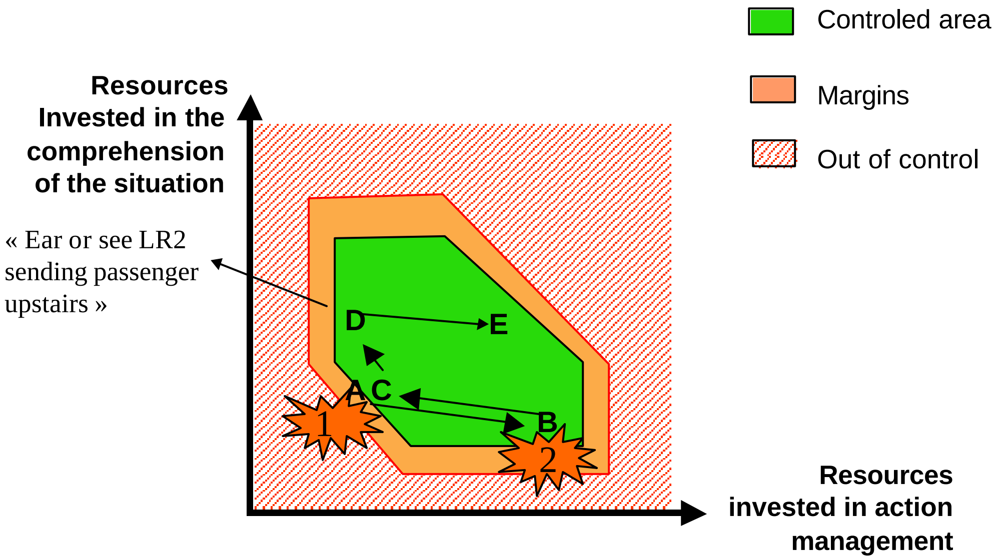


Figure 33

5.4.6. Appraisal of the 3rd case study

- No passengers used the stairs on their own to go upstairs.
- CCs are not passive operator, they manage a situation, they have objectives.
- In this scenario, procedures have been adapted in order to keep the control of the situation. CCs decide to leave their exits because staying is a too big risk to loose the control of the evacuation.
- Keeping the control of the situation requests to balance permanently the resources invested in ***action*** and in ***the situation awareness***

- Comparing the Figures 30 and 32 (LR2 CC with and LR2 without SC) and the Figures 31 and 33 (LL2 CC with and without SC), we can observed that the Figures are more "simple" with SC. Thus, managing recourses seems less complex with SC.

5.4.7. Cases studies Conclusion and related recommendations

According to the CCs, stairs are as the doors and the aisles, a strategic element that they have to take into account in order to keep the control of the situation.

The relevant information concerning the stairs was its status (usable, jammed, crowded, clear, people going upstairs, downstairs, both, big flow, few people moving…). Without any Stair Crew, managing the staircase flow (i.e. not having a "laisser-faire" management with the passengers using the stairs) is a way to enrich the situation awareness, thus, to make appropriate decision concerning the flow management.

The use of a cognitive model in the analysis of the cases highlight the fact that CCs behaviours was logical and efficient, even when they decided to adapt the procedure. Thanks to their adaptations, solutions were found, control of the situation was kept.

Safety evacuation procedure used in the trials was the one CCs used to apply in their company in jumbo aircraft (double deck with non-door cabin crew). According to the cases analysed, the actual procedure is not sufficient to allow CCs to be as efficient as possible, which can threat their control of the situation.

Whatever the safety procedures which will be designed for the use of the stairs, CCs will always need to know what it is happening in the staircase.

But safety procedures (necessary but not sufficient) are not the only way to facilitate the CCs work by allowing us to know what is going on for the other strategic elements of the evacuation process. Aircraft design and communication means between CCs should also allow the CCs to know what is happening elsewhere in the aircraft, and notably in the stairs.

For example, face to face communication between the LL2 and LR2 CCs was not possible because of the staircase location and LL1 and LR1 visibility was seriously forbidden by the staircase too. For all the CCs, knowing what was happening at the opposite door was another reason to move from the door position. The CCs is blind if she/he does not move. In these circumstances, a staircase with an open work design should improve the assessment of the stairs status and should allow long distance view.

The use of the model "keeping the control of the situation", by comparing the Figures, could become a very promising way to analyse experimental data. The attempt carried out in this report allow us to demonstrate that managing evacuation is more easy with Stair Crew, allowing CCs to invest more rapidly and more efficiently their mental resources in the action. Few seconds are sufficient to save a lot of life in such an emergency situation.

5.5. Results related with WP3.4 of the Verres project

The WP3.4 deals with the passenger mental representation of the a/c evacuation process.

5.5.1. Results of the Question 9 of the passenger questionnaire: "what would be the difference between actual evacuation simulation and real one?"

The following Table shows the percentage of people mentioning "panic" to explain difference with real evacuation (Question 9) (Day 1):

D1.1-FC	D1.2-GD-NOSC	D1.3-GUp-SC	D1.4-GD-SC
50	33	34	25

Table 41

The percentage of people mentioning "panic" to explain difference with real evacuation (Question 9) (Day 2) is presented hereafter:

D2.1-GD-SC	D2.2-GUp-SC	D2.3-GD-NOSC	D2.4-FC
41	34	28	21

Table 42

According to the results presented in Tables 41 and 42, the amount of answers mentioning "panic" decreases from the first to the fourth session of each day. We can explain this by the fact that while completing the passenger questionnaire, people felt bored to answer this question (the answer "already completed in previous trials" appears sometimes in the questionnaires for sessions 2 to 4 of both days)

An interesting statement to formulate is that in total, **33%** of people mentioned the "panic" as a danger. If we focus only on the first session of each day, the amount increases up to **46%**. This shows that the "panic" is a real fear, very present in the passenger representation of an a/c evacuation.

5.5.2. Results of the Questions 4 and 6 of the passengers questionnaire

Questions 4 and 6 of the passenger questionnaire (see *Appendix P* of this report) would help us to identify some of the elements that passengers missed during the evacuation. These elements are part of their mental representation of a/c evacuation.

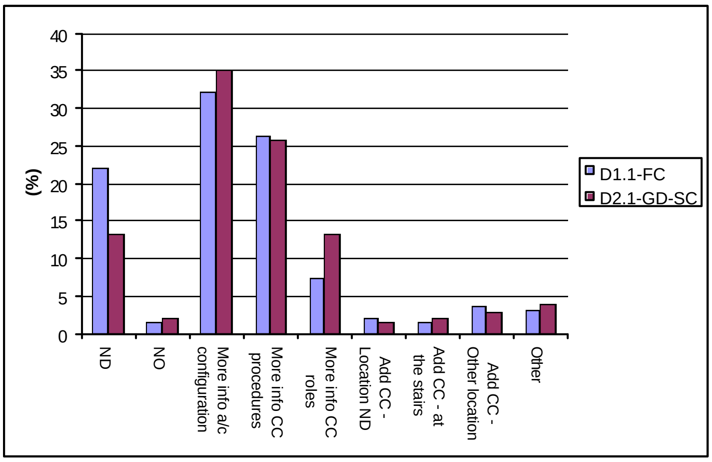


Figure 34: Do you think that some of the following items would facilitate the evacuation process?

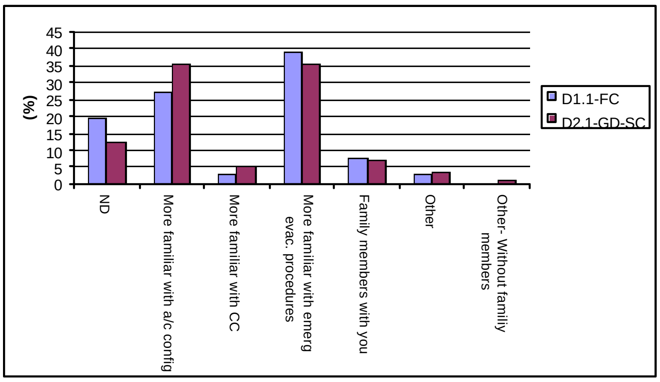


Figure 35: In real evacuation, what would have improved the evacuation process?

The main statements that could be formulated for Figures 34 and 35 are:

- One of the most cited answers is the need for more information concerning a/c configuration. As a matter of fact, a/c configuration information was available on the passenger safety cards. This is coherent with the low attention to written safety information paid by passengers in real life.
- Another very mentioned answer is the lack of familiarisation on emergency evacuation procedures. It could means that procedures are blurred in passenger mind.
- Finally, the third more important answer is the lack of information on CCs procedures and roles. The CCs tasks seem to be a source of interrogation for passengers. This issue should have impacted the way passengers reacted to CCs instructions.

6. CONCLUSIONS

During the development of the test plan for the experimental trials (Task 3.1), the Verres consortium identified a large number of potential variables of interest, and it became evident that it would be difficult for the consortium to limit the number of independent variables. It was therefore decided that the trials would explore a wide range of possibilities for future research within very large transport aircraft, as oppose to studying a limited number of issues in detail. For this reason the Verres experimental study was exploratory in nature and the results presented within the report are by no means conclusive, but do highlight issues where future research should be considered.

In this report the experimental methodology of the trials is described and is followed by the analyses conducted by three of the Verres partners - Cranfield University, University of Greenwich and Sofréavia. It is noted that each partner has used a different approach and has conducted their analysis independently, reaching their own conclusions. In this final section the main conclusions from each organisation are brought together.

The planned test programme was completed and no evacuations were halted. Data were therefore obtained for all eight demonstration evacuations. In total, 336 individuals participated in the evacuation demonstrations. One participant withdrew after the first trial on 25 January 2003. No injuries were sustained throughout the testing programme.

It is believed that the trials produced passenger behaviour representative of non-competitive evacuations and the crew behaved in a manner that might be expected under a set of simulated operational conditions in which no additional training concerning the use of stairs for evacuation was provided. Valuable information was gathered on the management of passengers on the stairs by cabin crew.

Although a number of pilot trials had been conducted, the experimental trials did not proceed in the controlled manner that was originally planned, however much has been learnt from these trials. However, 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 documented within the report.

In the event, the cabin crew behaved in a number of ways that differentiated from that which had been expected. During the free choice trials, cabin crew members at the unavailable UL1 exit, verbally and physically re-directed passengers towards the staircase as opposed to UR1. It had been the intention to use this condition to attempt to determine the number of upper deck passengers who chose to move to the lower deck to evacuate voluntarily without guidance from the cabin crew.

Although cabin crew are normally briefed to remain at their station during an evacuation, some crew stationed at the lower deck exits were also observed moving from their assist space during an evacuation towards the base of the staircase. The reason for this was that this position provided the crew with better visibility of the passengers descending the stairs and the cabin crew felt able to effectively control the passengers from this position. It was noted that the majority of door crew movement towards the staircase occurred when there were no additional cabin crew present at the base of the staircase. This crew movement had the effect of making it difficult to investigate the effect of additional staircase crew on passenger flow rates, as during the evacuations without additional cabin crew at the base of the stairs, the door crew played some part in passenger behaviour at the internal staircase.

It must be remembered that all crew (except those located at UR1) were line cabin crew who were trained in specific operator emergency procedures, commands and gestures as appropriate, with the aim of reducing the overall evacuation time of the aircraft. Ethically it could be argued that if the cabin crew were trained in behaviours that conflicted with their normal procedures, this could be potentially detrimental to their later performance in a genuine emergency situation. Although cabin crew knowledge and experience is crucial to our understanding of aircraft emergency evacuation, the Verres trials have demonstrated that in exploratory research where specific crew commands and behaviours are fundamental to the experimental design, in particular where these are not identical to those implemented by the operator, the use of researchers trained as cabin crew should be carefully considered. It is acknowledged that ultimately line cabin crew should be used within the experimental testing programme.

It is also noted that there were some difficulties in extracting passenger stair behaviour data on the first day trials due to the positioning of the cameras on the first test day. 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.

Unfortunately, the Cranfield University analysis was limited to descriptive analysis only on the passenger evacuation times, as inferential analyses of the evacuation data could not be conducted, as insufficient data was available to conduct comparisons across conditions. However within the free choice evacuations, there did appear to be differences in evacuation rates between the two demonstrations, with lower mean evacuation times, faster evacuation rates, and lower overall exit evacuation times evident on the last trial of the programme. However, this may simply be a function of the cabin crew, who by this time would have gained significant additional experience in passenger management and evacuation situations.

Within the conditions involving ascending the stairs, there did appear to be marked differences in evacuation rates between UR1 and UL1. The UR1 exit involved passengers evacuating down a slide whereas UL1 was out onto a platform. This difference in time through UR1 is most likely a function of the caution exercised by cabin crew at the UR1 exit. The evacuation slide used in these trials had not been used in any previous research, and hence passenger safety was considered of primary importance in the use of this escape means. Finally, within the evacuations involving descent of the stairs, the mean evacuation times, evacuation rates and overall exit evacuation times do appear to be broadly similar across the evacuation trials conducted.

The Cranfield University contribution also includes analyses on the data provided on the Cranfield University post evacuation questionnaire by condition. Again, this is descriptive data as it was not possible to conduct inferential analysis of this data across the different experimental conditions.

The University of Greenwich analysis reviewed passenger stair usage and the influence of the sill height from the upper deck. It was demonstrated from these trials that the cabin crew can exert an influence on the performance of passenger stair usage. The data on passenger behaviours 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. Situational awareness between decks should be the subject of further investigation.

Passengers were also noted to make heavy use of the central handrail while both descending and ascending the stairs. The presence of the central handrail 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 handrail. 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 increased 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 caution 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.

The analysis carried out by Sofréavia followed a French cognitive psychology approach using a model known as “Keeping control of the situation” (Amalberti 1996, Amalberti & Al. 2000). This approach is human behaviour oriented, and focuses on the operators’ work, i.e. the cabin crew’s work as evacuation manager and cabin crew performance. Thus, the interest was on the individual’s objectives of actions, their decision making process, their situation awareness building and the communication strategies evolving in the evacuation trials, through the use of interviews with the line cabin crew after each evacuation trial. The Sofréavia analysis has suggested the cabin crew’s objectives were to control the passenger flow, to anticipate the variations and to optimise the use of the exits. The negative aspects mentioned by the cabin crew refer to a lack of situation awareness, an inappropriate action, and the achievement of an undesirable state (missed objective) and the positive aspects refer to the ability to carry out appropriate action, ability to enrich the situation awareness, or the achievement of an objective.

A number of case studies have been highlighted within the analyses that have suggested that the cabin crew behaviours was logical and efficient, even when they decided to adapt the procedure. Due to the adaptations, solutions were found, and control of the situation was kept. The cabin crew also need to be aware of the status of the staircase as it perceived to be a strategic element in keeping control of the evacuation, similar in respect to the crew need for information concerning the status of the exits and aisles. It is proposed that procedures, aircraft cabin design and communication means should be carefully considered to ensure the cabin crew know what is occurring at all the strategic elements throughout the evacuation.

The Verres evacuation trials have identified a number of areas where future research needs to be conducted to generate essential data to improve our understanding of passenger performance, cabin crew performance, passenger-crew interaction and passenger-structure interaction within very large transport aircraft configurations. The next step should be to form clearly identifiable research objectives and to develop detailed research programmes combining partial experimental evacuation testing including statistically reliable results, evacuation computer modelling and qualitative analysis, in an attempt to address the complex issues relating to the safe evacuation of very large transport aircraft.

7. REFERENCES

Amalberti, R. and Al (1996). "*La conduite des systèmes à risques*" Coll. Le travail Humain, Paris, Presses Universitaires de France.

Amalberti, R. (2000). "*La maîtrise des situations à risque*". Psychologie Française

Civil Aviation Authority (1978) *JAR 25 - Large Aeroplanes*. London, UK.

Department of Transportation (1974) *Federal Aviation Regulations Part 25 - Airworthiness Standards*. Washington DC, US.

FAA (1990) *Emergency Evacuation Slides, Ramps, Ramp/slides and Slides/rafts*. Technical Standard Order C69c. Department of Transport, 18 August 1990.

HMSO (1991). *The building Regulations, Approved Document B, Section B1*, HMSO Publications, London.

Muir, H.C., Marrison, C. & Evans, A. (1989) *Aircraft evacuations: the effect of passenger motivation and cabin configuration adjacent to the exit*. London, UK; Civil Aviation Authority Paper 89019.

Pauls, J. (1995). Chapter in *The SFPE handbook of fire Protection Engineering*, published by the Nation Fire Protection Association, 2nd Edition, ISBN 0-87765-354-2.

Snow, C.C., Carroll, J.J. & Allgood, M.A. (1970) *Survival in emergency escape from passenger aircraft*. Office of Aviation Medicine, Department of Transportation, Report AM70-16.

Wilson, R.L., Muir, H.C., & Jolly, P.A. (2003) *Data supplement. Verres evacuation trials*. Cranfield University. Verres_WP3_CU_3.2_data supplement_1.0.

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