## Joint Aviation Authorities

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# Very Large Transport Aircraft (VLTA) Emergency Requirements Research Evacuation Study (VERRES) - A Project Summary.

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## Disclaimer

## Background

This report is a summary of individual work package reports for European Commission funded study GMA2/2000/32039 Very Large Transport Aircraft (VLTA) Emergency Requirements Research Evacuation Study (VERRES). VLTA is a generic title for future aircraft and no specific aircraft was considered during the study. The Airbus A380 has been labelled a VLTA by some but this study was much wider in nature, including potential future designs such as blended-wing style aircraft.

The study was for a duration of one year. This summary is intended to provide information to aerospace manufacturers, aviation regulators and aircraft operators. It is a summary of the results of independent research and therefore has no regulatory status. The purpose of this report is to summarise the knowledge of the configurational aspects of VLTA, to record state-of-the-art in evacuation modelling and to provide information that may be considered for training purposes. It is suggested that the individual work-package reports are studied if detailed information is required and these are available at www.sofreavia.fr

Work Packages that are available are:

1.1 Configurational Issues Related to Evacuation and Test Facilities
1.2 Configurational Aspects – incident and accident experience
1.3 Non-aircraft Evacuation Experience
1.4 Collation of Evacuation Information from Cabin Crew
1.5 The Identification of the Configurational Issues and Rules which will need to be Re-evaluated for VLTA
1.6 Requirements of Future Evacuation Testing
2.1 State of the Art of Evacuation Models, their Validity, Data Requirements and Current Availability of Data
2.2 Investigating VLTA Evacuation Issues using the airEXODUS Evacuation Model
2.3 A Methodology and Procedure for the Introduction of Aircraft Evacuation Simulation to the Aircraft Certification Process
3.1 Trial Definition – Cranfield VLTA Evacuation Simulator,
3.2 Trial and Data Analysis
3.3 Crew Coordination Aspects
3.4 Building a Mental Representation of the aircraft for passengers

The construction of this report has been through extract of material from the individual work package reports wherever possible. Additional material and amendments have been generally limited to that required for cohesive interpretation.

## Executive Summary

The purpose of Very Large Transport Aircraft (VLTA) Emergency Requirements Research Evacuation Study (VERRES) was to investigate many issues relating to post-accident survivability of larger aircraft in the future. A particular focus was on evacuation issues with detailed investigation of the role of computer models.

This report is a summary of the individual work packages in the VERRES study to provide an introduction to the research. The individual work package results should be studied for detailed information at www.sofreavia.fr

Conventional evacuation certification procedures incur a significant risk of personal injury to the participants (on average 6% are injured) and large costs (approximately US$2 million for a wide-body aircraft). Furthermore, as only a single evacuation trial is necessary for certification requirements, there can be limited confidence that the test - whether successful or not - truly represents the evacuation capability of the aircraft. The issue of the test being potentially unrepresentative is, however, recognised but nevertheless plays an important part as a yardstick for comparison with other aircraft design that may have more extensive evacuation experience. The large increase in passenger capacity and aircraft size being suggested for VLTA exacerbate these difficulties. The introduction of computer based analysis techniques coupled with partial practical testing using people offer the potential of reducing all of these risks and costs while making the certification process arguably more rigorous.

Computer based analysis techniques coupled with partial testing have a role to play in the following areas:

- Design and development of safer aircraft bringing safety matters to the design phase while the proposed aircraft is still on the drawing board.
- Implementation of safer and more rigorous certification criteria.
- Development of improved and more efficient crew procedures.
- Improved cabin crew training.
- Accident investigation.

The benefits would be experienced by:

- The aircraft manufacturers, who could bring certification priorities to the design phase and as a result design a safer aircraft, experience lower risk during the design process and incur lower certification costs.
- The travelling public will enjoy a safer aircraft knowing that during the certification process the aircraft has undergone a range of evacuation scenarios. In addition, the risks associated with the use of the public for full-scale evacuation demonstrations will be removed. These benefits would not just be experienced by European citizens but in a global view by all travellers.

The airlines would enjoy the cost benefits that better design and lower cost certification offer. In addition, the models used in the development of certification procedures could also be used to assist the airlines in recurrent crew training.

VERRES includes results of the first evacuation research trials of large double-deck aircraft (using the Cranfield University VLTA cabin simulator). These were intended to provide data for evacuation models, particularly related to the use of stairs. These exploratory trials were able to provide an indication of the many issues involved and provided useful pointers for future, more detailed investigations.

During the development of the test plan for the experimental trials, 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 opposed 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 used a different approach and has conducted their analysis independently, reaching their own complementary conclusions.

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. No injuries were sustained throughout the testing programme.

The trials did not proceed completely in the manner that was originally planned (some of the cabin crew reacted in a number of ways that were different from that which had been expected by the researchers) however, much has been learnt from these trials.

Whilst computer models provide a number of safety benefits, the need for partial testing of new cabin features using people is essential to provide confidence that models continue to accurately portray reality. Test facilities for evacuation studies and methodologies employed are described.

Cabin crew views of potential problems with managing large numbers of passengers in an emergency situation were collated, highlighting the need for clear information on the cabin situation to be effectively communicated between the crew. The study notes areas that may require amended cabin crew training, for example with substantial numbers of passengers likely to be at the foot of large slides that will require effective management. Safety communication is not restricted to crew and the study concludes that passenger safety briefing may need to be enhanced for evacuation in potentially complex cabin interiors.

The study compares aircraft evacuation with other forms of transport, for example the evacuation of a blended wing VLTA may be similar to a fast ferry with multiple aisles. The aircraft evacuation situation is however unique in the need for a very fast evacuation resulting from the fire threat that is not found to the same level in other forms of transport, or indeed buildings.

The study includes a review of techniques that may be considered for crew training for managing large numbers of passengers in emergency situations. The topics include crew co-ordination, communication and enhancing situational awareness.

The developments commenced here will play a vital role in the safe evacuation of future Very Large Transport Aircraft.

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**Summary of Work Package 1.1**

In the Work Package 1.1 report configurational issues associated with the rapid evacuation of passengers from a VLTA airframe were evaluated. The relevant information which is available from accident data is also included together with our current knowledge of the influence of passenger behaviour. The test facilities which are available for this work and the range of methodologies which have been developed are also reviewed. Areas where future research may be required to evaluate a possible requirement for a regulatory change have been proposed.

Regulators enforce and maintain safety standards through a set of essentially prescriptive rules that have evolved over time. In the USA the rules are known as the Federal Aviation Regulations (FAR), while in Europe they are known as Joint Aviation Requirements (JAR).

## 1.1 Review of Previous Evacuation Research into Configurational Issues in Evacuations

### 1.1.1 Exits

#### 1.1.1.1 Exit Regulations

Regulations for emergency exits are contained in JAR 25.807. The exits range from the largest, a Type A (a floor level exit door with dimensions of at least 42 inches wide and 72 inches high), the smallest, a Type IV (an overwing exit with dimensions of at least 19 inches wide and 26 inches high).

The regulations further mandate that ‘the means of opening emergency exits must be simple and obvious and may not require exceptional effort’ Crew members are required to operate each exit type on their aircraft during initial training and every 2 years thereafter. It is assumed that only ‘Type A’ exits (or larger) will be included on future VLTAs

#### 1.1.1.2 Research on Exits

In the emergency evacuation study conducted by the NTSB (Section 2.1.3.4) of passengers and crew involved in 46 evacuations, 67 floor level exits were opened during these evacuations. In this study, only two cabin crew reported any difficulty with opening floor level exit doors. In summary, in 43 of the 46 evacuation cases in the NTSB study, floor level exit doors were opened without difficulty. Accident severity can influence the ease with which passengers will be able to reach an exit. Severe damage to the fuselage, for example, can cause interior furnishings to be dislodged. Factors which have been reported as restricting the ability of passengers to access operational exits have included broken interiors, overhead bins, seatbacks and aisle width. In addition, cabin crew have reported that their seats and galley items can obstruct the evacuation. However, it should be recognised that in the majority of accidents, passengers have been able to access operational exits without difficulty.

The research which has been conducted on Type I exits showed that although the size of the exit did not appear to cause any problems, the size of the bulkhead adjacent to the exit together with the aperture between bulkheads could have a major impact on both the speed of the evacuation and the safety of the cabin crew. Research has been conducted in the UK (Cranfield University) involving Type A exits and slides, although the sill height has only been for that of a narrow bodied airframe. The findings suggest that the Type A exit size and mode of operation do not appear to present a problem.

Research should be conducted to enable the factors which influence evacuation performance through Type A exits with slides to be better understood.
These factors will include:

- Passenger access routes to the exits, including widths of aisles and cross aisles together with the aperture between bulkheads.
- Visibility of the exits when passengers are seated
- Lighting levels in the vestibule area and at the exit. This should include the evaluation of new materials and intelligent systems to make the location and status of the exit more apparent to passengers.
- The minimum configuration for cabin crew assist space should be reviewed.

A revision to the regulations could then be considered which would prevent exits which are smaller than Type As being introduced onto VLTAs.

### 1.1.2 Aisles

#### 1.1.2.1 Regulatory issues

Access to exits is governed by regulations in JAR 25.813. There must be a passageway leading from the nearest main aisle to each Type A, Type B, Type C, Type I or Type II emergency exit. Each passageway leading to a Type A exit must be unobstructed and at least 36 inches wide. If two or more main aisles are provided, there must be unobstructed cross-aisles at least 20 inches wide between main aisles. There must be a cross aisle which leads directly to each passageway between the nearest main aisle and a Type A exit. In addition, for aircraft with a passenger seating capacity of 20 or more, passenger aisles within the cabin should be a minimum width of 15 inches less than 25 inches from the floor and a minimum width of 20 inches at 25 inches and more above the floor.

#### 1.1.2.2 Research on aisles

The research, which was conducted in the UK following the Manchester Accident in 1985, clearly indicated that when the aperture between the bulkheads at the front of the cabin was increased from 20 inches to 30 inches, the speed of passengers able to pass through the aperture was significantly increased. Making the gap even wider did not significantly increase the flow rate and on occasions led to problems.

The possible multi-aisle configurations of future VLTAs will require careful consideration. It will be important that the evacuation procedures relating to the management of passengers and flow control at the cross-aisles are rigorously tested. In the event that testing indicates that congestion at cross aisles is a problem, it may be necessary to reconsider the minimum requirement for 20 inches for cross-aisles or the positioning of cabin crew at these locations.

It may also be the case that if exits are easily visible to passengers, rather than being hidden by a bulkhead, this will increase the speed of their progress from their seats and down the aisle in an emergency. Research will be required to clarify this issue and to determine optimum aisle widths when passengers from main aisles and cross aisles are required to merge together rapidly in an emergency.

### 1.1.3 Cabin seating

#### 1.1.3.1 Regulatory Issues

JAR 25.807 states that 'the maximum number of seats permitted depends on the type and number of exits installed in each side of the fuselage'.

Regulations concerning the minimum space requirements for seated passengers are contained within CAA AN 64 ( Civil Aviation Authority Airworthiness Notice 64, Minimum Space for Seated Passengers, Issue 1, March 1989). This (UK only) mandatory notice is based on anthropometric data for 5th percentile females and 95th percentile males, and also takes into account the minimum distance and the vertically projected distance between any seat, and the seat (or other fixed structure) immediately in front of it. The minimum distance required between the back support cushion of a seat and the back of the seat in front (the seat pitch) is 26 inches. In addition, the minimum distance between a seat and the seat or other fixed structure in front is 7 inches, and the minimum vertically projected distance between seat rows is 3 inches. These minima have been set in order to provide adequate space for passengers to both occupy a seat, and to stand and vacate the seat in order to move to the main aisle. An anthropometric study for JAA by Loughborough University (ICE Ergonomics, 2001) on minimum aircraft seating standards recommended changes to these dimensions.

#### 1.1.3.2 Research into cabin seating

There have been no published reports of research in which the influence of changes to seat pitch on evacuation performance have been investigated, although some pilot tests have been conducted by Cranfield University for Transport Canada.

There would appear to be no reason why the regulations regarding seat pitch and seating density for wide-bodied aircraft should be any different on a VLTA airframe. The key consideration should be the evacuation performance and ensuring that this can be achieved to a satisfactory standard in all circumstances. These circumstances could include the testing of evacuations involving highly motivated behaviour such as in the event of a fire, in order to ensure that no aspect of the cabin configuration will cause a problem when passengers are evacuating when there is smoke in the cabin. One of the conclusions from the Very Large Transport Aeroplane Conference that was held in 1998 in the Netherlands was that evacuation performance should be the primary criterion in the certification of future Very Large Transport Aeroplanes.

### 1.1.4 Slides and post-egress factors

#### 1.1.4.1 Regulatory Issues

The Emergency Evacuation Slides Technical Order (TSO C69c, August 1999) states that all slides must be capable of demonstrating rates of at least 70 passengers per minute, per lane. Therefore dual lane slides, must be capable of supporting a flow rate of 140 passengers per minute. In full-scale evacuation demonstrations, as with experimental evacuations and evacuation models, the actual flow rate obtained will depend on many factors.

#### 1.1.4.2 Research

Previous studies have indicated that injuries during egress are frequently associated with the use of the slide. The reasons for these include the airframe coming to rest at an unlevel attitude making some of the slides too short, severe weather conditions e.g. strong winds making the slide use hazardous, passengers endeavouring to use the slide before it is fully deployed, passengers falling off the side of the slide, or sustaining injuries either during their descent or at the bottom of the slide. The design of the escape slides will therefore require serious consideration in order to minimise the potential for injuries to passengers

Many of the reported injuries which have been associated with the use of slides, have occurred as a consequence of congestion at the bottom of the slides. The development of some new technology and procedures for marshalling passengers away from the airframe following an evacuation would be a safety benefit. Marshalling passengers away from the bottom of the slides is not currently an area manned by cabin crew. At present, if an aircraft has more than the minimum number of cabin crew on board, during an emergency situation, it is likely that they will be used to manage the flow of passengers to the exits. It is a possibility that with VLTA, the minimum number of cabin crew will need to be considered, taking into account the potential need for cabin crew to be located at the base of the slides to marshal passengers away to safety.

### 1.1.5 Access to upper deck

#### 1.1.5.1 Regulatory Issues

Although passenger access to the upper deck for loading and unloading in normal circumstances may be satisfactorily achieved using one or more dual lane staircases, the extent to which these staircases may be available for use in various aircraft emergencies will require consideration. Large numbers of passengers behaving in an uncontrolled manner, perhaps in the presence of smoke or with the airframe in an uneven attitude, may inevitably lead to serious injuries and possible fatalities.

#### 1.1.5.2 Stairs Research

Although some research into aircraft stair design was conducted by FAA in 1978, this only involved narrow staircases of 20 inches. Thus it will not be relevant for VLTAs where the stairs will be expected to accommodate two or more passengers simultaneously.
New research to evaluate the safety of the stairs to be used by large numbers of passengers will be important in order to minimise the risk of injuries. This may lead to regulatory specification of minimum dimensions and requirements for handrails etc. It must also be considered if the staircases should be treated as an exit in the respect that they are manned by cabin crew during an evacuation. If this is deemed to be the case, the number, location and procedures adopted by the cabin crew will need to be carefully researched, with some initial trials under the VERRES programme discussed in section 3.2

### 1.1.6 Direct view

#### 1.1.6.1 Regulatory Issues

The regulations currently require the cabin crew to have a view of the passengers in the cabin when seated for takeoff or landing. This requirement may influence the location of the seating for the cabin crew in conventional aircraft or VLTA.

#### 1.1.6.2 Research

The question of cabin crew stations with a direct view into the cabin has been debated over many years, as it can be difficult to achieve. To cabin crew representatives this has seemed an obvious requirement necessary for safety. The rationale is that during critical phases of flight, cabin crew are required to be seated at their emergency stations. However, despite the presence of warning signs in the cabin to make passengers remain seated in a safe position during critical phases of flight, passengers do not always respect these cabin signs. There have been numerous instances of passengers attempting to pick up their belongings from overhead bins on final approach, standing up during taxiing and putting their carry-on baggage into the aisle. In the event of an emergency landing, passengers often tend to leave their brace-for-impact position as soon as the aircraft is on the ground. Cabin crew need to visually monitor these situations to prevent this from happening. Cabin crew monitoring the cabin from their emergency stations can have a preventive effect. However, passengers do break the safety rules and it is sometimes necessary for crew to relay instructions over the P.A. system, by megaphone, or simply by shouting. There is cabin crew agreement that each member needs to be able to monitor a section of the cabin especially during critical phases of flight. The increased passenger load in future very large transport aircraft will make this issue even more important.

### 1.1.7 Novel Configurations

#### 1.1.7.1 Regulatory Issues

The suggestion has been made that in future very large airframes, some operators may request novel configurations including recreational and exercise areas. If these are to be introduced, the safety implications for their use in flight will require special consideration, especially with respect to turbulence. However, it will be assumed that all passengers will be required to be seated in a normal seat for takeoff and landing or in the event of a pre-warned emergency. The same will apply for the use of beds by passengers or crew.

A recent development on a wide bodied airframe is a lower lobe area below the main deck in order to provide additional toilet facilities. Again, it must be assumed that these will be unavailable for takeoff of landing or in the event of an emergency. While the proposed facility meets the airworthiness, design and certification criteria in the Joint Aviation Requirements, UK CAA noted that there is no recent in-service experience of passenger use of lower-lobe compartments and that the potential operational problems are significant. Potential operational problems could include issues of passenger control and monitoring, fire watch, decompression, medical emergency response and turbulence.

### 1.1.8 RESEARCH FACILITIES

#### Cranfield Large Cabin Simulator

In 1999, the UK CAA identified the need for improved evacuation research facilities to cover wide-bodied and double deck aircraft. They were aware that in the USA, the FAA was preparing to use a grounded Boeing 747 as a research facility. It was decided that a new large evacuation cabin simulator facility which was purpose-built, was required in Europe. This would allow a very wide range of studies to be undertaken, and would complement the US evacuation facility. They decided to locate the facility at Cranfield.

The facility is the world's first purpose-built large cabin simulator for research. The facility is modular, allowing cabins of a variety of lengths and widths to be created, and even allowing tests to be carried out on flying-wing multi-aisle aircraft in the future if required. In the shorter term, many aspects of large and double deck aircraft can be investigated. The position, number and size of exits can be modified as required for experiments and alternative stair designs between the two decks can be evaluated. The simulator will also support the development of a computer model being developed at Greenwich University with UK CAA support. Much of the data for this model has been obtained from previous trials at Cranfield. However, there is little data on the evacuation of wide-bodied aircraft and none on the new generations of very large aircraft. Trials on the new facility will therefore also be used as a source of data for the model which, in addition to its research capability, may be considered for use as a certification tool to complement the current ‘90 second’ evacuation test.

**Summary of Work Package 1.2 Relation between configurational issues and incident and accident experience for VLTA**

The objective of this task was to identify the potential impact of VLTA introduction from the real evacuation experience. To conduct the work on the possible impact of VLTA introduction, the factors and a validated task analysis (built up from accident and incident report analysis) were used. The work was mainly focused on emergency evacuation but most of the results should also be relevant for precautionary evacuations. The main difference would be that time pressure and danger are less important and the emphasis should be made on the limitation of the injury risk for the passengers during the evacuation. For each task the possible impact was identified in an exhaustive way. Then the impact was analysed in order to identify the need for conceptual or organisational attention or the need for more studies such as experimentation with a VLTA evacuation simulator.
Many tasks and domains were studied but only a few were identified as real issues that would require in depth study. Main issues concern the use of stairs and of upper deck slides, the communication, and the co-ordination between separated and out-of-direct sight parts of cabin. Moreover, the size of the passenger population raises crowd-handling issues.

### 1.2.1 Main relationship identification

The relationship considered as relevant were classified into two domains:

- The main issues that should be further studied
- Issues to be taken into account in the design of future VLTA and associated procedures

#### 1.2.1.1 The main issues are:

- **Intercrew communication:** as the number of crew members increases, it will be more difficult for them to communicate and will take them more time to exchange information. This intercrew communication concerns the flight crew-cabin crew communication and the communication between cabin crew (in a cabin area, and between each deck).
- **Cabin configuration and width**
- **Access to/from upper deck:** in a double deck aircraft it will be more difficult for a crew member to assess the situation inside (in the whole cabin) or outside the aircraft, to transmit information in the whole cabin. Passenger briefings should include some items specifying that there are two decks and the procedure linked with the stairs, which could be a critical point if needed during evacuation. Moreover, crew members could have more difficulty in managing people during the evacuation.
- **Location & size of aisles and cross-aisles:** this factor could impact the verification of unobstructed aisles and hinder the visual assessment of the situation at the opposite side or in other area of the cabin. It will be also more difficult for cabin crew to have a mental representation of the whole cabin. Moreover, the size of aisles will have an impact on the passenger flow management and on the empty cabin check.

- **Cabin Crew elements:** the number and location of cabin crew, the crew organisation, the procedure and training that will be used for future VLTA will have an impact on the evacuation process.

#### 1.2.1.2 Issues to be taken into account in the design of future VLTA and associated procedures

- **Exit size and location:** according to this factor, it could be more difficult for cabin crew to assess external conditions and dangers.
- **Cabin seating:** more seats in larger aircraft will correspond to more passengers to brief, to check and to manage.
- **Sill height:** it will be more difficult for crew members to assess the aircraft attitude and the usability of slides, and to have a visual access to ground conditions. Moreover the high upper deck sill height will possibly have an impact on the usability of a slide (more probability to have an unusable slide e.g. because of wind).
- **Slides:** deployment problems could happen more frequently with upper deck slides through larger size and it will be more difficult to check if these slides reach correctly the ground. Moreover, passengers will possibly feel apprehension when using them.
- **Emergency lighting/guidance means:** it is of utmost importance to support passenger guidance in larger aircraft in order to avoid if possible passenger disorientation.
- **Safety information:** the safety briefing given to passengers and Able Bodied Passengers should be specific to VLTA, should present the specific issues of a double deck aircraft and support passenger situation awareness to avoid passenger disorientation. Moreover, cabin crew and Able Bodied Passengers should have in mind that they will be confronted with more passengers at exits.

### 1.2.2 Recommendations

- Conduct experimentation on the use of stairs in the evacuation process for accident/incident and precautionary evacuations.
- Conduct experimentation on the use of upper-deck slides in accident/incident and precautionary evacuations.
- Conduct experimentation on the crew communication (with the flight crew and between cabin crew) in accident/incident and precautionary situations. (Attention should be paid to the crew organisation and communication means.)
- Conduct research work on the improvement of passenger information delivery process (objectives, media, sequences)
- Conduct experimentation on aircraft configuration impact on evacuation (aisle, cross aisle, bulkhead…)
- Conduct experimentation on cabin crew location impact (special attention should be paid to panic mitigation and passenger flow redirection).

## Summary of Work Package 1.3 Non-Aircraft Evacuation Experience

### 1.3.1 Evaluation of information available on the interaction between configuration aspects and human performance in emergency evacuations

The aim of the task was to review the available information on the interaction between configuration aspects and human performance in emergency evacuations in scenarios other than aircraft.

It is proposed that effective emergency evacuation of occupants is influenced by a number of factors. These include the configuration, the predefined emergency procedures, the staff training, the environmental conditions and the psychological and behavioural aspects of the occupants. In this report, the influence of the interior configuration and emergency procedures associated with the rapid evacuation of occupants from a variety of situations, including buildings, ships, trains, buses, underground stations and offshore oilrigs have been reviewed. The relevant information that is available from accident data is also included, together with research studies into evacuations and occupant behaviour during emergencies within these settings.

Accident investigation and evacuation research across various transportation modes and building settings has been reviewed, with emphasis on the influence of the configuration and the emergency procedures, on the safe and effective evacuation of all occupants. Accident analysis and research conducted within each setting has been reviewed, with a number of themes and issues highlighted within multiple areas.

In relation to the configuration, the review has demonstrated the importance of protected and unobstructed routes to egress points or safe waiting areas. It is also noted that when designing interior configurations, consideration should be given to the consistency of the location and style of exits and the location of corridors and staircases. Emphasis has also been placed on the information provided to occupants concerning ‘exit’ operation mechanisms, the safety information and the corresponding signage, with a number of recommendations made to assist occupants. A number of documented papers have also considered the emergency procedural issues that are of importance, these include the need for effective communication systems and realistic staff training programmes, to ensure staff know what to expect in the event of an incident, what actions to take and how to manage the occupants appropriately. It is also recommended that designers take into account human behaviour concerning the wayfinding principles used to move around a space. If designers are aware of strategies to assist effective wayfinding, these elements can be included into the configuration to assist occupants. The review has evaluated the literature and highlighted design and procedural recommendations with the aim of enhancing effective evacuation.

### 1.3.2 Accidents and survival

Whilst no two accidents can ever be the same, it is possible to learn from the similarities and differences between the causes of the accidents, their location, the environmental conditions present, the types of occupants involved and their responses to the emergency. From investigations into accidents within any industry, it is possible to build up a picture of the factors influencing survival.

In any accident situation, a priority must be to ensure that where possible, the numbers of fatalities and injuries are minimised. From an understanding of human behaviour in emergencies, together with knowledge concerning the factors contributing to survival in accidents, it is possible to determine the steps that could be taken to move towards the goal of 100% occupant survival in all vehicle and building accidents.

From the perspective of human behaviour and accident survival, we can generally regard all public transport vehicles or buildings as spaces with a limited number of exits and high seating density or occupant load. The major threats to life in an accident will be from either:

- Injuries as a result of an impact
- Injuries from fire, smoke or toxic fumes

- Injuries during or following the evacuation of the vehicle or building

The body of research into human behaviour during evacuation suggests that a number of factors are important for the safe evacuation of occupants. Physical dimensions need to be considered, including the number of exits and the distance between them. The width and length of egress routes and the emergency signage. Psychological factors and behaviours of the occupants including perception, understanding, decision making and actions. These factors may be influenced by previous experience, training or the information received. The actions and behaviours of the crew or staff, again this will be influenced by the crew's own interpretation of the situation, their previous experience, familiarity with the area and training. Finally the environmental conditions both inside and outside the area, this could include the presence of fire, smoke, toxic fumes, water, weather conditions and light levels.

When the factors influencing survival across air, land, rail, road and sea are reviewed, it is possible to observe major similarities and hopefully learn from experience and practice in other modes. A selection of these factors are summarised in Table 1.3.1 below:

**Table 1.3.1: Factors influencing survival**

| | Air | Land | Rail | Road | Sea |
|---|---|---|---|---|---|
| **Configurational design** | Number of exits, aisle widths, monuments | Number of exits, building configuration, corridor widths | Number of exits, emergency windows, descent to track | Location of exits, emergency windows, aisle width | Routes to muster stations, number of lifeboats |
| **Procedures and training** | Evacuation procedures, crew training | Evacuation procedures, staff training | Emergency plan, evacuation protocols, | Staff training, evacuation procedures | Evacuation procedures, crew training |
| **Environmental** | Interior and exterior conditions | Interior and exterior conditions | Interior and exterior conditions | Interior and exterior conditions | Interior and exterior conditions |
| **Behavioural** | Age, sex, occupant behaviour, prior knowledge | Age, sex, occupant behaviour, prior knowledge | Age, sex, occupant behaviour, prior knowledge | Age, sex, occupant behaviour, prior knowledge | Age, sex, occupant behaviour, prior knowledge |

Information obtained from accident experience suggests that fire and smoke are the most serious environmental factors to affect behaviour in accidents. Smoke and fire have the potential to limit the number of exits available for egress and produce toxic fumes, factors that will consequently induce certain behavioural responses. In addition to the impairment of breathing and vision which can occur when smoke is present, the toxic fumes which emanate from fires, also have the potential to influence psychological functioning, which may affect the behavioural responses of individuals in an emergency evacuation. The actual behaviour of individuals during an evacuation and accident situation will be an important element in shaping the outcome of the incident. It must be remembered that the average passenger will not have experienced a serious incident or a fire on board any passenger vehicle, let alone the mode of transport they are travelling in at the time of the incident (Noonan and Shields 1998). It is also likely that the majority of building occupants have not been involved in a serious incident that required an evacuation of the building unless occupants have been involved in a realistic fire drill.

### 1.3.3 Conclusions of Work Package 1.3

The factors that may influence the safe evacuation of occupants from buildings, ships, trains, buses and offshore oilrigs in an emergency have been reviewed, with emphasis placed on the interior configuration and emergency procedures. The information from relevant accidents and safety research provides knowledge and understanding that can be applied to future designs in order to enhance safety.

Evacuation issues aboard offshore oil platforms have been reviewed through the study of accidents and incidents. Accident analysis has allowed recommendations to be made relating to the platform configuration – in particular protected egress routes, exits, staircases and the notion of a temporary safe refuge. Inquiries and analysis have also provided insight and understanding which has assisted in the design of safety enhancements of new offshore rigs. The relevant literature concerning ship evacuation has highlighted the need for appropriate and effective communication systems to alert occupants to potential dangers, egress routes that are located in a consistent place across decks, routes that are free from potential obstructions, and crew who are fully trained in passenger management and evacuation protocols. Published experimental research into ship evacuation is currently limited, however it is anticipated that the SHEBA facility will be able to assess human performance in a number of areas found on board shipping vessels.

The available documented literature on evacuation from buses and coaches has been considered, with emphasis on configuration and means of emergency egress. Recent research has studied passenger evacuation via a range of egress points with a number of difficulties observed. This lead the researchers to test a number of design alterations to enhance passenger use of the exits. Passenger's ability to open emergency exits has also been conducted demonstrating that a number of factors influenced their ability to fulfil the task. A number of recommendations were made in relation to the operating mechanism, the relevant signage and the location of the operating mechanism in an attempt to improve various design features to enhance passenger's ability to open exits. A review of railroad accidents and experimental research conducted on evacuation from passenger railway carriages has demonstrated that a number of issues linked to the configuration of the carriage can cause occupants difficulties during evacuation. It is proposed that when designing the carriages, the rail industry must consider the behaviours that can be exhibited by passengers in the event of an accident and subsequent evacuation.

A brief overview of the published evacuation research from a variety of building types has been presented. This includes railway stations, office buildings, high-rise buildings, retail outlets and casino/hotel complexes. A number of issues have been raised, including the need for effective communication strategies, adequate staff training, occupants' use of familiar exits, the need for direct view of egress routes and exits and the use of wayfinding principles to minimise the difficulties occupants may experience when moving around a space. Research assessing the efficiency of trial evacuations from university buildings has also been cited. It was concluded within the research that the trial evacuations have effectively trained occupants in the correct procedures, behaviours and actions to take in an emergency evacuation situation. Although the occupants within the university buildings are likely to spend a considerable amount of time within the building, the trial evacuations have also allowed those responsible for safety to investigate difficulties experienced by occupants.

A number of issues relating to the configuration and emergency procedures have arisen from the review and it is noted that many of the issues are relevant to multiple situations and settings. It is proposed that those responsible for safety should review the evacuation and human behaviour research and accident investigations not only in one specific situation, but should also examine issues and events from other safety critical systems with the aim of improving the safe evacuation of all occupants.

**Summary of Work Package 1.4 Collation of information from cabin crew regarding configurational aspects for VLTA**

### 1.4.1 Background

In the Work Package, the configurational, cabin crew and passenger issues associated with the rapid evacuation of passengers from an airframe are considered, with particular reference to VLTA. The information was obtained via a focus group with representatives from a variety of organisations with operational and experimental experience.

The configurational issues that were discussed included the size and location of exits, direct view, bulkheads, aisle width and access both to and from the upper deck. Issues relating to cabin crew on board VLTA that were reviewed included the number and location of cabin crew, the training crew are required to complete and crew communication issues. In relation to passenger factors and VLTA, the discussion revolved around the provision of safety information to passengers.

It was concluded that there are a number of issues that need to be addressed relating to VLTA. It may be possible to resolve some of these issues through current knowledge and understanding, however it was acknowledged that there is currently limited knowledge concerning a number of the identified areas. Areas where future research may be required to evaluate a possible requirement for a regulatory change have also been highlighted.

The main objective was to collect information from cabin crew regarding the configurational aspects of VLTA in relation to the issues and concepts identified as important from research conducted on other tasks within the work package.

Although the requirements of the task only required an assessment of configurational issues, it was felt that important information would also be gained from discussions reviewing cabin crew and passengers issues in relation to the safety of occupants on future VLTA. At present there are two main potential designs for VLTA; firstly a conventional tube-like aircraft structure increased in size and potentially complexity from present tube-like aircraft design, and secondly, a new aircraft design based on a blended wing body.

### 1.4.2 Issues relating to the airframe configuration of VLTA

#### 1.4.2.1 Size of exits

The size of current exits on board aircraft was discussed and it was generally agreed that Type A exits, unless damaged by the crash impact, were successful in evacuating passengers. It was the belief amongst the group that Type III exits were not going to be present on VLTA as the regulations (JAR 25.807) state that on aircraft with passenger seating configurations of more than two hundred and ninety-nine seats, each emergency exit must be a Type A or Type I. The focus group agreed that due to the increase in size of the cabin and the number of individuals on board, Type III exits were not acceptable for VLTA.

#### 1.4.2.2 Number of exits and the distance between them

The regulations (JAR 25.807) state that for each Type A exit installed in each side of the fuselage, the maximum number of passenger seats fitted can be one hundred and ten and for each pair of Type I exits, forty-five passenger seats can be fitted. Participants questioned whether this is still an appropriate calculation for the number of exits on VLTA. It was concluded that research would need to be conducted to determine if this regulation was still appropriate for VLTA.

The distance between exits is at present governed by JAR 25.807 and states that if there are more than one pair of exits, no exit must be located more than 60 feet (18.28m) from another exit on the same side of the same deck. A suggestion was made that on VLTA, the 60-foot rule may not be the best way to approach exit distance, instead the dimensions of the aisles, cross aisles and the number of seats within an area should be considered when reviewing the distance between exits. It was expressed that the rationale behind the interior cabin and the fuselage design in relation to exit location should be developed together.

#### 1.4.2.3 Visibility of exits from the cabin and visibility of the cabin from exits

It was proposed that consideration should be given to the visibility of exits for the passengers when seated in the cabin or in the aisles. A number of operators and manufacturers place monuments, galleys and toilet facilities next to the exits, these all have the effect of blocking or severely reducing the visibility passengers have of the exit location. Although exit signs are present, it is possible that if passengers cannot easily see the exits, the time taken to reach the exit may be increased. Being able to locate visually the exits may also assist passengers in planning a potential emergency egress path should the need arise.

The idea of aisles leading straight through to the exits, as might be the case in a blended wing body aircraft was raised. It was felt that visibility of the exit would be clearer for passengers from the cabin, as they would not have to turn 90 degrees to exit, it was felt that this may influence evacuation times, although experimental research would need to be conducted on the issue.

#### 1.4.2.4 Bulkheads

Although issues were raised regarding problems associated with visibility of the cabin and exits due to bulkheads, it was the general opinion of the focus group that bulkheads were still desirable as they form a protective barrier for the crew and force passengers into more ordered lanes prior to the exit with the intention of creating optimum flow at the exit. It was also noted that operators do need to include toilet and galley areas for service purposes.

#### 1.4.2.5 Aisle width

At present the regulations state that aircraft carrying more than twenty passengers, the aisle width at 25 inches and above from the floor must be no less than 20 inches (JAR 25.815). Concerns were expressed over the possible differences in the widths of main aisles and cross aisles within the same section. It was felt that this would not be a major problem if the majority of exits on both sides of the aircraft were functioning, as passengers would not have to travel across the full width of the aircraft to an exit on the other side or if passengers went directly to their nearest exit. Research into human behaviour and survivor reports from accidents suggest this is not always the case. Exits may not always be available and passengers may not always travel towards their nearest exit. It was felt differences in aisle widths might become an important issue in the event of having to evacuate on only one side of the aircraft leading to flow and filtering problems at junction points, where if aisles are of different widths there is the potential for a different number of lanes of passengers attempting to move into one aisle.

#### 1.4.2.6 Assist space

During take-off and landing, cabin crew should be located as near as possible to the floor level exits, and shall be distributed throughout the aircraft in order to assist with effective egress of passengers in the event of an emergency evacuation. During taxi, cabin crew are required to remain at their duty stations, except to perform duties related to the safety of the aircraft and its occupants.

When the video tapes for certification evacuations were inspected, it became apparent that the lack of adequate assist space can lead to the cabin crew being unable to stay in the assist space when they are assisting the passengers to evacuate in quick succession down the slides. Thus the lack of adequate assist space can mean that the cabin crew reduces the possibility of continuous dual lane slide usage. By increasing the size of the assist space and relocating the grab handle it may be possible to design a situation in which the cabin crew can provide sufficient assistance to the passengers to ensure that there is continuous dual lane slide use without any restriction caused by the presence of the cabin crew.

Assist space was expressed as an important issue by the cabin crew, as it needs to be configured appropriately to allow them to conduct their tasks effectively at the exit during an evacuation. When determining the appropriate amount of assist space, it needs to be sufficient and correctly positioned to allow the cabin crew to control the flow of passengers and assist passengers at the exit if necessary, however must not interfere with the crewmembers positioning or the flow of passengers.

It was felt detailed research needs to be completed to determine the most effective amount of assist space at all exits.

#### 1.4.2.7 Upper deck slide

The possibility of different types of slide design was raised; examples include the traditional open slide, fully enclosed tubes and slides with high sides to limited passenger visibility from the top of the slide to the ground. Examples can also be drawn from buildings and ships – for example the Charles de Gaulle airport tower. It was noted that there are design implications in changing aspects of the slide. In relation to design it was raised that for some passengers being able to see the surroundings will make them anxious, it may be that for others, the unknown (not being able to see) is more uncomfortable. There was a suggestion that the slide could be designed in a way to allow it to be attached around the full door rather than just at the bottom, as this may decrease passenger’s anxiety and hesitation of using the slide. The issue of the number of passengers able to use the slide at one time and the number of lanes will also be of importance to the slide design.

Other issues that were considered to be of importance in relation to the upper deck slide included, passenger hesitation at the top of the slide; the speed at which passengers will travel down the slide and the post evacuation management of passengers. At current heights, cabin crew experience problems with the use of the slide, it is believed that current difficulties highlight the potential problems that may occur with the increase in the height of the slide from the upper deck of VLTA.

#### 1.4.2.8 Access to the upper deck

##### 1.4.2.8.1 Stairs

In relation to the stair design, it was felt that the most important factor during design is that all passengers can use the stairs safely and quickly. It was felt that although passengers may be required to go to the upper deck via the stairs in an emergency, going down stairs in an emergency had more risks associated with it and is where research at this stage should be focussed.

The physical dimensions of the stairs will need to be fully researched. Issues that will need to be reviewed include the capacity for descent, the staircase width, the angle or steepness of the stairs, the stair tread width, the number of stairs, the number of lanes and the inclusion or not of handrails. Once the optimum staircase design has been researched, it will also be important to assess the number of sets of stairs and their location on the aircraft i.e. fore, central or aft, for optimal evacuation egress.

Protocols will need to be developed to determine when it is appropriate to use the stairs and when it is not felt appropriate. Conducting a risk analysis of various scenarios may be useful during this assessment.

#### 1.4.2.8.2 Ramps

Although much of the discussion revolved around the issue of internal staircases, one suggestion was made that perhaps ramps and inclines should be considered as an alternative to stairs. It was felt that people do not fall and trip as easily on ramps or inclines as opposed to stairs. It was expressed that there are both positive and negative aspects to the use of ramps. It was concluded that it is important for designers to consider all possible alternatives for internal access between decks.

#### 1.4.2.9 Other concerns relating to configurational aspects on VLTA

It was expressed that manufacturers, researchers and regulators should be aware that the interior of VLTA will be an alien environment to both passengers and crew, particularly in the case of the blended wing body; this should be taken into consideration when designing configurations and developing emergency evacuation procedures.

### 1.4.3. Issues relating to the cabin crew on board VLTA

#### 1.4.3.1 The number of cabin crew required

JAR OPS 1 requires aircraft with a seating capacity of more than 100 passengers, to have two cabin crew, and, in addition, an extra member of cabin crew is required for each unit (or part unit) of fifty passenger seats. It should be recognised, however that those operators who fly with additional crew usually do so for reasons of service as opposed to safety requirements. VLTA designs with a large number of passengers, raises the question of whether a ratio of one cabin crew per 50 passengers is adequate.

When determining the number of cabin crew on board VLTA, there are a number of issues that need to be assessed including the number of exits, possible redirection points, potential blockage points where aisles cross or combine and the location and number of staircases.

#### 1.4.3.2 The role of cabin crew

The issue of the various roles cabin crew are required to fulfil was discussed, for safety at least one member of crew per door is required, however due to commercial and service reasons, some operators want additional cabin crew on board to assist in the service of passengers, without them being fully trained members of cabin crew.

It was strongly felt by many of the participants, that all crew on board the aircraft should be full members of cabin crew, with identical levels of training so they can easily replace each other if a problem occurs. If an individual is on board wearing a crew uniform they should be fully qualified and trained in all areas of the job. It is likely that passengers will assume that this is the case, and in the event of an incident, passengers will look to any member of crew for guidance, they will not be aware of who has trained to what level.

### 1.4.3.3 Emergency command and control procedures

During an evacuation it will need to be considered if one individual in a central location will control the evacuation or if each individual will operate within the confines of their own location and the knowledge that is immediately available to them. Examples of oil platforms and football stadiums were given, where there is a control centre with visual feedback of specific locations within the setting. The actions and behaviours of the occupants and the situation can be monitored and advice or interventions can be communicated to staff members from the central location.

### 1.4.3.4 Crew training

The crew will need to manage and communicate with an increased number of passengers on VLTA and additional training based on these requirements may be needed. It was suggested training might be beneficial in areas of crowd control, the use of passenger communication systems and evacuation from the upper deck. It was noted that crew should not be given too many additional tasks due to the potential of overload.

### 1.4.3.5 Cabin crew communication

#### 1.4.3.5.1 Communication with passengers

With aircraft of this size, it was suggested that there might be separate Public Address systems to communicate with passengers in different areas or compartments. Benefits of this may be that escape routes and the location of exits may be different for each section; it may also reduce the number of passengers moving within an area or along an escape route, potentially assisting with crowd control.

#### 1.4.3.5.2 Communication with other members of cabin crew

Research has already been carried out into various methods of cabin crew communication including headsets and mobile phones. It is generally felt within the industry that there is concern that mobile phones could easily get lost on board the aircraft. It was reported that the industry is becoming more open to the idea of crew headsets for communication.

### 1.4.3.6 Injuries to cabin crew

In a study to investigate the sources of injury to cabin crew and passengers in flight (NTSB 1992), it was found that the main causes were injuries as a consequence of lack of stability of the aircraft in turbulence, trolleys going out of control, passenger luggage or safety equipment falling from overhead bins, and in-flight fires. With the increased size and numbers of passengers in the VLTA it will be important that consideration is given to ways of minimising the injuries which can arise from these sources.

## 1.4.4 Passenger factors on board VLTA

### 1.4.4. 1 The provision of safety information

Operators ensure that all passengers are briefed before take-off. This briefing should include restrictions on smoking, the location of the emergency exits, the use of safety belts and when to use them, and the location and use of any required flotation means. In addition, each passenger-carrying operator provides a safety card in a convenient location for use by each passenger. This card supplements the briefing and should contain diagrams of, and methods of operating, the emergency exits, and other instructions necessary for the use of emergency equipment.

It must be considered that with the increase in passenger numbers, is it still appropriate to have the standard safety briefing that is provided at present? Although many of the issues relating to the safety briefing are not exclusive to VLTA, it was felt by the focus group that with the increase in the size of the aircraft, the number of passengers and the introduction of a potentially alien and complex environment, the communication of safety information to passengers becomes even more crucial.

#### 1.4.4.2 Personal space and disruptive passengers

With the increase in the numbers of passengers on board VLTA, the issue of an increase in the number of disruptive passengers was mentioned. It is felt that there are a number of factors that can increase the likelihood of passengers becoming disruptive – these include flight delays, passengers' perceptions of poor service, excessive alcohol, other passengers and the restrictive environment. Although the majority of the issues are not exclusively relevant to VLTA, it was suggested that the increase in the number of passengers might have an influence on the occurrence of disruptive behaviour.

#### 1.4.4.3 Passenger information overload

It was highlighted that the amount of information provided to passengers either pre-boarding, during the safety briefing or during an emergency evacuation must be assessed to prevent information overload. Research has shown that in times of high stress and anxiety, mental capabilities are reduced, therefore commands that are given to passengers, and the actions they are required to complete must be as simple and clear as possible.

### 1.4.5 Conclusions of Work Package 1.4

Configurational, cabin crew and passenger factors which may influence the safety of evacuations from VLTA have been reviewed. Information has been obtained from a variety of individuals with operational and experimental experience.

It was concluded that a number of issues that need to be addressed relating to VLTA have been raised within the discussion. It may be possible to address some of these issues from current knowledge and understanding, however it is acknowledged that there is currently limited knowledge concerning a number of these areas. These include individual's navigation of complex spaces, configurational elements, crew role requirements and passenger behaviours within VLTA. It may also be of some benefit to explore the views of flight crew members concerning a number of the identified issues.

With a number of the issues, research has been proposed that may need to be conducted to evaluate the possible requirement for regulatory changes for VLTA.

### Summary of Work Package 1.5 The Identification of the Configurational Issues and Rules which may need to be re-evaluated for VLTA

### Certification demonstrations

JAR 25.803 requires a demonstration of a full scale emergency evacuation in dark of night conditions using a trained crew, baggage in the aisle and a specified age/gender mix of passengers. There is concern about the potential risk of injury due to the large number of passengers who will be required to evacuate from each deck.

**Exit location**
JAR 25.807 states that no passenger emergency exit shall be located more than 60 feet from any adjacent passenger exit on the same side of the same deck of the fuselage. This distance has recently led to Type III exits being re-introduced on a wide-bodied airframe. The justification for this distance on future VLTAs will need to be evaluated.

**Exit Size**
JAR 25.807 states that each Type A exit allows 110 passengers and each Type I exit allows 45 passengers. These numbers were for passengers evacuating from a sill height up to 5 metres. Whether they will require revision for a sill height of 8 metres will require evaluation due to the possibility of an increase in passenger hesitation time from the upper deck.

**Width of Aisles and Cross Aisles**
JAR 25.813 which states that each passageway leading to a Type A exit must be unobstructed and at least 36 inches wide has been found to be satisfactory in the past and should be appropriate for VLTAs.

**Cabin Crew Assist Space**
JAR25. 813 specifies that 'an adequate space to allow crew members to assist the evacuation of passengers must be provided'. It may be advisable that for VLTA, with the importance of the performance of cabin crew, together with the potential risk to their safety, on the upper deck, that the minimum dimensions for assist space together with the location of the assist space are reviewed.

**Cabin Seating**
Recent anthropometric studies by scientists at Loughborough University should be used to determine whether CAA AN 64 requires revision as noted in 1.1.3.1.

**Slides and post-egress factors**
One of the novel features of future VLTAs will be the use of upper deck slides by a large number of passengers in an emergency. The majority of injuries which occur as a consequence of an emergency evacuation occur at the bottom of the slides. In an attempt to reduce the possibility of injury to passengers, consideration could be given to the introduction of clearly defined procedures, possibly supported by regulation, for the management of passengers post evacuation.

**Access to upper deck**
Although the stairs may not be used in the event of an evacuation, in practice many passengers will board by the lower deck and those to be seated on the upper deck will gain access via the internal stairs. In normal operations, the upper deck passengers may also disembark by the stairs. Consideration must be given to the possibility that passengers who are in the habit of using the stairs in normal operations, may decide to do so in an emergency.

**Attraction to operational exits**
Preliminary research suggests that new technology in the form of enhanced lighting in the vestibule area, changes to exit signage and directional sound may have the potential to provide passengers with enhanced information about operational exits.

**Direct View**
The regulations currently require cabin crew to have a view of passengers in the cabin when seated for takeoff and landing. With the increase in numbers of passengers it may be appropriate to consider whether passengers should have an unrestricted view of the crew and exits at take off and landing.

**Technology to assist Cabin Crew Communications in an Emergency**
It is accepted that in a double-deck VLTA emergency, the objective will be to evacuate each of the decks independently and that crew will perform as they are currently required on wide bodied aircraft. On current aircraft, with a maximum of 60ft between exits in the event of an exit becoming unavailable the crew are usually able to see the situation at adjacent exits and re-direct the passengers accordingly. On a double-deck airframe in an emergency, crew on one deck will be unaware of the situation on the other deck with implications for improved communications.

**Communications between the flight deck and cabin**
Operating companies currently develop their own procedures for commanding an evacuation in the event of an emergency. Whilst this may be the case for VLTA consideration should be given to who makes the decision and to how this decision is communicated within two decks.

**Cabin Crew**
The distribution of the minimum cabin crew will require consideration. If cabin crew are found to be needed at the top and bottom of the stairs their procedures in an emergency and the possible requirement for assist spaces will require evaluation.

**Passenger briefing.**
One of the issues which will need to be addressed is whether the current form of safety cards and passenger briefings by video and/or crew, will require modification for future VLTAs.

**Conclusions**
In this report, consideration has been given to the configurational and safety issues and rules which will need to be evaluated for VLTA.

The issues which will need to be addressed include reconsideration of the “sixty foot” rule between exits, minimum exit size, the 20 inch aperture between bulkheads, the configuration of the stairs and adjacent space, crew assist space, the potential contribution of enhanced lighting or sound systems and post evacuation management of passengers.

**Summary of Work Package 1.6**

**Proposal for Requirements of Future Evacuation Testing**

Within the report, the configurational issues have been considered and testing programmes have been recommended to establish minimum configurational standards for VLTA. Testing proposals have been suggested for the following configurational issues:

- Performance at Type A exits
- Cabin Seating
- Exit Location
- Slides and post-egress factors
- Access to Upper Deck
- Crew Communication procedures
- Passenger briefing

**Conclusions**

The areas which will require test programmes in order to establish minimum configurational standards for VLTAs have been identified. They include access to the upper deck, slides and post-egress factors, minimum distance between exits and configurational issues to assist evacuation rate from the upper deck including increased assist space.

**Summary of Work Package 2 Investigating the Requirements of a Methodology Utilising Analysis and Partial Testing**

**2.1 State of the Art of Evacuation Models, their Validity, Data Requirements and Current Availability of Data**

**2.1.1 State of the Art for Aircraft Evacuation Models**

Currently there are two main areas of application for aircraft evacuation models. These are for design/certification and for accident investigation. While design and certification application areas should be considered as two separate areas, essentially, the design requirement is predominately driven by the certification requirements. Thus, for the purposes of this report, these two areas will be treated as a single requirement.

As noted, regulators attempt to enforce and maintain safety standards through a set of essentially prescriptive rules that have evolved over time An example of one of the rules that has evolved over time relating to aircraft evacuation efficiency is the so-called "60-foot" rule. The rule appears in the JAR (i.e. 25.807) and states;

*"For an aeroplane that is required to have more than one passenger emergency exit for each side of the fuselage, no passenger emergency exit shall be more than 60 feet (18.288m) from any adjacent passenger emergency exit on the same side of the same deck of the fuselage, as measured parallel to the aeroplanes longitudinal axis between the nearest exit edges*

These prescriptive regulations specify design rules that must be followed in the design of all commercial passenger aircraft carrying more than 44 passengers. Compliance with these rules can easily be visually checked by inspectors both during design – by viewing aircraft scale drawings - and when the first aircraft rolls off the production line. In addition to these prescriptive rules is a performance-based requirement commonly known as the *'90 second certification test'.* Compliance with this rule is demonstrated by performing a full-scale evacuation demonstration. The demonstration is performed with a representative cross-section of the travelling public (age and gender distribution), in darkness and utilising only half of the normally available exits. Crew and passengers do not know beforehand which exits will be made available. The test involves evacuating all passengers and crew to the ground (using slides if they are fitted) within 90 seconds if the aircraft is to pass the performance test. The certification performance test is only intended to provide a measure of the performance of the aircraft under an artificial benchmark evacuation scenario. It is not intended to predict the performance of the aircraft under a realistic accident scenario. However, it allows the performance of different aircraft to be compared under a set of identical – if somewhat artificial – scenario conditions.

There are several difficulties with the current 90 second trial. There is considerable threat of injury to trial participants. Between 1972 and 1991 a total of 378 volunteers (or 6% of participants) sustained injuries ranging from cuts and bruises to broken bones. In October 1991 during the McDonnell Douglas evacuation certification trial for the MD-11, a female volunteer sustained injuries leading to paralysis. Another difficulty is the lack of realism inherent in the 90-second evacuation scenario. Volunteers are subject neither to trauma nor to the physical ramifications of a real emergency situation such as smoke, fire and debris, the certification trial provides little useful information regarding the suitability of the cabin layout and design or the cabin crew procedures in the event of a real emergency. The Manchester accident of 1985, in which 55 people lost their lives, serves as a tragic example. The last passenger to escape from the burning B737 aircraft emerged 5.5 minutes after the aircraft had ceased moving, while 15 years earlier in a UK certification trial, the entire load of passengers and crew evacuated the aircraft in 75 seconds. In the certification trial, while passengers are keen to exit as quickly as possible, the behaviour exhibited is essentially co-operative, whereas in real accident situations the behaviour may become competitive. Even if complex issues of fire etc are excluded from consideration, relatively simple issues such as exit selection are far from realistic. Providing all exits on one side of the aircraft bears little or no resemblance to realistic accident scenarios.

On a practical level, as only a single evacuation trial is necessary for certification requirements, there can be limited confidence that the test - whether successful or not - truly represents the evacuation capability of the aircraft. In addition, from a design point of view, a single test does not provide sufficient information to arrange the cabin layout for optimal evacuation efficiency, and does not even necessarily match the types of configuration flown by all the potential carriers.

Finally, each full-scale evacuation demonstration can be extremely expensive. For instance an evacuation trial from a wide-body aircraft costs in the vicinity of $US2 million. While the cost may be small in comparison to development costs, it remains a sizeable quantity.

A primary driver for the development of aircraft evacuation models is to augment or replace the current certification process. In this application the model is intended to simply replicate the live certification trial and if possible to address the identified problems and shortcomings of the certification process. Several models (e.g. airEXODUS, GPSS) have been developed to address these needs. However, at present it is worth noting that evacuation models designed to address 90-second certification applications have access to a plethora of data, in the form of video footage of previous 90-second certification trials, upon which behaviours within the model can be derived and key model parameters set.

The most significant developments in computer based evacuation modelling technology have occurred in the building industry. This has been the driving force for much of the development in evacuation modelling. This is somewhat ironic as one of the first computer based evacuation models to appear in the literature was an aircraft evacuation model, GPSS in the 1970s. Unfortunately, this model failed to capture the imagination of engineers and regulatory authorities of the day, perhaps due to the limitations of the computers of the time or limitations in its modelling capabilities. As a result, the area of aircraft evacuation modelling fell dormant for nearly 20 years.

Over the past 30 years only seven aviation evacuation models have been reported in the open literature. In chronological order they are:

| | |
|---|---|
| 1970 to 1980 | General Purpose Simulation System (GPSS) developed by the FAA, |
| 1987 to 1992 | Gourary Associates (GA) model developed by Gourary Associates, |
| 1990 to 1994 | AIREVAC/ARCEVAC developed by Aviation Research Corporation |
| 1994 to 1996 | Macey's Risk Assessment Model developed by Cranfield University |
| 1996 to 1996 | The Oklahoma Object Orientated (OOO) model |
| 1989 to now | EXODUS developed by the Fire Safety Engineering Group of the University of Greenwich |
| 2001 to now | Robbin's Discrete Element Method (DEM) developed by Department of Mathematics at The University of Strathclyde |

Three aircraft evacuation models have been developed primarily to simulate emergency evacuations (ARCEVAC and GOURARY), one model has been developed to simulate 90-second certification evacuations (GPSS) and two models have been developed specifically to simulate both 90 second certification trials and emergency evacuations (EXODUS, MACEY and DEM).

If the model is intended to simulate accident scenarios, it needs the capability to represent fire scenarios. This can be accomplished through the incorporation of a hazard sub-model. The hazard sub-model is intended to represent the spatial and temporal distribution of fire hazards such as smoke, heat and toxic gases. The method of representing fire hazards is in some part dependent upon the nature of the enclosure representation. Models that utilise a coarse network approach to represent space will be forced to simplify the representation of fire hazards. In such cases, the hazard distribution would be represented as uniform distribution within the defined spatial zone. Models utilising a fine spatial network to represent space can also represent the hazards as a uniform distribution over a predefined region of space (or zone) (e.g. GOURARY and ARCEVAC) or elect to represent the a unique hazard value at each node/tile location within the geometry (e.g. EXODUS and MACEY) Models such as EXODUS can utilise either approach.

Models that represent fire hazards should also have a representation of the effects on the simulated passengers. Human exposure to a thermo-toxic hazard affect passenger behaviour and physiology. The behaviour model employed determines the behavioural response however; a toxicity model is required to represent the passengers' physiological response.

A model with a simplistic representation of toxicity (e.g. GOURARY), typically assigns passengers with an arbitrary *endurance* or *stamina* attribute that represents the individual threshold to thermo-toxic exposure. The attribute is decreased by cumulative exposure until either incapacitation and/or expiry occurs. Unfortunately, the arbitrary nature of this attribute makes reliable predictions of human response to fire hazards difficult.

By contrast some models (e.g. EXODUS and MACEY) make use of complex fractional effective dose models (i.e. FED models) to predict the physiological response of passengers to fire hazard exposure (see Section ). Incapacitation/expiry is determined via an empirically determined cumulative fractional effect that is determined according to actual exposure during the simulation.

Other models may completely ignore the thermo-toxic affects of real emergency environments (e.g. ARCEVAC and DEM). However, its presence may affect the behaviour of passengers (ARCEVAC).

Another major feature of aviation evacuation models is their ability to represent the interaction of passengers with cabin crew. Unlike in most building evacuation scenarios, the actions of cabin crew are highly influential on the evolving dynamics of the aircraft evacuation. As examples, cabin crew members prepare exits for use, redirect passengers and assist passengers at exits. These actions must be represented within the aircraft evacuation model in some way. Methods of representing cabin crew within aircraft evacuation models are categorised as being IMPLICIT, EXPLICIT, USER DRIVEN or NONE.

Some models completely ignore cabin crew members (e.g. MACEY) Thus cabin crew member tasks, such as exit preparation, is performed by passengers. Models with an IMPLICIT representation of cabin crew (e.g. GPSS and DEM), do not physically represent cabin crew within the simulation, although their actions are represented.

Models that have an EXPLICIT representation of cabin crew (e.g. ARCEVAC ) physically model the cabin crew as an individual within the simulation. The model determines events, such as the length of time required to prepare exits for use. Using exit preparation time as an example, the model would move the crew member to the exit then the crew member would open the exit and deploy the escape slide. Other actions such as crew redirection can also be represented explicitly. Some models are capable of both IMPLICIT and EXPLICIT representation of cabin crew (e.g. EXODUS).

Finally, some models require user intervention in order to simulate the redirection of passengers (e.g. GOURARY). These types of models require the user to monitor the unfolding evacuation and determine from the model output when redirection is required.

A key feature of aircraft evacuation models, and one that distinguishes them from building models, is the need to represent the behaviour of passengers when using aviation specific components, such as exits or escape slides. Some models use empirical data (GPSS and EXODUS) to specify realistic delays appropriate to the aircraft components, i.e. Type-I, Type-III exits etc. Such data is derived from analysis of experimental studies and 90-second certification trials. Through the use of this empirical data these models predict realistic flow rates through the exit.

Other models use more novel methods of representing behaviour at these components. Some models (GOURARY, ARCEVAC, MACEY and DEM) use a probability of exiting as a function of exit size and cabin crew member proximity, other models tend to assume an arbitrary cap on exit capability such as only allowing one passenger to occupy an escape slide at any one time (DEM ). Essentially, these approaches impose a flow rate upon the exit. The models parameters are then altered until something approaching the desired flow rates is generated.

The EXODUS software was developed by University of Greenwich Fire Safety Engineering Group with support from the UK CAA. EXODUS is a suite of software tools designed to simulate the evacuation of large numbers of individuals from complex structures. Development on EXODUS began in 1989. EXODUS was originally designed for use with aircraft, however, its modular format makes it ideally suited for adaptation to other types of environment. As a result its range of application has grown, as has the number of specific EXODUS products. The family of models consists of buildingEXODUS for the built environment, marine/off-shore industries and aviation applications respectively. airEXODUS is designed for applications in the aviation industry including, aircraft design, compliance with

90 second certification requirements, crew training, development of crew procedures, resolution of operational issues and accident investigation.

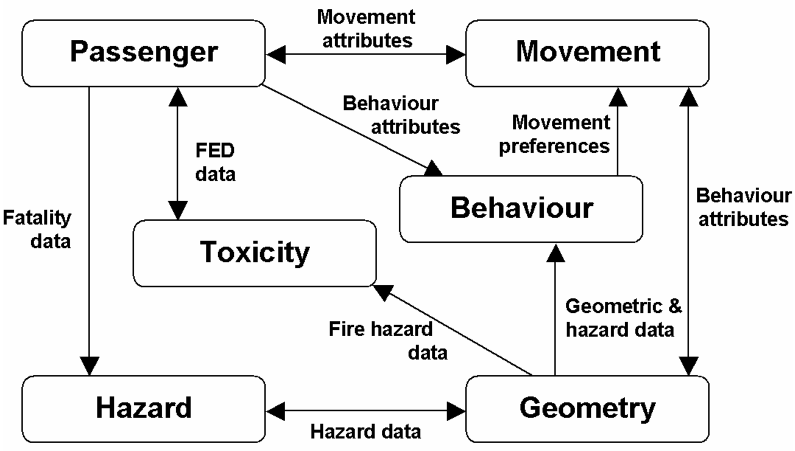


**Figure 2.1: airEXODUS Submodel Interaction**

EXODUS comprises five core interacting sub-models: the Occupant, Movement, Behaviour, Toxicity and Hazard sub-models (see Figure 2.1). The software describing these submodels is rule-based, the progressive motion and behaviour of each individual being determined by a set of heuristics or rules.

The Population Sub-model allows the nature of the passenger population to be specified. The population can consist of a range of people with different movement abilities, reflecting age, gender and physical disabilities as well as different levels of knowledge of the ship layout, response times etc. airEXODUS assigns passengers with over 20 defining attributes, such as *Gender, Age, Weight, Height, Agility, Drive, Six different movement speeds* (for different types of motion and terrain), *Response Times, Patience* and *Social Genes.*

On the basis of an individual's personal attributes, the Behaviour Sub-model determines the occupant's response to a situation, and passes a decision to the Movement sub-model. The Behaviour sub-model functions on two levels. These levels are known as GLOBAL and LOCAL behaviour. GLOBAL behaviour involves implementing an escape strategy that may lead an occupant to exit via their nearest serviceable exit or most familiar exit. The desired GLOBAL behaviour is set by the user, but may be modified or overridden through the dictates of LOCAL behaviour, which includes such considerations as determining the occupants initial response, conflict resolution, overtaking and the selection of possible detouring routes. In addition a number of localised decision-making processes are available to each individual according to the conditions in which they find themselves and the information available to them. Social relationships, group behaviour and hierarchical structures are modelled through the use of a "gene" concept, where group members are identified through the sharing of social "genes".

The Toxicity submodel determines the physiological impact of the environment upon the occupant. To determine the effect of the fire hazards on occupants, airEXODUS uses a Fractional Effective Dose (FED) toxicity model. This model considers the toxic and physical hazards associated with elevated temperature, thermal radiation, HCN, CO, $CO_2$ and low $O_2$ and estimates the time to incapacitation. In addition to this behaviour, the passengers are able to respond to the environmental conditions by adjusting their behaviour. The thermal and toxic environment is determined by the Hazard submodel. airEXODUS does not predict these hazards but can accept experimental data or numerical data from other models including a direct software link to the CFAST fire zone model.

airEXODUS makes use of 90-second certification data to specify certain model parameters. One of the most important parameters for representing aircraft style exits is the Passenger Exit Delay Time. This time represents two stages of the exiting process, the exit hesitation time and the exit negotiation time.

In general, the exit hesitation time is due in main to passengers either waiting at the exit for the path to clear and/or contemplating how to negotiate the exit. In either case, the exit negotiation stage does not usually start until there is space for it to commence. Furthermore, the process of passing through the exit and travelling from the exit to the ground are considered as separate events that can occur in parallel.

Within airEXODUS the exit delay time distribution is segmented into subintervals described by uniform distributions. The technique is dependent on the user having a good representation of the actual delay time distribution. In the current version of the software this data is extracted from past certification trials. For example, consider main deck Type-A exits with assertive cabin crew. Data from 11 previous certification tests involving Type-A exits with assertive cabin crew was available.

### 2.1.2 Validation

Confidence in any model is gained through its accuracy at reconstructing or predicting what happens in reality. Thus a convincing record of verification/validation is essential. Indeed, software validation should be considered as an on-going activity. For any complex simulation software, validation is not a “once and forget” task, but should be considered as an integral part of the life cycle of the software.

The verification/validation of evacuation software is no exception. Indeed, the lack of a large battery of convincing data for the verification of evacuation software has meant that a rigorous procedure needed to be established for the validation/verification of evacuation software. There are at least four forms of validation/verification that evacuation models should undergo. These are,

(i) component verification,
(ii) functional verification,
(iii) qualitative verification and
(iv) quantitative verification.

**(i) Component Verification.**
Component verification involves checking that various components of the software perform as intended. This involves running the software through a battery of elementary test scenarios to ensure that the major subcomponents of the model are functioning correctly.
**(ii) Functional Verification.**
Functional verification involves checking that the model possesses the ability to exhibit the range of capabilities required to perform the desired simulations. This requirement is task specific. To satisfy Functional Verification, the model developers must set out in a comprehensible manner, the complete range of model capabilities, and inherent assumptions and give a guide to the correct usage of these capabilities.
**(iii) Qualitative Verification.**
The third form of model verification concerns comparing the nature of predicted human behaviour with informed expectations. While this is only a qualitative form of validation, it is nevertheless important as it demonstrates that the behavioural capabilities built into the model are capable of producing realistic behaviours.
**(iv) Quantitative Verification.**

Quantitative verification involves comparing model predictions with reliable data generated from an evacuation demonstration. This must be viewed in light of the earlier comments concerning the integrity of the data, the suitability of the experiment and the repeatability of the experiment.

Which aspects of the numerical predictions are to be compared with experimental data must also be established. This is somewhat dependent on the nature of the intended application.

#### 2.1.2.1 Model discussion

Originally designed in the 1970's, GPSS is now very dated both in terms of platform (large mainframe computers) and capabilities. It contains little human behaviour with the result that passengers simply behave like mindless ball bearings.

DEM assumes passenger movement to be analogous to Newtonian soft spheres. As such, passenger shape is assumed to be round. This model treats the movement of passengers much like ball bearings, an approach that is now considered dated. In addition, some of the assumptions on which the model is based undermine its ability to reflect reality accurately. For example, one of the assumptions is that only one passenger may use an escape slide at any one time. This is simply not realistic, as more than one person can and do occupy slides at the same time. In addition, the logical consequence of this approach is that for much of the simulation the length of the slide determines the flow rate through the exit. This assumption alone undermines the results of the model. This casts serious doubts on the usefulness of the validation exercise presented in support of the model.

The GA model demonstrated many of the qualitative behavioural features of emergency evacuations. In terms of qualitative features it included a more comprehensive representation of the behaviour than either GPSS or DEM. In addition the GA model had a rudimentary toxicity and hazard model. However, the main criticisms with the GA model are that their model parameters were not empirically determined and that their hazard and toxicity models were completely arbitrary. As such it is difficult to derive meaning from the results. Finally, the model was only capable of simulating the evacuation of narrow-bodied aircraft. These failings were compounded by the lack of validation performed on the model.

ARCEVAC contained numerous complex behavioural features that distinguished itself from other evacuation models of the time. ARCEVAC, provided an explicit representation of cabin crew members that were capable of performing complex procedures (such as checking aisles or seats) whilst the simulation ran. Whilst containing numerous behavioural capabilities it may be criticised, as its behaviours were not based on empirical evidence from experiments or air accidents. In addition, the model was limited to simulating the B727 aircraft, although other aircraft may have been possible if the code was rewritten. Finally, the ARCEVAC model was only validated once and the results were unclear.

EXODUS contains numerous complex behavioural features. With respect to simulating 90-second certification trials, its model parameters are based on comprehensive research relating to previous certification trials. It is arguable whether all human performance data generated from certification trials is strictly relevant to accident applications. The model attempts to use such data in addition to data derived from accident investigations and laboratory based experimental trials for accident related scenarios. EXODUS models cabin crew members both explicitly and implicitly, allowing them to perform many complex actions, such as opening exits and redirection. EXODUS has been successfully validated against numerous certification trials and experiments, two of which were performed blind. EXODUS is capable of simulating the evacuation of narrow-bodied, wide-bodied, double deck and blended wing bodied aircraft. This model treats each person within the simulation as an individual allowing them to follow and adapt their individual evacuation strategies. Work is continuing on EXODUS model development. Work is focused on a range of activities including the study and development of behaviour exhibited in accidents, the quantification of behaviour during emergency evacuations and the further development of the models capabilities to simulate 90 second certification scenarios.

Like many other evacuation models, MACEY's risk assessment model suffers from arbitrary parameter assignment. Whilst a wealth of empirical data was used in setting the scenario, very little empirical data was used within the evacuation sub-model. As such, the performance of components such as exits were imposed on the model rather than generated by the model as results. In addition, whilst the model was capable of simulating evacuation via aircraft fuselage ruptures, no data was employed in representing the delays that passengers were likely to experience in negotiating them. As the designers conceded the exit flow rates would not be appropriate in real emergency accidents. Furthermore the model completely ignored cabin crew members. Consequently, passengers prepared exits for use. During the validation exercise, this was cited as a possible reason for the model continually over estimating evacuation times. Finally, the Macey model makes use of two-dimensional fire and airflow sub-models. These are extremely simplistic and are incapable of reproducing important fire effects such as smoke layering.

### 2.1.3 Data for Evacuation Models

Associated with the development of computer based evacuation models is the need for comprehensive data collection/generation related to human performance under evacuation conditions. The nature of the particular type of scenario to be simulated will dictate the type of data required and the capabilities the model will require. Factual data regarding the evacuation process is essential to the development of computer evacuation models. Evacuation models have a high reliance on factual data regarding the evacuation process in order to:

(a) Identify the physical, physiological and psychological processes that contribute to, and influence the evacuation process and hence inform the formulation of appropriate models (examples of relevant processes include seat jumping, aisle swapping, family group coherence, movement in smoke, incapacitation due to inhalation of toxic products etc.)

(b) Quantify attributes/variables associated with the identified processes.

(c) Provide data for model validation purposes.

Three forms of data are useful in providing the required information. Accident reports containing interviews with accident survivors, video footage from 90 second certification trials and data generated from full-scale and component experimentation. Each of these data sources provides useful information for modelling.

Accident investigation reports that contain human factors analysis and survivor interview accounts are vital in providing information to identify the human element (i.e. item (a) above) that needs to be simulated if the model is to be used in performing simulations of realistic accident scenarios. Equally, data from 90 second certification trial videos can provide similar information suitable for models intending to simulate certification trials.

Once identified, the behaviours and occupant performance attributes must be quantified (i.e. item (b) above). For models intended to simulate real incidents a useful form of data is derived from full-scale and component tests.

For models intended to simulate 90 second certification trials, detailed analysis of video footage from trials can be used to quantify the identified attributes (i.e. item (b) above).

Finally, data is necessary to validate the predictions of evacuation simulations. Ultimately, the worth of a model is gauged against its ability to realistically and accurately reconstruct and/or predict the real world. Again, data from 90-second certification trials and contrived experimentation can be used to validate models.

#### 2.1.3.1 Data from 90-second certification trial evacuations

By detailed study of video recordings from 90 second certification trials, both qualitative and quantitative data can be generated relating to passenger behaviour. From the analysis of videos of 90-second certification trials it is possible to establish various behavioural traits common to certification trials. For example, passengers spend an insignificant amount of time in releasing seat belts, very little aisle swapping occurs, passengers are very compliant to crew instructions, seat jumping is extremely rare, passengers hesitate at slide exits prior to committing to jump, etc. It is important to note that while these behaviours are extremely relevant to certification trials they may be completely irrelevant in real accident situations.

It is however extremely difficult to obtain access to this type of data as the aircraft manufacturers that produce the data consider it to be valuable proprietary information that would provide advantage to their competitors. However, FSEG of the University of Greenwich with sponsorship of the UK Civil Aviation Authority and through strict confidentiality agreements with all the major manufacturers (i.e. Airbus Industries, Boeing Commercial Airplane, British Aerospace, and Douglas Aircraft Company Inc (McDonnell-Douglas (MDC) Corporation – now part of Boeing Commercial Airplane) has access to all the 90 second data video footage that exist. This information has been analysed by FSEG and forms an integral part of the airEXODUS model. While the regulatory authorities have access to this data it is not generally available to other model developers.

In total some 30 evacuation trials of 24 aircraft have been analysed, that cover the period 1969 to 1996 and include commuter, single aisle, dual aisle and double deck aircraft. The data represents the evacuation of 68 Flight Crew, 194 Cabin Crew and 8865 passenger participants.

The data extracted concerns exiting behaviour of the passengers and crew on an aircraft by aircraft and an exit by exit basis. From the data the following information was collated: Cabin Crew Response Times, Exit Opening Times, Slide Inflation Times, Exit Ready Times, Passenger Exit Use, Passenger Exit Hesitation Times, Passenger Escape slide / Wing Use `Off Time', Flow Rates, efficiency measures and Type-A Exit Lane Usage. This data has been presented in tabular form for each aircraft investigated.

Furthermore, the data provides a means to validate models designed to simulate 90 second certification trials. This is enabled by a thorough knowledge of; the starting conditions for each evacuation, the end times for each exit, the number of people to use each exit, the location of bottlenecks, flow rates through exits, etc.

Whilst these video records do provide much of the data required for the development and testing of models intended for the simulation of certification trials, the data is not perfect. Two main shortcomings are apparent.

Firstly, data generated for certification trials were not intended for computer model development. Thus, they are not carried out in the controlled experimental manner that would be most desirable for model development. Consequently, there is very little control over variables examined in the trials and modellers have to contend with “gaps” in the data. For instance, there may be insufficient data available covering all possible combinations of cabin crew assertiveness and exit type.

Secondly, for model validation purposes – as opposed to quantification of model variables – as only a single trial is produced for 90-second certification requirements we do not have an indication of the likely spread in experimental results for any given configuration.

The need to perform repeated experiments should come as no surprise as even under the most controlled experimental conditions, no evacuation exercise involving crowds of real people will produce identical results if the exercise is repeated - even if the same people are used.

#### 2.1.3.2 Data from aircraft accident/incident reports

Unlike certification evacuations, in real emergency evacuations passengers are subjected to psychological, physiological and physical threats that may engender competitive behaviour (as opposed to the co-operative behaviour seen in certification trials). Consequently, the modelling of actual behaviour and events during aircraft accidents is far more challenging than the simulation of certification trials. It also means that the collection of data describing and quantifying this behaviour is also much more challenging - unlike 90-second certification trials and experiments, in aircraft accidents there are no cameras positioned to record proceedings!

Given the fact that the 90-second certification trial is not an accurate measure of evacuation performance during real emergency evacuations it is necessary to identify potential sources of data describing and quantifying behaviour in real emergency evacuations.

A source of information concerning human behaviour in aircraft accidents is provided through aircraft accident human factors reports produced by organisations such as the NTSB of the USA and AAIB of the UK. These reports contain a wealth of information in the form of interviews with survivors (crew and passengers). Without strong evidence to support the development of general behaviours we are in danger of relying on a combination of, intuition based on an incomplete knowledge of past accidents, recorded experiences from 90 second certification trials, full-scale experimentation and possibly worst of all, mythology. By mythology we mean the common practice of accepting a behaviour to be generally true, when there is little or no convincing evidence to support this belief.

Needless to say, in developing evacuation models capable of simulating real accidents, it is vital to understand the phenomena that is to be modelled. One of the first systematic studies at piecing this information together was undertaken in 1970 by Snow et al in which they analysed four air accidents to highlight common factors that influence survival. This paper concluded that configuration, procedures, the environment and passenger behaviour were vital in understanding survival. This work was the first attempt at building an empirical understanding of the dynamics of real emergency evacuations, and is an approach that is widely used today.

To date there have been two detailed studies into human behaviour over a range of accidents, one, an on-going study by FSEG of the UK known as the AASK (Section 2.1.3.3) database and another by the NTSB of the USA covering a number of recent accidents and precautionary evacuations.

The information available in these studies is based on air accident investigation reports and the passenger and crew testimonies that they contain. This data tends to take the form of anecdotal evidence, sometimes with third party corroboration. Using this data insight into the behaviour of passengers and crew during real emergency evacuations can be gained and appropriate behaviours and/or modifications to existing behaviours made within evacuation models. Thus, a model that is more realistic to real emergency evacuation can be developed.

#### 2.1.3.3 The AASK database

The AASK database has been developed by FSEG of the University of Greenwich with financial support from the UK CAA. The AASK database is a repository of survivor accounts from aviation accidents. Its main purpose is to store observational and anecdotal data from the actual interviews of the occupants involved in aircraft accidents. With support from the UK CAA, the AASK concept has evolved into an on-line prototype system available over the internet to selected users.

Security of the database is maintained at a number of different levels with passwords for the software and control of machine access. Those interested in using AASK may register at the site http://fseg.gre.ac.uk/aask/index.html.

AASK V3.0 consists of five main components ,

- User Interface,
- Data Entry interface,
- Data Viewer,
- Data Query interface, and
- Seat Plan Viewer.

Data contained within AASK V3.0 consists of information derived from both passenger and cabin crew interviews, information concerning fatalities and basic accident details. The cabin crew component has become a significant aspect of the database providing insight into cabin conditions and passenger behaviour as seen from professionally trained cabin specialists. The fatalities component holds data for all fatalities documented in the accident reports while the Seat Plan Viewer graphically displays the starting locations of all the passengers – both survivors and fatalities - as well as the exits used by the survivors.

Data entered into the AASK database was extracted from the transcripts supplied by the Air Accident Investigation Branch in the UK and the National Transportation Safety Board in the US. Data imported into AASK V3.0 comprises information from accidents that occurred between 4/4/77 and 8/3/98. This consists of:

- 55 accidents,
- 1295 individual passenger records from survivors,
- 110 records referring to cabin crew interview transcripts, and
- 329 records of fatalities (passenger and crew).

The AASK database provides a versatile aid in the analysis of human experience in aircraft evacuations. While much data exists for input to the database, the data is limited in scope in that the qualitative aspects of the data far outweigh the quantitative. As such, conclusions drawn from the database must be treated with caution and with full knowledge of the implications of the questions posed and the nature of the data used to provide the responses.

- AASK has been used as a development tool for the airEXODUS evacuation model. It is being used to highlight the type of behaviours that should be included within models aimed at simulating real accident scenarios.

#### 2.1.3.4 The NTSB Accident Survey

The NTSB has completed a data collection exercise from September 1997 to June 1999 involving 46 evacuations, 2,651 passengers and 18 different types of aircraft.

The study examined a range of evacuation aspects. Evacuees (passengers and crew) were surveyed in order to ascertain their views on the evacuations and to answer specific

questions concerning the evacuation performance. The study investigated the following issues concerning exits and evacuation issues in general: access to the exits, emergency lighting, Type III over wing exits, exit row passenger tasks, flight crew member exit assignment, evacuation slides, exit height from the ground. In addition evacuation procedures were examined specifically those for planned evacuations, exit selection, slide commands, aircraft familiarisation, and guidance on when to evacuate. Finally the report examined communication issues between crew members and passengers
This report contains some useful data for evacuation modellers. Firstly, information concerning the nature of probable types of evacuation scenario is presented. Data of this kind is essential in developing a holistic approach to certification, i.e. one that takes a performance-based approach considering the evacuation performance of the aircraft under representative scenarios.

Secondly, the report contains useful qualitative data on evacuations. For example, of those passengers that carried baggage onto the aircraft, nearly 50% of passengers reported attempting to evacuate with at least one item of their luggage. This is quite significant as some 66% of the interviewed cabin crew cited carry-on luggage as an obstruction and 37% of passengers thought that carry-on luggage slowed their evacuation. During 90-second certification trials passengers have no carry-on luggage although some luggage is distributed within the cabin to simulate accident debris.

#### 2.1.3.5 Current Data Requirements

As has already been described, the nature of the intended simulation, i.e. certification or accident simulation, determines the quantity and quality of data required to perform the simulation. While there is a large amount of data available from certification trials and controlled experiments there are still gaps in these data sets that need to be addressed.

One of the most significant components of evacuation models concerns the manner in which the model represents the exiting process. To simulate this accurately requires data, either from certification trials or from experiments. The trial data best represents the conditions found in certification trials while experimental data has the potential to represent conditions found in real emergency evacuations through the use of the competitive evacuation experimental protocols. From the study of video footage of these trials or experiments it is possible to extract passenger exit hesitation time distributions and exit flow rates that can be used by the model developers to define the passenger performance at the various exits.

Other exit type/assertiveness categories are also not represented within the FSEG database. Namely, any data for Type C or Type B exits as defined by amendment FAR807 25-88. Those exits of Type B dimensions, Type C dimensions and Type I dimensions all with unassertive cabin crew members. Also, data for floor level exits without slides is lacking from the database.

Certainly, data can and should be made available to the research community and extracted from future certification trials to help fill the data shortfall however, there are unlikely to be sufficient certification trials to completely satisfy this requirement. Targeted manufacturer component testing offers a possible way to plug the data gap. However, to be valid, this testing must be done under strict certification conditions.

Other data that would be useful for certification analysis includes, passenger flow rates in aisles for different seating configurations, slide times, flow rates from specific passageway and cross aisle configurations, flow rates from evacuations in which cabin crew members impede flow through the exit.

For accident analysis, there is a wide array of data that requires a systematic collection strategy. The collection of this data differs from that of certification data as the experiments can be undertaken using competitive behaviour protocols that attempt to simulate accident conditions. It must be emphasised that such data should be collected for both wide and narrow body aircraft configurations. This data includes passenger exit hesitation times for different exit and crew assertiveness combinations, exit flow rate data, passenger aisle movement rates for different cabin orientations, passenger movement rates on staircases for different cabin orientations, passenger aisle/staircase movement rates in smoke for different cabin orientations, impact of cabin luggage on evacuation efficiency, frequency of aisle swapping, passenger instigated redirection to alternative exits, etc.

Furthermore, it would be a valuable exercise to compare passenger exit hesitation time data collected from certification trails with the equivalent data collected from competitive evacuation trials. Some have assumed that this data may be significantly different however, until a detailed systematic analysis is undertaken this will not be known for certain. It is the belief of the authors that there are unlikely to be significant differences in this data, especially for situations involving assertive crew. If this were shown to be true, this would be a tremendous advantage, as it would justify the use of certification data in accident analysis and vice versa.

Existing data from experimental studies performed by the Civil Aerospace Medical Institute (CAMI) in Oklahoma City and Cranfield University may help to bridge some of the data gap. Unfortunately, the data that has been published in the literature is not presented in an appropriate form for integration into evacuation models. Typically, published literature summarises qualitative features, perhaps providing an overall measure of performance such as a flow rate or an average time for a specific action. Data in this form is not usually sufficient to satisfy the requirements of model developers. For example, data in the form of distributions of measured quantities would be more valuable. Where appropriate, this data should be re-analysed and presented in a form that will satisfy the model developers. Ideally, in future, when new experiments are undertaken the needs of the model developers should be considered in order to gain the maximum benefit from the experiment.

Cabin crew play a vital role in managing the evacuation process. As such, their behaviour and influence should be included within evacuation models. Analysis of video recordings from 90-second certification trials and transcripts of interviews with cabin crew following accidents has provided insight into this interaction and allowed complex models to be developed. However, more information is required to improve these models, in particular in real accident situations. Analysis of evidence from accidents involving dense irritant smoke suggests that the effectiveness of cabin crew at redirecting is severely reduced in real emergency evacuations. Research at FSEG using the AASK database is attempting to determine the significance of the qualitative differences in cabin crew effectiveness between real emergency evacuations and 90-second certification trial. While this is useful, quantitative data is required. This can only be achieved through controlled full-scale experimentation. Such a study could provide useful data for both evacuation models and safety regulators.

Numerous studies have shown that exit hesitation time data is dependent on passenger physical characteristics of age, gender and size. If sufficient data were collected it would be possible to specify the exit hesitation time distribution not as simply a probability distribution but as a probability distribution dependent on these physical attributes. This would require considerably more data then currently exists and a concerted effort between the various experimental facilities to co-operate in the generation of such data.

Finally, with the exception of anecdotal data from accident investigations, very little data is available concerning passenger/crew performance in evacuation situations involving ditching or situations involving cabin ruptures. Experimental data relating to these types of incidents could be collected and used in evacuation models.

#### 2.1.3.6 Future Data Requirements for VLTA and BWB aircraft

Very Large Transport Aircraft (VLTA) pose considerable challenges to designers, operators and certification authorities. VLTA designs currently being considered are capable of carrying 800+ passengers with interiors consisting of two aisles and two full-length passenger decks. Other more radical concepts consist of a Blended Wing Body (BWB) design, involving one or two decks with possibly four or more aisles. The drive for increased efficiency, passenger capacity and aircraft size is balanced by the need to maintain, and if possible, improve current safety standards. One of the highest safety priorities for aircraft designers and regulators alike concerns the evacuation efficiency of aircraft design. Questions concerning seating arrangement, nature and design of recreational space, the number, design and location of internal staircases, the number, location and type of exits, the number of cabin crew required and the nature of the cabin crew emergency procedures are just some of the issues that need to be addressed. Computer models offer a means of addressing these issues but only if the data requirements of these models can be met.

The massive increase in passenger capacity and aircraft size being suggested also challenge some of our preconceptions in equipment design and crew emergency procedures. For instance, in order to efficiently complete an evacuation, will it be necessary to extend emergency procedures to the marshalling of those passengers evacuated to the ground? Imagine a situation with 800 passengers on the ground, possibly on one side of the aircraft. What impact will they have on fire fighting and rescue operations? Who should take responsibility for the grounded passengers? Should evacuation procedures be developed that allow passengers to travel between decks before exiting the aircraft? How will crew communicate effectively to control such an evacuation on a single deck and between decks? Will the proximity of multiple emergency slides have a detrimental effect on evacuation efficiency and safety? Can exits be safely spaced further apart than the current arbitrary 60 foot limit? What impact will this have on evacuation times and survivability?

If BWB aircraft become a reality, should designs incorporate continuous solid cabin partitions along the length of the aircraft? Should these cabins have cross aisles linking each cabin section? Will it be sufficient to simply have exits in the forward and aft sections of the aircraft? Can the largest exits currently available cope with passenger flow arising from four or five main aisles? Do we need to consider new concepts in exit design, perhaps introducing three or four lane exits? How efficient can a three or four lane exit be in evacuating passengers? Should the main aisles be made wider to accommodate more passengers? How much time is actually required for safe egress from a BWB aircraft? Does the 90-seconds evacuation concept have any relevance to VLTA and BWB aircraft?

While there are currently no VLTA flying, the A380 has been labelled a VLTA by some. The A380, while physically the largest passenger aircraft currently planned does not represent a massive increase in passenger capacity, at least for its standard configuration. The standard passenger seating capacity of the A380 is reported to be 550 passengers in a three class configuration however, significantly greater seating capacity options are possible, with 822 passengers being suggested for the single class configuration. This is compared with the B747-400 that carries 416 in a three-class configuration with a reported maximum of 660 for the single class configuration. Another feature of the A380 is that it has two passenger decks positioned one on top of the other. This in itself is not unusual or novel as the B747 has flown with an upper deck for many years. While it may be debated whether the new A380 should be classified as a VLTA, the number of passengers that are seated on the upper deck make the A380 different to existing aircraft.

With the upper deck comes the need to evacuate passengers using the upper deck exits and slides. A feature of upper deck exits is that the exit slides are much longer than those of more ‘standard’ exits. For example, on the B747 the upper deck sill height is 7.8 metres and on the A380 it is set to be 8.1 metres above the ground . One assumption concerning the use of high sill height exits is that passengers would hesitate longer at the upper deck exit before they jumped onto the slide compared to lower height main deck exits. While there is very little data concerning the use of upper deck slides under certification evacuation conditions, what data that is available suggests that this is not the case, and that passenger exit hesitation delays while slightly longer are similar to those of more standard exits. Clearly, more research in the form of component testing is required to generate the required data.

In addition to higher sill heights, longer exit slides and large numbers of passengers located on upper decks, VLTA double deck aircraft can possess one or more staircases. Again, in itself this is not a new concept as the B747 has flown for many years with a staircase connecting the two decks. While evacuation procedures for VLTA may not require the use of the staircase(s) in order to pass an evacuation certification trial, it is desirable that staircase design be appropriate for evacuation situations. Emergency evacuation scenarios may develop where it is necessary or desirable to evacuate all or some passengers down the stairs and out the main deck exits rather than out the upper deck exits. While less likely, accident situations may also develop where it is necessary to move some passengers to the upper deck and out the upper exits. While this may not be a problem for existing aircraft, the sheer number of passengers located on the upper deck of VLTA configurations makes this an issue worth investigating.

Currently, aviation regulations are generally silent on the issue of staircase design. This omission could lead to the development of sub-optimal conditions during an evacuation should the staircase be needed as a means of escape. As an example, the height of a stair riser and the depth of a stair tread are known to be important factors in determining the ease of use and efficiency of staircase design. Additionally, the requirement for handrails that separate a wide staircase into lanes has long been recognised as essential in building and marine regulations. It is recognised that central handrails enable passengers to use the entire width of the staircase during an emergency evacuation as opposed to ‘hugging’ the walls close to the outer handrails. Handrails are mandatory in building codes as they provide support to occupants and serve as guides for people whose vision may be impaired due to smoke and/or lighting failure. In addition, within building codes it is recognised that to be effective the handrails must be within reach of staircase users. On board marine vessels the requirement for handrails is of even more importance as marine vessels are subject to dynamic and static changes in pitch and roll. Similar situations could develop on aircraft that have crashed and have gear failure.

As previously mentioned, aircraft staircase design has been studied in previous research undertaken by the FAA Civil Aero Medical Institute (CAMI) in 1978. The staircases that were investigated were very narrow having an effective width of 20 inches. As such the passengers evacuated in single file and used the handrails extensively. Unfortunately, the staircase width used in these experiments is simply not relevant for staircases that are expected to accommodate two or more passengers simultaneously

#### 2.1.3.7 The use of Evacuation Models for Certification Applications

Before computer models can reliably be used for certification applications they must undergo a range of validation demonstrations. While validation will never prove a model correct, confidence in the models predictive capabilities will be improved the more often it is shown to produce reliable predictions.

The success of at least some aircraft evacuation models in predicting the outcome of previous 90-second certification trials are compelling arguments of the suitability of these models for evacuation certification applications - at least for derivative aircraft. For aircraft involving truly 'new' features it is expected that evacuation models in conjunction with component testing of the new feature will be necessary.

However, it is not sufficient to simply replace full-scale testing of aircraft with a combination of computer modelling and component testing. While this may make testing the aircraft a safer and more efficient process, can we also make the aircraft itself safer by design? If we are to rise to this challenge it is essential that we begin to question some of our current preconceptions concerning certification.

Evacuation models have the capability of examining many different types of evacuation scenario. What scenario should be considered for certification by computer model? Should the current certification scenario be maintained or should a range of scenarios be considered? Perhaps a selection of the most likely evacuation scenarios should be considered or simply the most severe likely evacuation scenario? The selection of suitable evacuation scenarios could be guided through analysis of past accident data.

Furthermore, unlike full-scale testing, evacuation models allow the possibility of performing many repeat simulations for any particular scenario thereby producing a range of results for any given scenario or collection of scenarios. Indeed, it may even be argued that rather than simply testing a single interior layout configuration, each layout flown by a carrier should be tested by computer simulation.

Regardless of the accident scenario selected for certification testing, how do we determine that an aircraft has met the pass/fail criteria, how do we establish the "deemed to satisfy" requirement? For a particular scenario should the requirement stipulate that ***every*** simulation be sub-90 seconds? Or should the distribution mean or the 95 percentile result be sub-90 seconds? In the hypothetical example discussed in section 2.2, 950 of the 1000 simulations (i.e. 95%) produced an evacuation time less than 90 seconds. Should this aircraft configuration be deemed to pass or fail the certification criteria?

An interesting example of this dilemma was shown during an airEXODUS validation exercise. In this example, one of aircraft achieved an actual certification performance of 83.7 seconds with a mean airEXODUS predicted evacuation time of 82.7 seconds. While these times represent the out-of-aircraft time for the passengers, the actual certification on-ground time for the passengers and crew was such that the aircraft clearly passed the certification requirement. However, the airEXODUS analysis suggested that of the 1000 simulations, three or 0.3% are predicted to marginally fail the certification requirement. If the mean rule (i.e. 50% less than 90 seconds) or the 95% rule were adopted the aircraft would clearly satisfy these requirements and be considered acceptable. However, if the 100% requirement were adopted the aircraft would not be considered acceptable. As this aircraft is considered to be acceptable (on the basis of the single actual certification trial result) perhaps the deemed to satisfy limit should be placed at 0.3%? If this general approach were considered viable, it would require all of the past aircraft that have undergone the certification process to be assessed using computer simulation and a suitable acceptance level derived from this analysis.

Any aircraft configuration will produce a range of evacuation times over a number of tests, some of which may well be over the 90 seconds. Under the current 'make or break' single test regime, a single performance result is selected from this 'unknown' distribution of possible evacuation times and put forward as the certification performance. The aircraft will pass as long as the result is below the 90 second threshold. It is impossible to know whether or not the outcome is a fair reflection of the aircraft's evacuation capability. In contrast, the

multiple tests enabled by computer simulation generate a distribution of times, reflecting what would happen if the full-scale evacuation could be repeated. It has been argued by some that to achieve parity with the current certification process, 100% of the generated simulations should produce times less than 90 seconds to pass
For those who wish to achieve some form of parity with the current certification process, an alternative approach may be to generate only a single evacuation time from the modelling analysis. As part of this methodology it would still be necessary to first generate the evacuation time distribution using many repeat simulations. This would generate the probability space of possible evacuation times for the aircraft configuration under the selected certification scenario. From this probability distribution a single evacuation time would be selected at random and deemed to be the certification performance of the aircraft. This in essence is equivalent to the current practice of performing only a single trial for certification. Using this approach, the same acceptance criteria could be applied to the numerically generated certification time as that applied to the full-scale trial generated certification time. In this way, the modelling process would replicate the current certification process where only a single evacuation time is put forward and so provides a means to circumvent the need to re-define acceptable performance. However, a significant downside of this methodology is that a considerable amount of potentially useful information regarding the performance of the aircraft is disregarded. Rather than attempting to achieve parity with the current standard the industry should be endeavouring to produce a more meaningful measure of aircraft evacuation performance.

This raises the question - does the “magic number” 90 seconds for the certification demonstration test have any actual meaning under these circumstances? Internationally, throughout the building industry, similar issues are being addressed through the replacement of the old prescriptive building requirements with performance based regulations. Prescriptive building regulations the world over suggest that if we follow a particular set of essentially configurational regulations concerning travel distances, number of exits, exit widths, etc it should be possible to evacuate a building within a pre-defined acceptable amount of time. In the U.K. for public buildings this turns out to be the “magic number” 2.5 minutes. Part of the risk analysis process involves the concept of the Available Safe Egress Time or ASET and Required Safe Egress Time or RSET. For a particular application the ASET may be based on the time required for the smoke layer to descend to head height while the RSET may be the time required for the occupants to vacate the structure. Put simply, the ASET must be greater than the RSET. The circumstances of the scenario under consideration dictate both the ASET and RSET and several scenarios may need to be examined before any conclusions can be reached. As part of this risk analysis process credible fire scenarios (including fire loads, fire evolution, fire size etc) are postulated along with credible evacuation scenarios (including number and type of people, occupant response characteristics, etc). Computer based evacuation and fire models are being used to assist in the determination of both the ASET and the RSET. In this way evacuation models are providing a means by which the complex interacting system of structure/environment/population can be assessed under challenging design scenarios.

Recently in the marine industry a half way house approach has been adopted. Rather than use the building industries ASET/RSET approach, IMO have adopted as draft guidelines a methodology where the ASET is set by a prescriptive limit, similar in concept to the 90 second “magic number” used in the aviation industry while the RSET can be determined by computer simulation. To determine the RSET the submitted design is subjected to four benchmark scenarios each evaluated by computer simulation. The precise nature of the benchmark scenarios are prescribed in a similar way to the current 90 second certification trial. The ship design must pass all four benchmark scenarios in order to be deemed to satisfy the requirement. Furthermore, IMO have acknowledged that a distribution of evacuation times will be produced for any single evacuation scenario. As a result, they have adopted the 95% rule described above.

A similar approach to either the building or maritime industries should be considered for aviation.

Other disciplines such as the building and maritime industries accept computer based simulations as part of the certification process. As indicated, these have adopted a common approach to the validation and verification of evacuation models that could easily be adapted for aviation applications. Furthermore, in the marine industry, specific documentation is required to be submitted along with the simulation results. This documentation is intended to demonstrate the credibility and appropriateness of the approach adopted and furthermore allow easy verification and reproduction of the submitted results. These requirements include the specification of:

- the variables used in the model to describe the dynamics, e.g. walking speed of each person;
- the functional relation between the parameters and the variables;
- the type of update used within the model;
- the representation of stairs, doors, … and other special geometrical elements and their influence on the variables during the simulation and the respective parameters quantifying this influence;
- a detailed user guide/manual specifying the nature of the model and its assumptions and guidelines for the correct use of the model and interpretation of results should be readily available.

Certification analysis performed for the aviation industry using computer simulation should require a similar level of documentation.

## 2.2 Investigating VLTA evacuation issues using the airEXODUS Evacuation Model

### 2.2.1 Introduction

Very Large Transport Aircraft pose considerable challenges to designers, operators and certification authorities. VLTA designs currently being considered are capable of carrying 800+ passengers with interiors consisting of two aisles and two full-length passenger decks. The drive for increased efficiency, passenger capacity and aircraft size is balanced by the need to maintain, and if possible, improve current safety standards. One of the highest safety priorities for aircraft designers and regulators alike concerns the evacuation efficiency of aircraft design. Questions concerning seating arrangement, nature and design of recreational space, the number, design and location of internal staircases, the number, location and type of exits, the number of cabin crew required and the nature of the cabin crew emergency procedures are just some of the issues that need to be addressed.

Quite apart from questions of emergency evacuation, issues concerning the appropriateness of VLTA designs in allowing the rapid and efficient movement of passengers during boarding and disembarkation are an additional essential design consideration. Furthermore, these requirements may potentially conflict with the requirements for emergency egress. Ultimately, the practical limits on passenger capacity are not based on technological constraints concerned with aircraft aerodynamics but on the ability to evacuate the entire complement of passengers within agreed safety limits.

Computer based aircraft evacuation models – together with reliable data - have the potential to address all of these issues and provide manufacturers, operators and regulators a means of assessing novel designs, procedures and accident scenarios associated with VLTA. In a previous publication, the authors demonstrated how aircraft evacuation models could be used to investigate the rationale behind existing prescriptive rules associated with exit separation, the so-called 60-foot rule.

### 2.2.2 VLTA configuration Issues examined using airEXODUS

Here we demonstrate how evacuation models may be used to examine configuration issues associated with VLTA. Several scenarios will be considered, namely the use of all exits on both decks, the use of half the normally available exits as in a certification demonstration trial and the use of all the exits on the main deck. The last case will require the upper deck passengers to make use of the main staircase during the evacuation.

To demonstrate the use of airEXODUS a hypothetical VLTA was designed by the authors. The aircraft – designated the UOGXXX - has two decks and a capacity of 580 passengers in a three-class configuration. The upper deck seats 236 passengers in first and business class while the lower deck seats 344 passengers in first and economy class (see Figure ).

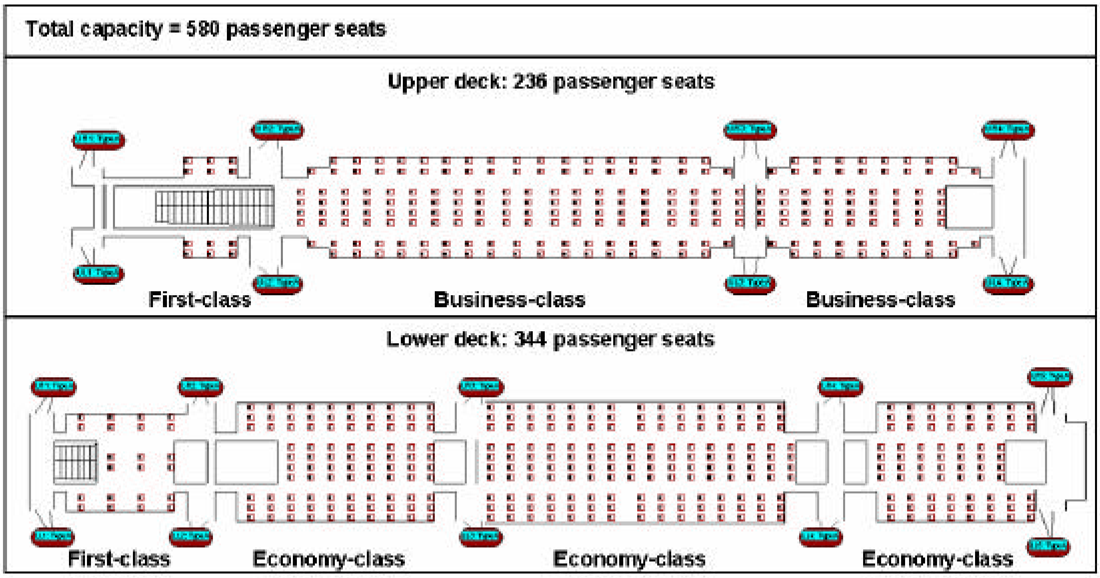


**Figure 2.2: A schematic of the UOGXXX VLTA**

The UOGXXX has nine pairs of Type A exits, four on the upper deck and five on the lower deck. This is in excess of the six exit pairs that would be required to simply cater for the number of passengers. The larger number of exits result from other regulations that dictate that exits are required at each end of the cabin section and that the distance between any exit pair was not in excess of 60ft. Furthermore, the authors wished to avoid overwing upper deck exits and mixing different exit types. A schematic of the aircraft design is shown as Figure 2.2 .

A staircase was positioned towards the front of the aircraft so as to assist in the expeditious boarding and disembarking of passengers. Other considerations included the desire not to split a class, maintaining a three-class layout and causing minimal disruption to the first class passengers. The staircase was sufficiently wide to accommodate two passengers side by side separated by a central handrail. The staircase has dimensions typical of that found in buildings. Within airEXODUS, the behaviour of the passengers on the staircase is based on that found in buildings, where the speed of passengers is dependent on the age and gender of the passenger and whether they are travelling up or down the stair.

### 2.2.3 Population Specification

The population complies with JAR requirements for certification testing. Passengers defined in airEXODUS are created using the 90-second Population function available in the software.

This function generates the required numbers of passengers according to the specified mix (in terms of age and gender) as set out in JAR.

**Table 2.1: Core attribute ranges for the 90-second populations used in airEXODUS simulations**

| Group | Attribute | Min | Max |
|---|---|---|---|
| Males 18-50 | Drive | 10.0 | 15.00 |
| | Walk (m/s) | 0.5 | 0.60 |
| | Fast Walk (m/s) | 1.0 | 1.2 |
| | Stair Up (m/s) | 0.63 | 0.63 |
| | Stair Down (m/s) | 0.86 | 0.86 |
| | Response Time (s) | 0.0 | 5.0 |
| Males 50-60 | Drive | 6.0 | 12.0 |
| | Walk (m/s) | 0.35 | 0.55 |
| | Fast Walk (m/s) | 0.70 | 1.10 |
| | Stair Up (m/s) | 0.51 | 0.51 |
| | Stair Down (m/s) | 0.67 | 0.67 |
| | Response Time (s) | 4.00 | 7.00 |
| Females 18-50 | Drive | 5.00 | 13.00 |
| | Walk (m/s) | 0.45 | 0.60 |
| | Fast Walk (m/s) | 0.90 | 1.20 |
| | Stair Up (m/s) | 0.59 | 0.59 |
| | Stair Down (m/s) | 0.67 | 0.67 |
| | Response Time (s) | 0.00 | 6.00 |
| Females 50-60 | Drive | 5.00 | 8.00 |
| | Walk (m/s) | 0.25 | 0.45 |
| | Fast Walk (m/s) | 0.50 | 0.90 |
| | Stair Up (m/s) | 0.49 | 0.49 |
| | Stair Down (m/s) | 0.60 | 0.60 |
| | Response Time (s) | 5.00 | 8.00 |

**Table 2.2 : Core passenger attribute ranges used in simulations presented in this report**

| Attribute | Min | Max | Mean |
|---|---|---|---|
| Drive | 1.19 | 14.99 | 9.82 |
| Walk (m/s) | 0.26 | 0.60 | 0.49 |
| Fast Walk (m/s) | 0.52 | 1.20 | 0.99 |
| Stair Up (m/s) | 0.49 | 0.63 | 0.57 |
| Stair Down (m/s) | 0.60 | 0.86 | 0.73 |
| Response Time (s) | 0.02 | 8.00 | 3.93 |

Table 2.3: Core passenger attributes

In airEXODUS, simply specifying the age and gender of each passenger is not sufficient. Each person has 21 defining attributes, each of which must be assigned a value. The population tools in airEXODUS allow a range for each attribute to be specified, so that when a person is created, each attribute is assigned a random value between the limits set. The 90-second Population consists of four population groups: Males aged 18-50, Males aged 50-60, Females aged 18-50 and Females aged 50-60. The core parameters for these groups are distributed as indicated in Table 2.1. In addition the Patience attribute was set at a very large value for all the simulations in order to model a compliant (non-competitive) population. Passengers when attributed with infinite patience will always wait patiently in queues whilst moving religiously towards their nearest exit. Listed in Table 2.2 is the range of core attributes generated for the passenger populations.

### 2.2.4 Relevant airEXODUS parameters

Several airEXODUS parameters will be presented within this study. These are; Personal Elapsed Time (PET), Total Evacuation Time (TET), Cumulative Wait Time (CWT), Exit Flow Rates, Distance and OPS.

The TET is a measure of the evacuation time for the aircraft. It is measured from the start of the evacuation to when the last passenger exits the aircraft. A single TET is determined for each evacuation simulation. Perhaps of more interest to an individual passenger is the PET. The PET is a measure of an individual's evacuation time. It is measured from the start of the evacuation to when the passenger has exited the aircraft. A PET is determined for each passenger in the evacuation simulation. The Response Time is the time a passenger takes to respond to the call to evacuate, release their seat restraint and stand. A Distance parameter is calculated for each passenger. The Distance parameter records the total distance that each passenger had to travel during the evacuation.

The CWT measures the total amount of time a passenger has spent in congestion. This is measured after the passenger has completed their Response Time, i.e. unbuckled seat belts and stood up, to when the passenger has exited the aircraft. This can include time spent in the seat row attempting to get into the aisle, time spent stationary in the aisle and time spent queuing at the exit. A CWT is determined for each passenger in the evacuation simulation.

The exit flow rate measure gives an indication of the performance of exits during an evacuation. It can be calculated for each exit by dividing the number of passengers that used the exit by the duration of the flow. An exit flow rate represents an *average* flow rate for the entire duration of passenger flow.

As a measure of optimal performance FSEG have developed a statistic known as the OPS or Optimal Performance Statistic. The OPS measure has been described in detail in previous papers. The OPS can be calculated for each evacuation, providing a measure of the degree of performance. The OPS is defined as follows:

$$OPS = \frac{\sum_{i=1}^{n} TET - EET_i}{(n-1) * TET}$$

**Equation 2.1**

***n*** = number of exits used in the evacuation,

$\boldsymbol{EET_n}$ = Exit Evacuation Time (time last pax out) of Exit ***n*** (seconds),

***TET*** = Total Evacuation Time (seconds) i.e. max[***EET***].

While it is unlikely that an aircraft will achieve an OPS = 0, near optimal performance will be marked by very low values of OPS. Selecting an acceptable value for OPS is somewhat arbitrary. For the purposes of this report we will consider OPS values of 0.1 or less as being optimal.

The Off-Time (for Type-A exits) is the time required for the passenger to reach the ground once they have mounted the slide. Like the passenger Exit Delay Time, this is derived from certification data. However, in the present study, this is ignored. Thus the evacuation times represent the time out of the aircraft, not the on-ground times. If on-ground times are desired, a suitable slide time can be added to the TET.

### 2.2.5 Defining airEXODUS scenarios

All of the modelled scenarios that are presented within the study were simulated under 90-second certification trial conditions and are thus representative of controlled physical experiments involving real passengers. Only one scenario is detailed in this Paper as an example, however the other scenarios are recorded in the individual work-package reports. Whilst airEXODUS has the capability of modelling more extreme behaviours of the type witnessed in real emergency evacuations they will not be activated in these scenarios. In addition, in all the cases examined the "off-times" have not been included. To find the on-ground time it is necessary to add an appropriate slide time.

The scenarios considered in this section examine different combinations of exit availability and the impact that they have upon total evacuation time, exit flow rates and travel distances. In addition, the type of cabin crew member communication and procedures necessary to ensure an optimal evacuation are examined.

In total four main scenarios were considered. Scenario 1 investigated a precautionary evacuation in which all of the exits on the aircraft were available for use during the evacuation. This scenario provided an indication of the best possible evacuation time for the proposed aircraft design.

Scenario 2 investigates the standard 90-seconds scenario, in which only one side of the aircraft's exits are available for evacuation. This case provides an indication of how the UOGXXX will perform in a standard 90-second certification trial.

Scenario 3 represents a variation of the precautionary evacuation in which all passengers use the main deck exits. Thus passengers and crew from the upper deck are required to descend the staircase that joins the two decks. Two variations of this scenario, 3b and 3c are also investigated in which cabin crew attempt to optimise the evacuation. Scenario 3d investigates the impact that widening the main staircase has on the performance of the evacuation, while scenario 3e considers moving the location of the staircase. The final scenario investigates the repercussions of sending some passengers from the lower deck to the upper deck.

**Table 2.3: Summary of exit availability in each of the four scenarios**

| | Type-A exit pair availability | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Upper 1** | **Upper 2** | **Upper 3** | **Upper 4** | **Lower 1** | **Lower 2** | **Lower 3** | **Lower 4** | **Lower 5** |
| **Scenario 1** | Left + Right | Left + Right | Left + Right | Left + Right | Left + Right | Left + Right | Left + Right | Left + Right | Left + Right |
| **Scenario 2** | Right Only | Right Only | Right Only | Right Only | Right Only | Right Only | Right Only | Right Only | Right Only |
| **Scenario 3a** | None | None | None | None | Left + Right | Left + Right | Left + Right | Left + Right | Left + Right |
| **Scenario 3b** | As 3a with intelligent ACCM at the base of the stairs | | | | | | | | |
| **Scenario 3c** | As 3a with crew alternating redirection at base of the stairs | | | | | | | | |
| **Scenario 3d** | As 3b and 3c with increased stair width | | | | | | | | |
| **Scenario 3e** | As 3d with relocation of stair case | | | | | | | | |
| **Scenario 4a** | None | None | Left + Right | Left + Right | None | None | None | Left + Right | Left + Right |
| **Scenario 4b** | As 4a with partial movement between decks controlled by ACCM on the lower deck | | | | | | | | |

Finally, airEXODUS is stochastic in nature. This means that every time a simulation is repeated a slightly different evacuation time will result, as the individual passengers and crew members are unlikely to exactly repeat their actions. In addition, as the passenger Exit Delay Time is randomly attributed according to the specified distribution, passengers will not necessarily incur the same Exit Delay Time on exiting the aircraft in subsequent simulations. For this reason, it is necessary to repeat a simulation numerous times in order to generate a distribution of results (see Figure 2.4). Each simulation case detailed in this paper has been run 1000 times by airEXODUS to capture stochastic variations.

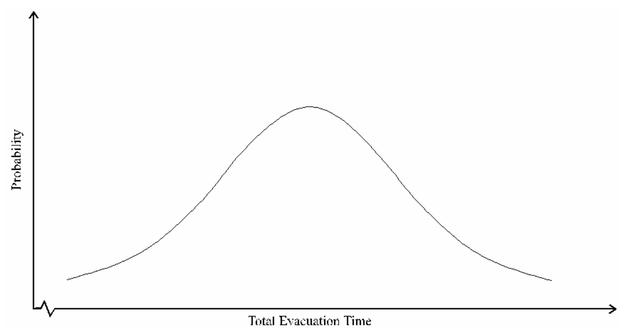


**Figure 2.4: Hypothetical distribution of the total evacuation time for a given structure/population/environment combination**

### 2.2.6 Example -Scenario 1: Precautionary evacuation using all available exits

Scenario 1 simulated a precautionary evacuation in which all of the exits were available. These simulations generated an average total evacuation time of **46.8** [44.5-56.9] seconds, with an average personal evacuation time of **25.0** seconds . In all of the simulations evacuation is achieved in a relatively short amount period of time . Furthermore, all of the simulations that were generated by the model produce evacuation times that are well within the JAR requirement (i.e. 90 seconds).

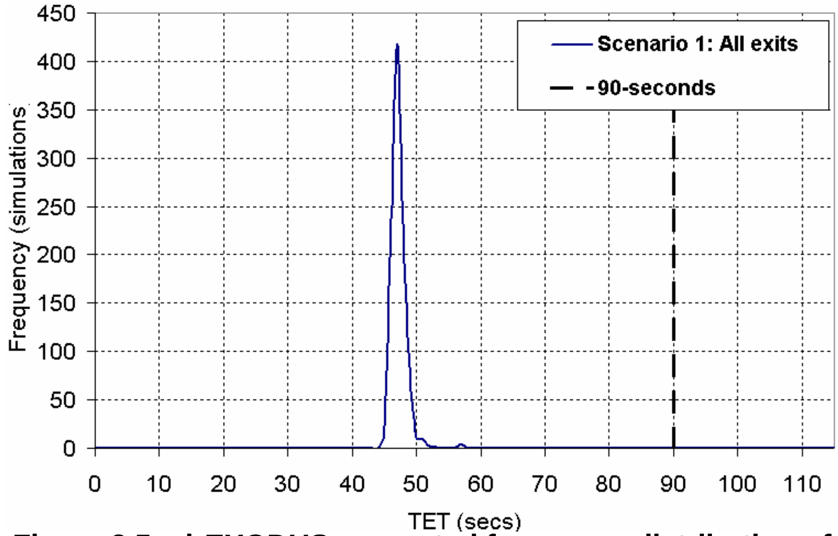


**Figure 2.5: airEXODUS generated frequency distribution of TETs for Scenario 1**

Whilst the final outcome of the evacuation is important, another measure of evacuation is provided by cumulative exit performance. This is a measure of the total number of passengers to exit the aircraft in each second of the evacuation.

In airEXODUS the personal evacuation time (PET) of each passenger is recorded. From this the cumulative number of passengers who have exited the aircraft in each second of the evacuation can be determined. This process can be repeated for each of the repeat simulations. For the series of simulations a simulation envelope can be defined by taking the minimum and maximum number of passengers who have exited the aircraft in each second. For the simulations considered here, each case was repeated 1000 times. The simulation envelope for each scenario represents the minimum and maximum from 1000 simulations. Thus, each of the 1000 repeat simulations will produce a curve that falls within the envelope. In addition, the median of the 1000 airEXODUS simulations is plotted at every second of the simulation.

Initially there is a period during which no passengers evacuate whilst the doors are readied for use. This is typically followed by a short period during which the passenger flow is established. This is marked by the rapid initial increase in gradient at around 14 seconds. Very quickly the exits are at near maximum flow capacity, indicated in Figure 2.6 by a near constant positive gradient. This state persists for the majority of the evacuation. Near the end of the evacuation, when the supply of passengers to exits begins to diminish the gradient begins tail off. The flow terminates when there are no more passengers to evacuate. It is apparent that the majority of passengers evacuate the aircraft in a very short period of time.

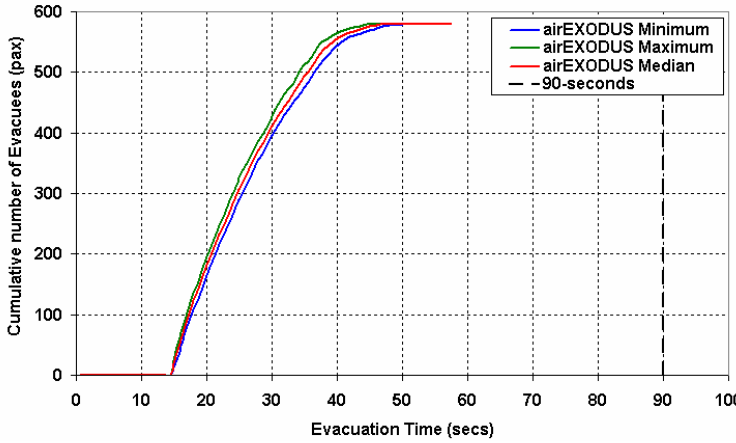


**Figure 2.6: Cumulative number of evacuees as a function of time for scenario one**

Further examination of the data reveals that, on average, a passenger wastes some 46% of their personal evacuation time in congestion. It is apparent that when all of the exits are available the UOGXXX can easily meet the 90-second evacuation requirement. This should come as no surprise, as the number of exits that are installed on the aircraft is well in excess of those required for the population size. The high OPS values indicate that the exit flows did not finish together. This suggests that it is possible to improve the evacuation times still further if a better passenger exit usage could be achieved. In particular the forward exits were under utilised. One way of achieving a better exit utilisation is to have a better passenger distribution between the exits. Another possible solution (at least for the certification case) would be to introduce an active cabin management system that would allow cabin crew to by-pass passengers to the under utilised exits.

**Table 2.4: Summary of results for Scenario 1 (precautionary evacuation using all exits)**

| All Decks | | | | | Upper deck | | | Lower deck | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TET (secs) | CWT (secs) | Dist (m) | PET (secs) | OPS | TET (secs) | Evacuees (pax) | OPS | TET (secs) | Evacuees (pax) | OPS |
| 46.8 [44.5-56.9] | 11.6 [11.3-12.0] | 7.2 [7.1-7.3] | 25.0 [24.6-25.5] | 0.23 [0.18-0.37] | 44.6 [41.3-49.1] | 236 [236] | 0.24 [0.16-0.33] | 46.7 [43.9-56.9] | 344 [344] | 0.22 [0.17-0.37] |

We also note that on average, the upper deck finishes **2.1** seconds ahead of the lower deck. It should be recalled that these times do not include the slide times. While not reported here in detail, it is also interesting to note that the generated exit flow rates of practically all the Type-A exits were below the average performance for Type-A exits under certification conditions [. The lower deck exits were 19% slower while the upper deck exits were 20% slower than expected. This lower than expected exit performance results from the relatively poor passenger supply to the exits which in turn is a result of having both exits in an exit pair operating.
In this scenario the achieved flow rates of the Type-A exits were constrained by the flow rates of the main and cross-aisles that supplied the exits. The cross-aisles were scarcely utilised in this scenario hence the supply of passengers to each exit was reduced. In the case of forward or aft exits and for some mid-section exits (depending on the nature of the cabin splits) passenger flow to the exit was limited as it was fed from a single main aisle. In contrast, in certification evacuation scenarios, only a single exit from an exit pair is available. In these cases both main aisles effectively feed the exit (see Figure 6b), as passengers from the far main aisle make use of the cross aisle to access the exit.

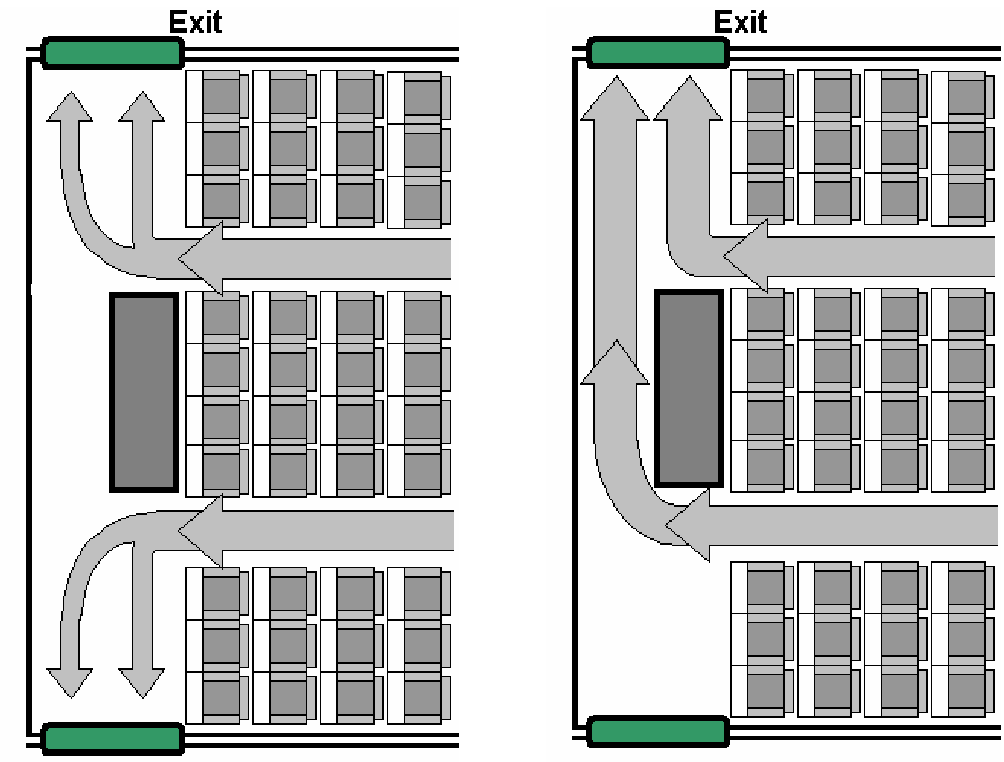


**Figure 2.6: Hypothetical flow pattern at an end of section exit when (a) both exits from exit pairs are available and (b) one exit from and exit pair is available**

In contrast, in certification evacuation scenarios, only a single exit from an exit pair is available. In these cases both main aisles effectively feed the exit , as passengers from the far main aisle make use of the cross aisle to access the exit.
In a balanced evacuation system, the supply of passengers to the exit should be broadly equivalent to the flow rate capability of the exits.   In an ideal situation we should find that:

$$\textit{Discharge (capacity)} \sim \textit{Supply (capacity)} \qquad \textbf{Equation 2.2}$$

If an inequality exists between the supply or the discharge capacities either a bottleneck will develop (discharge < supply) or the exit will be under utilised (discharge > supply).  In the case of Scenario 1, the supply capacity, i.e. the aisle, was less than the exit discharge capacity resulting in the poor exit flow rates achieved.

## 2.3 Simulation for certification

### 2.3.1 Introduction

In this section we suggest a methodology for the application of computer simulation to the certification of aircraft, with particular emphasis to Very Large Transport Aircraft (VLTA). Given the current state-of-the-art in aircraft evacuation modelling, the proposed methodology is reliant on the use of reliable evacuation data in the form of historic certification data and component testing.

The certification performance test is only intended to provide a measure of the performance of the aircraft under an artificial benchmark evacuation scenario.  It is not intended to predict the performance of the aircraft under a realistic accident scenario.  However, it allows the performance of different aircraft to be compared under a set of identical – if somewhat artificial – scenario conditions.

In the certification trial, while passengers are keen to exit as quickly as possible, the behaviour exhibited is essentially co-operative, whereas in real accident situations the behaviour may become competitive. Even if complex issues of fire etc are excluded from consideration, relatively simple issues such as exit selection are far from realistic. Providing all exits on one side of the aircraft bears little or no resemblance to realistic accident scenarios.

On a practical level, as only a single evacuation trial is necessary for certification requirements, there can be limited confidence that the test - whether successful or not - truly represents the evacuation capability of the aircraft. In addition, from a design point of view, a single test does not provide sufficient information to arrange the cabin layout for optimal evacuation efficiency, and does not even necessarily match the types of configuration flown by all the potential carriers.

Modelling real emergency evacuation is far more complex than certification modelling for a number of reasons. Firstly, intrinsic variability in real emergencies leads to a myriad of different possible evacuation scenarios. For example, whereas in one emergency evacuation the aircraft fuselage may expose the cabin interior to a life threatening fire, in another, the cabin may remain intact but passengers may be subjected to a mild threat of smoke. The aircraft could be on its landing gear in one scenario but may have partial failure in another; the aircraft may be partially immersed in water as in the case of a runway overrun, etc. Thus the range of human behaviour that needs to be modelled is far more extensive than that found in the certification scenario.

Furthermore, reliable data on human behaviour and performance under these realistic accident scenarios is more difficult to obtain. There are fewer sources of accurate quantitative information on human performance in emergency evacuation situations. Unlike, 90-second certification trials there are no video recordings of the unfolding evacuation upon which behaviour can be identified and model parameters set. As such information regarding the evacuation is limited to the testimonies of surviving passengers, crew, and rescue workers and data from contrived experimental trials.

For more realistic scenarios involving possible accident situations, there is a wide array of data that requires a systematic collection strategy. The collection of this data differs from that of certification data as the experiments can be undertaken using competitive behaviour protocols that attempt to simulate accident conditions. It must be emphasised that such data should be collected for both wide and narrow body aircraft configurations. This data includes, passenger exit hesitation times for different exit and crew assertiveness combinations, exit flow rate data, passenger aisle movement rates for different cabin orientations, passenger movement rates on staircases for different cabin orientations, passenger aisle/staircase movement rates in smoke for different cabin orientations, impact of cabin luggage on evacuation efficiency, frequency of aisle swapping, passenger instigated redirection to alternative exits, etc. In addition, in the analysis of accident scenarios, passenger cultural differences may be an important factor and so should be examined both in accident analysis, such as through the AASK database and in controlled experiments.

Furthermore, it would be a valuable exercise to compare passenger exit hesitation time data collected from certification trails with the equivalent data collected from competitive evacuation trials. Some have assumed that this data may be significantly different however, until a detailed systematic analysis is undertaken this will not be known for certain. It is the belief of the authors that there are unlikely to be significant differences in this data, especially for situations involving assertive crew. If this were shown to be true, this would be a tremendous advantage, as it would justify the use of certification data in accident analysis.

### 2.3.2 Suggested Certification Methodology

As in the marine and building industries, it is essential that a protocol be developed for the acceptable use of computer simulations for aircraft certification applications. However, it is essential to note that such a methodology is not intended to replace the entire certification process. Existing testing such as slide inflation testing, door opening times, etc would still be required as would compliance with prescriptive rules. The protocol is only intended as an alternative to the current full-scale evacuation demonstration.

Such a protocol should address the following five key issues:

**(i) Model validation and demonstration requirements**

Before a model is used for a certification application it must be demonstrated that the model is capable of simulating the certification test with a specified degree of accuracy. The cases examined in the recent report on the validation of the airEXODUS aircraft evacuation model could form the basis of such validation/demonstration cases.

**(ii) Simulation protocols**

It is necessary to specify the manner in which the simulations are to be run and the nature of the core results must be presented. This should include for instance the number of repeat simulations required, the nature of the data used in the simulations, the nature of the population to be used, etc.

**(iii) The Scenarios to be Investigated**

The number and nature of the scenario(s) to be investigated must be specified. For example, a range of scenarios could be considered which includes the standard 90 second scenario as a base case and additional scenarios drawn from accident analysis

**(iv) The Acceptance Criteria**

Due to the probabilistic nature of the results produced from repeated simulations, it is essential that a rational acceptance criterion be developed. This should be based on meaningful statistical analysis.

**(v) Supporting Documentation.**

The evacuation analysis must be supported by appropriate documentary evidence. This should provide a thorough justification for the analysis presented – covering both the numerical technique and data used - and provide a means of reproducing the analysis in some way.

### 2.3.3 Suggested use of models for certification

In suggesting the use of computer models for aircraft certification we must be mindful of the point made earlier that it is not sufficient to simply replace full-scale testing of aircraft with a combination of computer modelling and component testing. While this may make testing the aircraft a safer and more efficient process, computer modelling should also improve the certification process i.e. provide the aviation community and the passengers that use the aircraft something more than the simple one-off testing provides.

It has also been demonstrated through computer simulation that even though an aircraft may pass a single one-off certification trial, there may be a finite chance that the aircraft will fail to meet the requirements of the certification process if the trial were repeated a number of times. This information is invaluable when attempting to assess the true evacuation performance of the aircraft. It provides insight into the design of the aircraft that can only be practically provided through evacuation simulation.

Thus, computer based aircraft evacuation simulation using the standard evacuation certification scenario has been shown to:

- be capable of reproducing the evacuation performance of aircraft, passengers and crew in full-scale certification trials,
- be a safer and more efficient process than full-scale evacuation trials,
- provide better insight into the actual performance capabilities of the aircraft by generating a performance probability distribution or performance envelope rather than a single datum, and
- be capable of easily and efficiently investigating a range of relevant certification scenarios rather than a single scenario.

These capabilities provide the aviation community (passengers, crew, manufacturers, airlines, regulators) with significantly more than the current simple one-off testing procedure provides and thus should be considered a useful alternative to full-scale testing. Thus as an alternative to full-scale testing, aircraft evacuation models could be used to simulate the performance of the aircraft using the current single certification scenario. The simulations would be run using the outlined methodology and would provide better insight into the actual performance capabilities of the aircraft by generating a performance probability distribution or performance envelope rather than a single datum. If suitable data were not available to perform reliable simulations, than component testing in conjunction with simulations would be necessary to satisfy the certification process. All other prescriptive rules and requirements would still apply, the evacuation simulation simply replacing the final full-scale demonstration. This approach should be considered the first step in the process of introducing computer simulation to aircraft evacuation certification. As confidence in the technique develops, additional, more representative and demanding scenarios could be added to the certification process.

### 2.4 Conclusions from VERRES Work Package 2

As part of VERRES Work Package 2, it has been suggested that evacuation models offer a possible alternative to the current practice of performing a single live evacuation demonstration. While the introduction of computer models for aircraft evacuation will potentially solve some of the existing difficulties and shortcomings posed by current certification testing, it will introduce new questions, pose new challenges and offer new opportunities that need to be addressed. However, by addressing these new challenges we may achieve our goal of producing safer aircraft.

One of these challenges concerns the existence and availability of data. In order to perform reliable simulations, evacuation models are reliant on data. The nature of the intended simulation will dictate the type and quantity of the required data, with accident reconstruction possessing the greatest challenges. For the simulation of the current certification scenario, much data already exists and has been analysed while much more data is available and yet to be analysed. However, more data is required and a concerted effort must be undertaken to collect and analyse the required data. This will require co-operation between manufacturers, regulatory authorities and research groups.

A second challenge concerns the development and adoption of a framework for the application of aircraft evacuation models to the regulatory environment. As in the marine and building industries, it is essential that a suggested protocol be developed for the acceptable use of computer simulations for aircraft certification applications. Until such protocols are in place, it is unlikely that the aviation industry will adopt the use of computer simulation for evacuation certification analysis. An outline of such a protocol has been suggested in this document.

Thirdly, the challenge facing all the stake holders involved in aircraft certification i.e. regulators, approval authorities, accident investigators, manufacturers, airlines, unions, and ultimately the travelling public, is to develop a better understanding of the modelling technology being developed and with that understanding specify relevant design protocols and standards. Here examples from both the building and maritime industries provide useful models upon which to base an aviation strategy. For this to have a proper perspective it is essential that all the stakeholders have a good appreciation of the current certification process and its limitations.

While some 30 evacuation models have been developed for the building industry, to date, there have only been seven models proposed for the aviation industry. It should be noted that building evacuation models cannot easily and reliably be used for aviation applications. This is due in part to the unique behaviour exhibited by passengers and crew in aircraft evacuations and key structural features that differentiate aircraft from buildings. Of these seven models, one is believed to have not gone beyond the concept stage and another was developed in the early ‘70s and is no longer in use. Of the remaining five models, development work appears to have stopped on the Gourary and Arcevac models with the current status of Macey’s and Robbin’s model being uncertain as they formed part of university students research dissertations. Of these models, only airEXODUS appears to be currently still receiving development attention. Furthermore, of these five models, only airEXODUS appears to make use of fundamental human performance data to characterise the capabilities of passengers. In addition, while all the models have undergone some form of validation/verification, the airEXODUS model has the most thorough battery of validation evidence and it is also in line with validation protocols suggested in other industries.

It has been suggested in this paper that evacuation models offer a possible alternative to the current practice of performing a single evacuation demonstration with people. While the introduction of computer models for aircraft evacuation will potentially solve some of the existing difficulties and shortcomings posed by current certification testing, it will introduce new questions, pose new challenges and offer new opportunities that need to be addressed. However, by addressing these new challenges we may achieve our goal of producing safer aircraft.

One of these challenges concerns the existence and availability of data. In order to perform reliable simulations, evacuation models are reliant on data. The nature of the intended simulation will dictate the type and quantity of the required data, with accident reconstruction possessing the greatest challenges. For certification simulation, much data already exists and has been analysed while much more data is available and yet to be analysed. However, more data is required to and a concerted effort must be undertaken to collect the required data.

The success of at least some aircraft evacuation models in predicting the outcome of previous 90-second certification trials are compelling arguments of the suitability of these models for evacuation certification applications - at least for derivative aircraft. For aircraft involving truly ‘new’ features it is expected that evacuation models in conjunction with component testing of the new feature will be necessary. For the next generation of VLA, one of the areas requiring this form of collaboration concerns passenger exit hesitation times (or exit flow rates) at upper deck exits.

Furthermore, the challenge facing all the stake holders involved in aircraft certification i.e. regulators, approval authorities, accident investigators, manufacturers, airlines, unions, and ultimately the travelling public, is to develop a better understanding of the modelling technology being developed and with that understanding specify relevant design protocols and standards. Here examples from both the building and maritime industries provide useful models upon which to base an aviation strategy. For this to have a proper perspective it is essential that all the stake holders have a good appreciation of the current certification process and its limitations.

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. Using this concept and the results from a detailed modelling exercise, it was shown that staircase design and location are critical factors in evacuation scenarios where passengers are required to use the lower deck exits on a double deck aircraft. In the specific design investigated, it was shown that the two-lane staircase could not cope with the passenger flow generated by the two main cabin aisles resulting in a bottleneck at the head of the stairs and under-utilisation of the main deck exits. Suggestions for improving the overall evacuation time under such conditions include, widening the staircase or providing an additional staircase. If the staircase were widened, relocating the staircase to a more central location with access to additional lower deck exits would also be required in order to reap the full benefits afforded by additional stair capacity.

It was also shown how crew procedures could be represented in aircraft evacuation models and how this could be used to assist in the development of crew procedures, and for exploring the potential usefulness of devices such as communication head sets for relaying information that would otherwise not be available to the crew. An important issue that must be borne in mind is that gaps exist in our understanding of human behaviour and the quantification of human performance in some of the configurations examined. One of the areas that requires further attention is the collection of passenger exit hesitation time data at high sill height exits. While some data exists, more data is required to increase the confidence in model predictions. Another area that requires attention is the performance of passengers on stairs in these type of aircraft. In the work presented here, it was assumed that this would be similar to human performance on building stairs. However, where data does not exist in abundance, models can also be used to limit and refine the design concepts that may need testing in experimental facilities. Clearly, a sensible balance of modelling and experimentation is required to address all of the challenging issues posed by VLTA aircraft.

Finally, computer based aircraft evacuation models – together with reliable data - have the potential to be used for aircraft certification and provide manufacturers, operators and regulators a means of assessing novel designs, procedures and accident scenarios associated with VLT and BWB aircraft.

## 3 Summary of Work Package 3 Trial and Data Analysis

### 3.1 Trial Definition

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.

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 initial plans 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.

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. It was agreed that 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 used the eight trials available to explore passenger movement in three types of situations. 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).

### 3.1.1 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 of 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.

There was a specific 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 passengers into two groups on each of the two trial days. 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 3.1.1.

**Table 3.1.1: Evacuation trials on 25 January and 1 February 2003**

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

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.

On completion of a 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. Each scenario included a whistle 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 trials staff outside the exits would know when to signal to the cabin 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.

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. 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.

**Summary of Work Package 3.2 Trials Results**

### 3.2.1 Introduction

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.

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.

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 video data primarily concerning the passenger use of the stairs and passenger exit hesitation time analysis for the upper deck slide.

The Sofréavia analysis has utilised a human behaviour approach and has 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 participant data obtained from the Sofréavia post evacuation questionnaire.

### 3.2.2 Cranfield University Analysis

The planned test programme was completed and it is believed that the trials produced passenger behaviour representative of non-competitive evacuations. It was also felt that 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. Data were obtained for all eight demonstration evacuations and no evacuations were halted. In total, 336 individuals participated in the evacuation demonstrations.

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 where there was a build-up of passengers waiting to evacuate on to the slide. 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 at the debrief at the end of the testing programme the crew member explained that they 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 expected was crew from both the upper and lower decks moving from their assist space during an evacuation towards the staircase. During some of the evacuations crew at LL2 and LR2, whilst passengers were still evacuating, were observed on the video footage 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. At the debrief session at the end of the testing programme, the crew commented that they perceived the need for crowd control to be necessary to ensure an efficient evacuation. It is noted from the video footage that the crew members only left their assist space once their immediate area (i.e. the lower deck) was clear. At the debrief session, the crew questioned whether they would have moved out of their assist space and left the exit unattended had slides been present, therefore it is a possibility that the presence of platforms 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 was noted from the video footage that the majority of door crew movement towards the staircase occurred when there were no additional crew present at the staircase. The cabin crew's comments on the debrief session indicate that their main objective was to evacuate the aircraft as quickly as possible. They felt to achieve this it was essential that they position themselves so that they could be seen and heard by the passengers using the stairs. 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. The qualitative analysis of interviews conducted with cabin crew after each trial by the Sofréavia team provides some insight into these behaviours. It must be remembered that all crew (except those located at upper right 1) were line cabin 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.

**Table 3.2.1: Summary statistics for free choice evacuations**

| 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 threshold.

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.

### 3.2.2.1 Free choice evacuation

The results, split according to whether passengers were seated on the upper or lower deck, are provided below in Table 3.2.2.

**Table 3.2.2: Free-choice evacuation responses for choice of door**

| 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%) |

#### 3.2.2.2 Moving upwards evacuations

Summary statistics for the moving upwards evacuations are provided in Table 3.2.3 below.

**Table 3.2.3: Summary statistics for moving upwards evacuations**

| 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.

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.

**Table 3.2.4: Moving upwards evacuation responses for choice of door**

| 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%) |

### 3.2.2.3 Moving downwards evacuations

Summary statistics for the moving downwards evacuations are provided in Table 3.2.5 below.

**Table 3.2.5: Summary statistics for moving downwards evacuations**

| 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<br>**Trial 4**<br>**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<br>**Trial 1**<br>**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.

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.

**Table 3.2.6: Moving downwards evacuation responses for choice of door**

| **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%) |

### 3.2.3 RESULTS - UNIVERSITY OF GREENWICH

The following aspects were highlighted by the consortium for investigation and were part of the University of Greenwich analysis

1) Given a free choice (i.e. without direct intervention of cabin crew), 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 could be satisfied. In summary, the main difficulties associated with these trials preventing the intended data analysis are as follows:

The cabin crew did not behave as originally expected. For example, in the first trial where free choice was intended, crew at the forward exits on the upper deck directed participants to use the stairs and exit via the lower deck exits. This meant that it was not possible to (a) measure the propensity of participants 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 participants 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.

1) It should be noted that cabin crew 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 only generically representative of current or future slide designs, 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 researcher 'cabin 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.

**Table 3.2.7: Planned and actual experimental goals**

| | 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** |

The data that could be generated from the trials is summarised in Table 3.2.8.

**Table 3.2.8: Summary of data that could be extracted by UoG from the video footage**

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

### 3.2.3.1 Staircase performance

Table 3.2.9 records participant staircase performance

| Trial | Participant Direction on Stairs | CC activity at top of stairs |
|---|---|---|
| **Day 1 Trial 1** | Four participants descend stairs before cabin crew (CC) arrives. Most participants who then descend | Arrives at 36 s and directs participants downstairs then departs to re-direct participants downstairs |

| | | |
|---|---|---|
| | stairs were re-directed to them by CC. | 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 3.2.9 Staircase performance**

Extensive information on stair behaviour and ‘passenger’ density is available in the Work Package 3.2 report. The stair passenger density during Trial 2.1 is depicted below as an example.

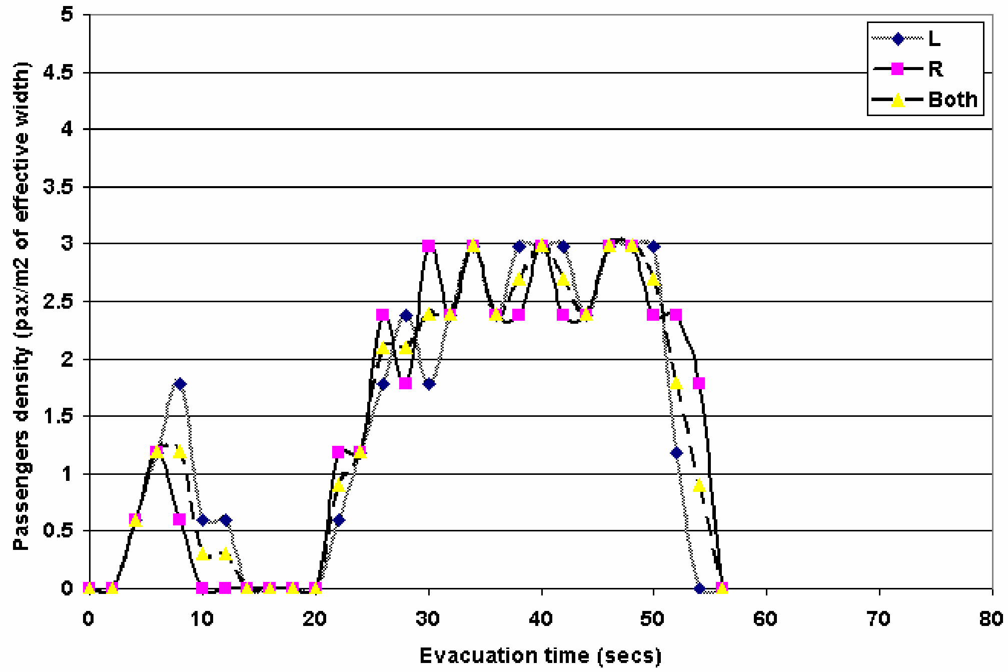


**Figure 3.2.1: Density in visible portion of stairway during Trial 2.1 (DOWNWARD TRAVEL)**

The average stair flow rates measured in the trials is presented in Table 3.2.11. As can be seen from these results, the mean flow rate in the upward direction is greater than the mean flow rate in the downward 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 upward 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 upward travel speed has been hypothesised to be less than the average downward 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 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. Cabin crew activity on the lower deck may also have affected stair flow rates.

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

**Table 3.2.10: Average stair flow rates for all trials**

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

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

### 3.2.3.2 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. 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.

### 3.2.3.3 Participant Average Exit Flow Rates

Participant average exit flow rates were measured by dividing flow time into the number of participants per trial. This was 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. 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 cabin crew. 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 cabin crew, which average 120 passengers/minute.

**Table 3.2.11: Participant average exit flow rates**

| Trial | Participants | Average flow rate (passengers/minute) |
|---|---|---|
| **1.1** | 33 | 31.13 |

| | | |
|---|---|---|
| **1.3** | 48 | 43.70 |
| **2.2** | 56 | 44.97 |
| **2.4** | 36 | 63.34 |

#### 3.2.3.4 Greenwich University Analysis Conclusions

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

### 3.2.4 Results – Sofréavia

#### 3.2.4.1 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, cabin crew interviews, and passenger 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 explain and describe in details the data collected during the VERRES trials, we would like to use the cognitive model named 'Control of the situation model'.
This model, built by French researchers (Amalberti) is used in several fields for teaching purposes or Human Machine Interface design.

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 consider the perception and information processing potential usable at the same time by the brain (short term memory capacity, attention capacity, mental representation capacity). The mental resources limitation is a major constraint when using 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 expended by two main categories: ***Actions management*** and ***Situation Awareness management***. One feeds the other: on one hand we need to understand sufficiently the situation in order to carry out the right action, on the other hand the action provides us new information on the situation. The Figure 3.2.2 presents the way resources can be spent.

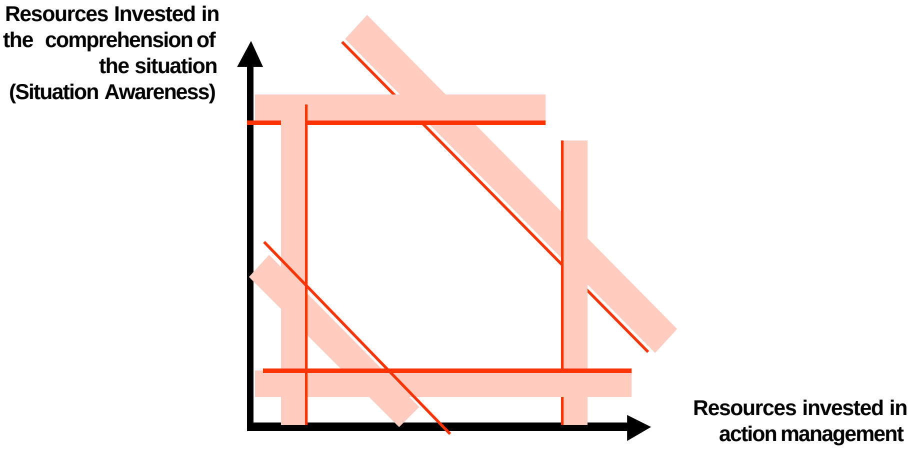


**Figure 3.2.2**

Because our mental resources are limited, some vertical and horizontal limitations are indicated on the figure. 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 memory, perception and other tasks.

We have to indicate also minimum investment limitations because human being are obliged to invest a minimum amount of resources to be able to act or think. Thus, we obtain a "*resource area"* (green in Figure 3.2.3) symbolising an area where the situation is kept in control by the 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**: which is to potentially lose control of the situation.

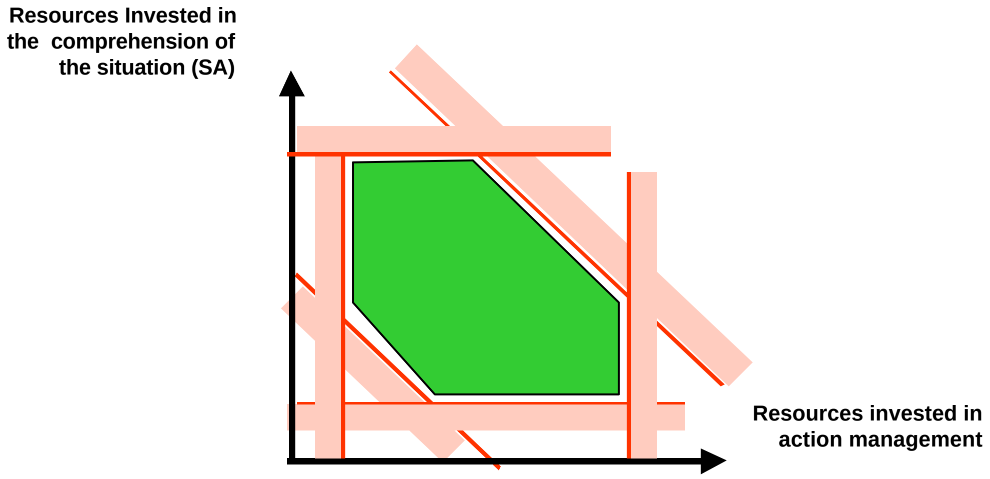


**Figure 3.2.3**

Let's recapitulate by showing in figure 3.2.3 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 into the controlled 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 cabin crew managing an emergency evacuation?
To answer this question we first have to state (from observation of video and interview data) several elements of the cabin crew task during an evacuation:

- **Objectives**: to control the passenger 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
- **Situational Awareness 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 many passengers – jams – no more passengers at the door), anarchical behaviour of the passengers.

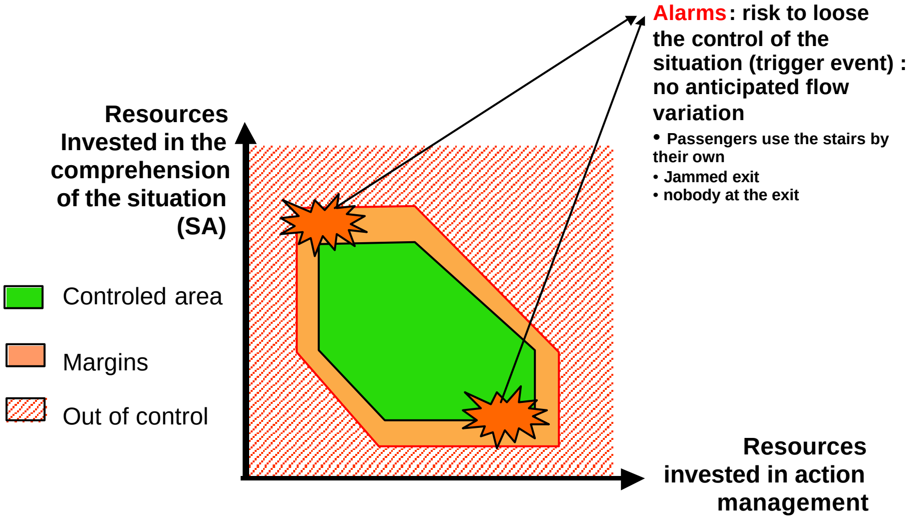


**Figure 3.2.4**

In order to reach our objective we need to know different kinds of information from the trial:

- the objectives of participant actions,
- 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 valuable source of reliable data because the way they cope with an evacuation is not comparable with (albeit trained) researchers. Knowledge, experiences and culture impact on the evacuation management. They are essential elements to reach the research objective to understand how those who are in charge of it manage the evacuation process. This approach is complementary from those applied by the consortium partners, which are more quantitative data oriented.

The case study below has been selected as an example, as being the most simple.

### 3.2.4.2 Case study n°1: Day One, 1st session, Free choice condition

Objective of the trial: with no Stair crew, the objective was to observe passengers using the stairs, and cabin crew managing passenger flow.

Door status during this trial: UL1 was blocked during all the evacuation, UR1 was 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:

- Video
  - The spontaneous use of the stairs by 4 passengers before any intervention of the cabin crew.
  - The intervention of the UL1 cabin crew member in the management of the stairs, encouraging passengers to use the stairs
- Interviews with cabin crew directly concerned
  - UL1 interview data (relevant data are referenced in the following analysis)
- Passenger questionnaires

The answers of the passengers in group A (located at upper deck seats during this trial) are presented in Tables 3.2.12 and3.2.13.

| | 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 3.2.12**

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 a queue at slide | 23% (12/52) |
| Stairs seemed nearest exit | 6% (3/52) |

**Table 3.2.13**

At minimum, 15 passengers used the stairs by their own decision because there was too long a queue at UR1 exit ('too long queue at slide' and 'stairs seemed nearest exit'). About 10 passengers specified that they were directed by the cabin crew to use the stairs ('cabin crew directed me elsewhere'). These two facts are confirmed by the video data.

Analysis of the situation management by the UL1 CC:

- Just after the 10 seconds delay (slide inflation delay), UL1 realises that his door is blocked (**1st alarm**), with a large amount of passengers waiting at his door to exit (**A** location on the figure 4)
- Then, first planned action is impossible (use the exit door). To be able to choose another action (solution), he has to increase 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 3.2.5).
- Thus, he decides to go down stairs to check the availability 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 3.2.5).
- He becomes aware of the usability of the lower deck exits.
- As the cabin crew objective is to keep the control of the situation by optimising the passenger flow, he decides to enhance this solution (**D** in figure 3.2.5): redirecting passengers downstairs
- Because the situation is very dynamic (time pressure) the decision chosen is not the best possible but the one which appear as sufficient at the time, involving an immediate action (i.e. *Naturalistic Decision Making*).

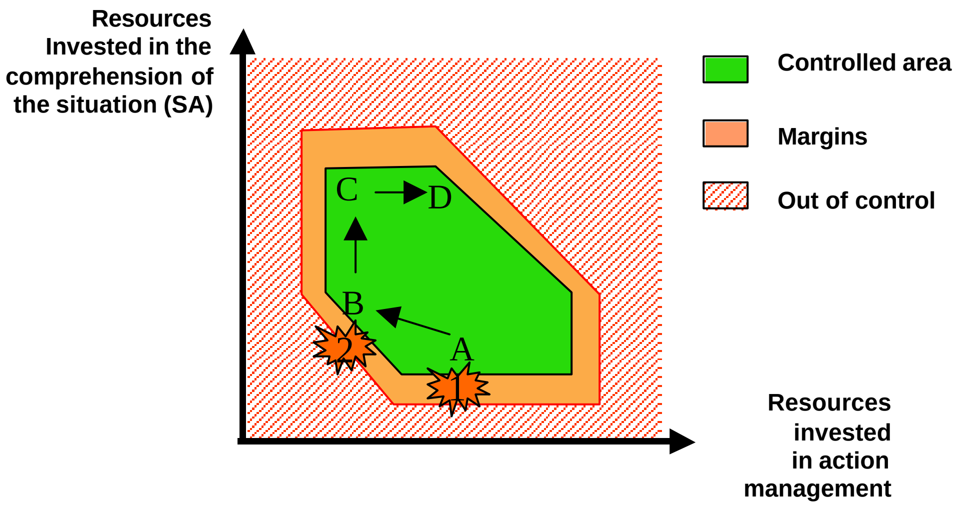


**Figure 3.2.5**

### Appraisal of the 1st case study example

- A few passengers did go down the stairs to try to evacuate faster.
- Without Stair Crew, the UL1 cabin crew member 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, Stair Crew in this scenario would have been useful to feed the cabin crew (door manager) with relevant information concerning the staircase flow and usability of other doors.
- According to the scenario analysed, Stair Crew would allow cabin crew to better manage their own limited mental resources by giving them faster information. Then mental resources can be more invested in the management of actions.

### 3.2.4.3 Sofréavia conclusions and related recommendations

According to the crew, stairs, as are 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 status (usable, jammed, crowded, clear, people going upstairs, downstairs, both, large 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 situation awareness, thus, to make appropriate decisions concerning flow management.

The use of a cognitive model in the analysis of the cases highlights the fact that cabin crew behaviour was logical and efficient, even when they decided to adapt procedures. Thanks to their adaptations, solutions were found and control of the situation was kept. Safety evacuation procedure used in the trials was the one cabin crew use in their company in B747 aircraft (i.e. double deck with non-door cabin crew). According to the cases analysed, the actual procedure is not sufficient to allow cabin crew to be as efficient as possible, which could threaten their control of the situation.

Whatever the safety procedures which will be designed for the use of the stairs, cabin crew 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 cabin crew 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 cabin crew should also allow the cabin crew 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 cabin crew members was not possible because of the staircase location and LL1 and LR1 visibility was seriously restricted by the staircase. For all the cabin crew, knowing what was happening at the opposite door was another reason to move from the door position. The cabin crew member is effectively blind if she/he does not move. In these circumstances, a staircase with an open design should improve the assessment of the stair status and should allow long distance views.

### 3.2.5 General Conclusions from the analyses by Cranfield University, Greenwich University and Sofréavia.

While the trials did not proceed in the controlled manner that was originally planned, 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 by some members of the consortium. 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.

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 participant 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 by the Cranfield University post evacuation questionnaire. 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 influenced 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 cognitive psychology approach using a model known as ‘Keeping control of the situation’ (Amalberti ). 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, inappropriate actions, and the achievement of undesirable states (missed objectives) and the positive aspects refer to the ability to carry out appropriate actions, ability to enrich the situation awareness, or the achievement of objectives.

A number of case studies have been highlighted within the analyses that have suggested that the cabin crew behaviours were logical and efficient, even when they decided to adapt the procedures. 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 was 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 was considered that the analysis of cabin crew and cabin crew/passenger behaviour had provided an interesting insight into the situations that had developed during the trials. 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, 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 evacuation testing including statistically reliable results, with evacuation computer modelling and qualitative analysis, in an attempt to address the complex issues relating to the safe evacuation of very large transport aircraft.

## Summary of Work Package 3.3 Crew Co-ordination and VLTA

### Introduction

The objective of this section is to provide information concerning the co-ordination issues of cabin crews in Very Large Transport Aircraft regarding preventing and managing emergency situations. The purpose is to provide an overview of the theoretical aspects concerning crew teamwork and co-ordination. An assessment of the actual practices and difficulties in current aircraft, trying to identify the relevant information concerning VLTA is made. The final section deals with the points related to co-ordination of cabin crew in VLTA.

We can consider several types of crew with different compositions for double deck VLTA: cabin crew of one deck only, joined cabin crew of both decks, cabin crew with the cockpit crew, and in some specific cases as an emergency evacuation, the ground staff (firemen, airport staff, boarding staff) can be seen as part of the evacuation team.
A number of crew attributes are required:

- <u>An accepted leader:</u> captain or purser – who is responsible for what?
- <u>A common understanding of the team objectives</u>: this condition can be reached thanks to a good pre-flight briefing and regular communication. In the context of the VLTA, airlines will have the opportunity to organise briefing with all the crew (both decks) together and/or each deck separately. The participation of the cockpit crew in the cabin crew briefing is to be encouraged.
- <u>A shared situational awareness between members</u>: the situational awareness is already a core aspect of Crew Resource Management (CRM) issue. The double deck feature should increase the difficulty and generate a totally opposite effect, unless there are good pre-flight briefings, specific and specified communication procedures to allow information to circulate within the large cabins.
- <u>Role and tasks have to be properly distributed between members</u>: the roles and responsibilities sharing between captain and purser(s), on VLTAs, are still in question, within several potential organisations to be considered:
  - 1 main Purser responsible for the two decks, in addition to 2 ‘deck pursers’, and in charge of the communication with the cockpit.
  - 2 ‘deck pursers’ with one in charge of the relationship with the cockpit.
  - 1 independent purser for each of the two decks both of them in direct contact with the cockpit.

- Good communication between cabin crew members: communication procedures and communications means to be developed according to the team characteristics (size, number of leader, location of the leader, …)

### 3.3.1 Co-ordination types

Co-ordination consists of organising tasks and action between several operators taking into account their objectives and the time available. Different co-ordination types are possible.

- Redundancy : strict duplication of actions in order to obtain the summation of the results. Communication is obligatory for carrying out the action.
- Co-operation : knowledge is shared among operators, they share common references, common representation. They work on the same task, in the same place, and have similar objectives in the short term. Operators have to communicate in order to:
  - Share the situation awareness
  - Synchronise future actions
- Co-action : The operators work in the same place but on totally dissociated tasks. Thanks to communication, good relationships between members is maintained. Objectives are different in the short term but the same in the long term.
- Co-activity : the operators (likely to have different expertise), work in the same place, on different aspects. There are no real common objectives.
- Collaboration : Same as co-operation but with a wider scale. The operators works on different aspects of the same object, in a same or in a different place. Objectives are shared in the short term. They share few common references. This situation is often resources demanding and antagonistic.

In emergency situations, as an evacuation, the team performance is mostly based on :

- emergency procedures,
- emergency typical situation training common background,
- anticipation of the team leader: tasks performed are based on anticipated response to conditions,
- communication performance is of paramount importance, but in a VLTA context communication is a complex issue, especially in emergency situation when team communication is difficult to maintain at a sufficient level of quality.

Co-ordination breakdown is then very likely to occur. When co-ordination breakdown occurs, it can take several forms:

- when there is pressure to seek alternative solutions
- when an unexpected non-routine procedure is started
- when there is a unclear responsibility

The most efficient way to prevent co-ordination breakdown is to preserve communication means between whatever the working environment, and to train in usage under difficult operational situations.

### 3.3.2 Communication

Good communication is of paramount importance to maintain co-ordination. When dealing with emergency situations, some of the communication features become key factors such as emergency phraseology and feedback.

Emergency phraseology allows faster communication. Emergency phraseology is a tool to avoid misunderstandings, for example, a VLTA double deck structure will impact emergency phraseology between decks, and with the management of the different potential links between decks (PA, security phone, hand of head sets, stairs). Specific predefined emergency phraseology should be necessary to communicate between the two decks, with two separated, out of sight, groups of cabin crew and maybe two pursers. The formalisation of the communication should follow precise procedure to allow information to circulate quickly in a large space.
Feedback is a useful communication mean to insure a common situation awareness and a good collective decision making process. Feedback is also a good way to check information where there is some doubt about a situation. But feedback procedure is time consuming and resources demanding :

- the right interlocutor must be identified,
- they must be in touch rapidly
- feedback communication is time and resource consuming for both interlocutors
- If direct access is used, communication may interrupt or spoil ongoing tasks.

### 3.3.3 Issues in cabin management in normal operation

The following table presents a list of issues a purser and her/his cabin crew are likely to cope with during a flight. This table has been completed by cabin crew in the airline member of the project consortium (Virgin Atlantic).
Issues listed could be linked to anything the purser has to organise and check and the problems she/he can find at each stage of the flight.
Our purpose is to describe the actual difficulties in order to understand the possible impact in the VLTA cabin environment.
In the table, each issue is presented considering the flight stage it occurs, the persons involved. With a score scale (from “0” to “3”), the time needed to solve the problem, the difficulty and the frequency of the issue are assessed.
To facilitate the reading, issues are numerated.

| **Flight step(s) (preparation of the cabin, boarding, …)** | **Issues description<br>CO-ORDINATION OF:** | **Person(s) involved (passenger, pilots, Cabin crew, …)** | **Time needed to solve the problem<br>0= almost immediately<br>1= fast<br>2= time consuming<br>3= very time consuming** | **Technical Difficulty<br>0= very easy<br>1=easy<br>2=difficult<br>3= very difficult** | **Frequency<br>0= very rare<br>1= occasionally<br>2= often<br>3 = almost every flights** | **Total** |
|---|---|---|---|---|---|---|
| PRE-PAX BOARDING | 1. SAFETY EQUIPMENT CHECKS | FLT & CABIN CREW | 2 | 1 | 3 | 6 |
| | 2. SECURITY CHECKS | FLT & CABIN CREW | 2 | 1 | 3 | 6 |
| | 3. GALLEY PREPARATION | CABIN CREW | 2 | 1 | 3 | 6 |
| **PAX BOARDING/ PRE-TAXI** | **4. PAX BOARDING.** | **FLT& CABIN & GROUND CREW** | **3** | **1** | **3** | **7** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 5. REFUELLLING PROCEDURES | FLT & CABIN & GROUND CREW | 1 | 1 | 3 | 5 |
| | 6. SEATING PROBLEMS | FLT & CABIN CREW | 2 | 2 | 2 | 6 |
| | **7. PAX WITH SPECIAL NEEDS e.g. DISABLED, INFANTS, UNMINS, ETC.** | **CABIN & GROUND CREW** | **2** | **2** | **3** | **7** |
| | **8. OFFLOAD OF UNDESIRABLE PAX,** | **CABIN & GROUND CREW** | **3** | **3** | **1** | **7** |
| | 9. EXCESS CABIN BAGGAGE, | CABIN & GROUND CREW | 2 | 1 | 2 | 5 |
| | 10. SERVICES IN PREMIUM CABINS | CABIN & GROUND CREW | 2 | 1 | 3 | 6 |
| | 11. SERVICE DURING DELAYS | CABIN CREW | 2 | 2 | 0 | 4 |
| **TAXI** | 12. DOOR CLOSURE | FLT, CABIN & GROUND CREW | 1 | 0 | 3 | 4 |
| | 13. ARM DOORS | CABIN CREW | 0 | 0 | 3 | 3 |
| | 14. SAFETY DEMONSTRATION | CABIN CREW | 2 | 1 | 3 | 6 |
| | 15. CABIN SECURE CHECK | FLT & CABIN CREW | 2 | 1 | 3 | 6 |
| **TAKE-OFF** | 16. 30 SECOND SAFETY REVIEW AT CREW STATION | CABIN CREW | 0 | 0 | 3 | 3 |
| | 17. DIRECT VIEW OF CABIN/PAX | CABIN CREW | 0 | 2 | 3 | 5 |
| | 18. PAX REMAIN SEATED TO TOP OF ASCENT | CABIN CREW | 0 | 1 | 3 | 4 |

| **Flight step(s) (preparation of the cabin, boarding, …)** | **Issues description**<br><br>**CO-ORDINATION OF:** | **Person(s) involved (passenger, pilots, CCs, …)** | **Time needed to solve the problem**<br>**0= almost immediately**<br>**1= fast**<br>**2= time consuming**<br>**3= very time consuming** | **Technical Difficulty**<br><br>**0= very easy**<br>**1=easy**<br>**2=difficult**<br>**3= very difficult** | **Frequency**<br><br>**0= very rare**<br>**1= occasionally**<br>**2= often**<br>**3 = almost every flights** | **Total** |
|---|---|---|---|---|---|---|
| **IN-FLIGHT** | 19. SERVICE PREPARATION | CABIN CREW | 2 | 1 | 3 | 6 |
| | **20. SERVICE DELIVERY** | **CABIN CREW** | **3** | **2** | **3** | **8** |
| | 21. CABIN SECURITY SURVEILLANCE | CABIN CREW | 2 | 1 | 3 | 6 |
| | 22. FLIGHT CREW MONITORING | CABIN CREW | 2 | 1 | 3 | 6 |
| | **23. TOILET MONITORING** | **CABIN CREW** | **2** | **2** | **3** | **7** |
| | 24. TURBULENCE | FLT & CABIN CREW | 1 | 1 | 1 | 3 |
| | 25. ABNORMAL INCIDENTS | FLT & CABIN CREW | 2 | 2 | 1 | 5 |
| | **26. DISRUPTIVE PAX** | **CABIN CREW** | **3** | **2** | **2** | **7** |
| | 27. MEDICAL INCIDENTS | FLT & CABIN CREW | 2 | 2 | 2 | 6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **PRE-LANDING** | 28. CABIN SECURE CHECK | FLT & CABIN CREW | 2 | 1 | 3 | 6 |
| | 29. SECURITY CHECKS | CABIN CREW | 2 | 1 | 3 | 6 |
| | 30. SAFETY REVIEW AT CREW STATION | CABIN CREW | 0 | 0 | 3 | 3 |
| | 31. DIRECT VIEW OF CABIN/PAX | CABIN CREW | 0 | 2 | 3 | 5 |
| **LANDING/ TAXI** | 32. PAX REMAIN SEATED TO ARRIVAL. | CABIN CREW | 0 | 1 | 3 | 4 |
| | 33. AT TERMINAL DISARMING OF DOORS | FLT & CABIN CREW | 0 | 0 | 3 | 3 |
| **PAX DISEMBARK** | 34. DOOR OPENING | CABIN & GROUND CREW | 1 | 0 | 3 | 4 |
| | 35. REFUELLING PROCEDURES | FLT & CABIN CREW | 1 | 1 | 3 | 5 |
| | **36. PAX DISEMBARKATION** | **FLT, CABIN CREW & GROUND CREW** | 3 | 1 | 3 | 7 |
| | 37. PAX WITH SPECIAL NEEDS e.g. DISABLED, INFANTS, UNMINS, ETC. | CABIN& GROUND CREW | 2 | 2 | 2 | 6 |
| **POST PAX DISEMBK** | 38. SECURITY CHECKS | CABIN CREW | 2 | 1 | 3 | 5 |

**Table 3.3.1**

From Table 3.3.1 the Purser and his cabin crew have to deal with many issues while they carry out their work. Among the 38 items listed in the table, 29 items have a frequency of "3 "(almost every flight) and, an amount of 21 items have a cumulated score equal to 6 or more (9 is the maximum possible).
The 7 items displayed in bold are the ones which represent the more serious issues cabin crews have to cope with (a cumulated score bigger than 6). It is remarkable that among the 7 selected items, 6 are safety related (the last one is more related to commercial activity):

- N°4 - Pax boarding/ pre taxi: Passengers boarding
- N°7 - Pax boarding/ pre taxi: Passengers with special needs disabled, infants etc.
- N°8 - Pax boarding/ pre taxi: Offload of undesirable passenger(s)
- N°20 - In flight : service delivery
- N°23 - In flight: toilet monitoring
- N°26 - In flight: disruptive passenger
- N°36 -Pax disembark : passengers disembarkation

If we try to imagine the impact of VLTA environment on the issues with a lower score, several inferences can be made:

- Crew co-ordination would be impacted, whatever the crew composition, at least by the direct impact of the size of the crew.
- Crew co-ordination is directly related to safety. In a VLTA environment, the link between safety and co-ordination should be stronger regarding the management of key safety tasks.
- The frequency of some issues (n° 6, 8, 9, 25, 26, 27, 37) are likely to increase (they will happen almost every flight) due to the bigger amount of passengers, above if co-ordination with Flight crew and Ground staff is not particularly reinforced.
- Regarding the time needed to solve problems, some of the listed issues are likely to require more time because of the VLTA's features (n°1, 2, 5, 9, 15, 35). Here also, in all those issues, the crew activity may be considered as two independent parts, one around commercial support and the other one around safety. The two parts requiring conflicting attitudes and interests in co-ordinating cabin crews in a VLTA.

### 3.3.4 Task Allocation

Task allocation between cabin crew is a very important issue. It consists of:

- Deciding who is responsible for what tasks, according position, location in the aircraft, qualification.
- Tasks sharing. The objective of the tasks sharing is to divide the workload (co-operation). As a result of the task sharing, cabin crew should be able to build complementary mental situation representation.

It is may be possible to imagine another way to organise work and information circulation. The principle is a centralisation of the information to one or two persons (purser), with a pyramidal hierarchical structure between cabin crew. In order to be able to manage a very large cabin, cabin crew responsibilities could be changed. A pair of cabin crew could be responsible for an area of the cabin (chief commander of the area), with one of two emergency exit in the area. This kind of distribution of the responsibilities is very demanding in terms on information availability and circulation.

Previous studies has shown that the speed at which passengers are able to evacuate is influenced by the behaviour and number of cabin crew. The results indicated that passengers were able to evacuate the aircraft more quickly when two assertive cabin crew were present than with only one assertive cabin crew member . Moreover, if the slide design enable a two line passenger flow, 2 cabin crew members per door could be needed to control the organisation of each line.

### 3.3.5 Non door Cabin Crew

Another element in relation with future cabin crew numbers in VLTA role of non door cabin crew members. These additional crew members may be on board for safety, operation or commercial reasons.

In future VLTA, with a greater passenger number and a larger cabin, non door cabin crew may have an important part in passenger direction towards usable exits, avoiding crowded exits and re-direction in case of unavailable exit situation, in passenger management (reassuring passengers and structuring the evacuation).

### 3.3.6 VLTA feature in emergency evacuation : Double deck

One of the possible specificity of future VLTA is the double deck feature.
There are at least two ways to consider the two decks.

***The two decks may be considered as independent (two cabins, one above the other with little or no communication).***

This is the official hypothesis that has been selected for the emergency evacuation certification demonstration (90 second test) of the Airbus A380. In this condition, the stairs are not considered as an evacuation means and are not supposed to be used during the certification evacuation.. But certification conditions are not real life and in a real evacuation any available means may be used to evacuate the aircraft. Additional research should be conducted on the management and configuration of stairs in order to be as efficient as possible in case of real evacuation operation.

If the amount of available exits at one of the decks is not sufficient for some reason, then passengers will have to use the stairs. But how will cabin crew co-ordinate the redirection with no procedures of communication and no idea of what is going on in the opposite deck? Even if the number of exits is sufficient, some passengers in a hurry will not be queuing . They will think about a faster way to get out, and will use the stairs. Such passenger behaviour has been observed in the VERRES experiments. This situation could rapidly become out of control with all the cabin crew busy at their own doors.
In time-constrained situations like emergency evacuation, the usable exits should be employed in an optimal manner with the objective to minimise the total evacuation time. At the current time, there are no efficient tools providing cabin crew with global awareness of the usability of the other exits. If such a tool could be provided to cabin crew, the stairs would probably be considered as an implicit means of access to the other deck as it would be realistic to consider that information regarding exit status on both decks would be accessible at each door.

***The two decks may be considered as a single entity.***

Deck co-ordination is an essential aspect of the work in order to be able to manage evacuation. The main difference is that the use of stairs may be considered in nominal cases and not only in extreme cases. Interaction between the decks should remain as limited as possible to keep the ‘evacuation system’ simple. Nevertheless the use of stairs should be incorporated into the procedures and training.
The deck co-ordination could be ensured thanks to a set of elements as:

- new safety procedures,

- new safety briefing
- new safety devices.
- additional cabin crew at the staircase and studied during the VERRES experiments, are essential aspects of this co-ordination.

Limits of this choice

Communication channels are the main issue of this organisation: there is a strong need to relay the information between the two decks and between cabin and cockpit, above all during an evacuation process.

To perform this task properly, the cabin crew at the stairs should be informed in real time of exit status on both decks. There is a strong need for specific communication procedures, tools, and specific training. In addition, if available doors of one deck are not sufficient to ensure a quick exit of all the passengers, cabin crew should know about the state of the other deck in order to transfer passengers between decks.

### 3.3.7 Recommendations from Work Package 3.3

Recommendations are organised in order to highlight the facts that VLTA would have a strong impact on operational issues and associated cabin equipment. The recommendations are classified within those two fields, although many overlaps exist.

***Operational issues***

Based on the appraisals of each chapter the several recommendations can be suggested:

- Training
  - Crew management training: cabin crew should have joint recurrent training (e.g. CRM, communication) with cockpit crew and ground staff
  - Specific training modules should be designed in order to train cabin crew to work safely in VLTA:
  - Simulation of emergency situations taking into account that redundancy and co-operation are required according to crew composition.
  - Simulation of specific situations likely to become more demanding in VLTA features
  - Formalisation of the use of the stairs and stair management
  - Double deck management training: focused on communication procedures.
  - Communication skills should be trained frequently to maintain appropriate skills.
- Task allocation should be based on the number of fully qualified cabin crew in the cabin.
- Task position for Non Doors Cabin crew should be formalised in order to incorporate them into the evacuation process management. Study should be conducted to support this new function.
- A special emphasis should be given to Purser role definition, procedures definition and the specific equipment to support their activity in a VLTA.

***Cabin crew equipment***

To avoid co-ordination breakdown during emergency procedures, new communication tools should be studied.

**Summary of Work Package 3.4 Building a mental representation of the aircraft for passengers**

## Introduction

Mental representation (MR) is a quite wide concept. For the purpose of this study, we considered that the passenger MR carried out during an evacuation is more than a simple mental map of the aircraft and includes social and emotional aspects.
The worst failure of MR is panic. Panic induces social disorganisation, violence and mental confusion. The contributing and limiting factors of collective pathological behaviour will be addressed within the scope of theoretical domains:

- Cognitive psychology: cognitive theoretical models are useful to understand how a mental representation is built, managed and used by human beings.
- Sociology: knowledge and the way information is selected in the environment are influenced by the characteristics of the group we belong to.
- Clinical psychology or psychiatry: passengers are individuals with their own experiences and emotion which have an impact on their mental representation.
- Human ethology: this specific field provide us with information concerning our way of acting when a group is not effectively organised

The **Cognitive Psychology** field deals with the activities and the processes of knowledge acquisition and uses. Mental representation (MR) is a key concept in the field of cognitive psychology. MR is an essential 'tool' because of its effect in controlling a system or a situation. MR can be considered from a static point of view (the MR of an object) or from a dynamic point of view (MR of a situation which keeps developing). We can differentiate between the MR built only for action (*operative image*), the MR built in order to understand the global situation (*mental image*), and the one we build to be able to understand and act in a specific situation (*situation awareness*):

- *Mental image* can involve the construction of prejudices. For example, if most people think that they have very few chances of surviving an aircraft crash, then they will not be very attentive to safety briefing, thinking it is useless.
- *Operative Image* is very functional in nature and adapted to the realisation of the task. It allows us to plan and guide actions.
- *Situation Awareness* consists of understanding the present situation due to past events and expectation concerning the future situation.

**Sociology** is the science studying the group and organisation functioning. This scientific discipline allows exploring the social representation carried out by passengers while they fly.

The passenger mental representation is influenced by the functioning of two interrelated groups: the airlines (communication policy, procedures, cabin crew training), and the passenger's group (social beliefs about aircraft performance and risks).

The influence of the airlines is determined through the attention paid to the passengers before and during the flight:

- The information given to passengers before the flight (advertisement, news …), during the flight (check-in, safety briefing), and the balance between commercial and safety information.
- Positioning of the crew regarding their role and responsibility in the cabin (availability, ability to inform and reassure, skills, …)
- Boarding organisation (complexity of the route from the start of travel to the allocated seat in the cabin, support from ground staff, long time waiting, time pressure stress, cabin welcome, …)

**Psychology**, as is well known, looks at how behaviours will be influenced by individual circumstances, according to background, experiences and awareness.

**Ethology** studies the human behaviours in the physical and social environment.
Human beings are able to build links with each other and to act together as a consequence of the affiliation feeling within a group. There is no need for a strong group experience to build it. The affiliation feeling enables to structural perception of the environment. A given stressful situation will affect individuals differently according to affiliation feelings, because interpretation of perception would be different (we feel stronger if we think that we belong to a group of people). From a cultural point of view, building a group with an affiliation feeling is a challenge in Europe, because the Western culture of independence works against it.

### 3.4.1 Threats to effective Mental Representation (MR)

The MR of a passenger, freshly constructed, is quite weak. Fear, doubt, the absence of information to update MR can result in an inappropriate reaction during an evacuation process, specially in the case of an emergency evacuation. Strong emotions are able to freeze the judgement and to stop the availability of MR to plan actions. As a consequence, it is of paramount importance to create and maintain a good and robust MR for the passenger, allowing her/him to react properly to an emergency situation.

### 3.4.2 The influence of passenger group cultures, beliefs, and habits

While the passenger is in flight, he belongs to a (external to the aircraft) social grouping, bringing into the aircraft his/her beliefs and culture. All the social values determine the way the flight, the cabin crew, the other passengers will be perceived. The expression of “social representation” is used to describe the common thinking characteristics of a social group.
Some elements of the “social representation” have on influence on:

- Beliefs about the reliability of the flight: media, invulnerability syndrome, responsibility, (airlines, cabin crew), defeatism (no chance to survive a crash)
- Perception of cabin crew by passengers - safety role often hidden by commercial aspects.
- Strength of the habit - experienced passenger, impression to already have all the necessary knowledge concerning the flight and the aircraft.
- Collective reactions/crowd effect are linked to social beliefs: panic is a collective reaction to threat, influenced by social representation.

All those aspects should be taken into account in the design of the safety procedures and in the information delivery process for the passengers. Those social elements are part on the MR of the passengers and play a key role in the way they behave during an emergency situation.
Some specific aspects of VLTA such as the number of passengers and the design of new safety procedure will impact the individual’s mental representation. The stronger impact on MR is the MR breakdown that may lead to panic behaviours, when individuals don’t have strong enough references to conduct their actions appropriately in a particular situation.

### 3.4.3 The Practical Application of Mental Representation - safety briefings

Previous studies have identified points that could have an impact on the passenger MR for safety. The following paragraph synthesises recommendations which have been made in previous publications, selected to be relevant to VLTA.

**Passenger attention to safety briefing**

It is assumed that:

1- passengers will always read or pay attention to pre-flight instructions,
2- having done so, they will have understand them,
3- that they will remember them,
4- and then that they will apply them in an emergency situation.

Unfortunately, accident investigations have proved that this is not often the case. One conclusion of the NTSB report (Section 2.1.3.4) was: "we don't know the answer, but we know that the problem has not changed in at least 30 years and we really have not made progress in getting people to watch these safety briefing".

Thus, method could be changed, giving up the FAA logic saying "Fly smart travellers always listen to the safety briefing" as it is first mentioned in the FAA Air Traveller's Guide. In reality, to be a passenger is generally a choice, not a job with specific training.

Some airline assume that explicit emergency instruction in a pre-flight briefing would be too anxiety provoking. Others, generally the larger ones use their safety policy as an advertisement. A passenger opinion survey from a major European company showed that 40% of the passengers put safety as the major argument to choose a major airline.

A US airline's passengers made a list of reasons for inattention to pre-departure safety briefings after 18 aircraft evacuations (1997-1999):

- Passenger had seen the safety briefing previously
- Passenger believed the content was common knowledge
- Passenger was reading during safety briefing (or listening to recorded music)
- Passenger said view of safety briefing was obstructed
- Repetition means belief that they already have learned the safety information
- Underestimation of the probability to survive and thus the need to use safety equipment (powerless feeling)
- They see themselves in a passive role, cabin crew manage safety and the airlines are responsible.
- Unaware of the underlying reasons when cabin crew or pilot gives safety instructions
- Too optimistic (nothing can happen)
- They may experience social pressure to ignore safety briefing perhaps to show others that they are seasoned travellers
- Finally, they overestimate their knowledge of security aspects and don't have in mind that safety equipment could differ from one aircraft to another and that in emergency situation passengers should follow some specific procedures.

Some classical recommendations listed by previous studies are:

- Briefing must be carried out at a time when it is possible to obtain the passenger's attention, not when they are busy settling in their seats. In some air force procedures patients and passengers are briefed prior to boarding the aircraft.
- The cabin crew should walk to, and physically point out the emergency exit.
- Use of video in or outside the cabin. There are often relatively long delays prior to aircraft boarding. Continuous slides and/or films could be shown in the holding area during this period. They could be mixed with commercial or operational information (estimated boarding time, seating information, meteorological data, aircraft performance, flight plan…)

- Mock-ups of emergency equipment could be used while the passengers are waiting to board the plane. Thus, they could attain some skills in the actual manipulation of the equipment.
- Colour coded seats so that during evacuation people know what code colour door to go (in absence of counter-order of the cabin crew).
- Special arrangements for seating people during the check-in process
- Specific briefing of nearby passengers of emergency exits and escape slides.
- Splitting safety briefing into smaller briefings related to the flight phase (take off, cruise, landing).

### 3.4.4 The limits of safety cards

Despite guidance in the form of JAA circulars, many air carrier safety briefing cards do not clearly communicate safety information to passengers. Several recommendations have been made:

- Operators and ticketing agencies should include passenger safety information, similar to that contained in the UK CAA's Air Traveller's Code, with flight tickets.
- No other cabin crew duties should be performed during safety briefing.
- Specific sentence structures and vocabulary should capture passengers attention.

Creative and effective methods could use state-of-the-art technology to convey safety information to passengers. The presented information should include a demonstration of all emergency evacuation procedures, such as how to open the emergency exits and exit the aircraft, including how to use the slides.

There is currently limited knowledge relating to the navigation by individuals of complex interior spaces that may feature in aircraft cabins in the future. A variety of methods may be appropriate to develop passenger MR, however limited practical appraisals have been made. However the passenger MR is constructed, it should develop:

- A good mental map of the aircraft with the location of emergency exits.
- A precise idea of the emergency tasks involved in the evacuation (life jacket, route to reach the exit, slide use...)
- A rational idea of the chance to survive and then motivation to be attentive to all the safety information
- An affiliation feeling with the passengers for mutual survival.
- A cabin crew leadership recognition
- A cabin crew safety role recognition

## 3.5 Summary of VERRES Study Conclusions

This study, funded by the European Commission and undertaken by a European consortium has been able to investigate a wide variety of issues related to the evacuation of Very Large Transport Aircraft (VLTA). Some exploratory evacuation trials have been carried out and areas for future research have been identified.

The study work plan followed a parallel approach that enabled development of results in the limited time frame of an eighteen month study. The consortium was composed of a national aviation regulatory authority, an aircraft manufacturer, an airline operating wide body aircraft, a university specialised in the software modelling of emergency evacuation, a university experienced in the experimentation of aircraft emergency evacuation with dedicated cabin simulators, an engineering company specialised in the civil aviation domain and a cabin crew personnel representative association. The work was reviewed by the Joint Aviation Authorities. The consortium involved three European countries and represented key stake holders involved in the emergency evacuation of aircraft.

**The use of computer models**

The value of computer models of evacuation have been assessed as a major part of the study with a particular focus on VLTA. Computer based analysis techniques coupled with partial testing have been shown to assist in the design and development of safer aircraft, particularly significant for the more complex interiors that may be offered in VLTA. The use of models could bring safety matters to the design phase while a proposed aircraft is still on the drawing board, which may be particularly useful for novel interiors such as blended wing bodies with no prior operational experience. Computer models would allow implementation of safer and more rigorous certification criteria than the current single '90 second' evacuation demonstration, which as a one-off test is used as a yard-stick for comparison with other aircraft rather than a full exploration of the variations in evacuation that may be experienced in practice. Models may be run many times, allowing detailed investigations to be carried out at low cost and at no risk of injury. Models could also assist with the development of improved and more efficient crew procedures and training. In addition to the safety benefits, aerospace manufacturers could bring certification priorities to the design phase and as a result design a safer aircraft, experience lower commercial risk during the design process and thereby incur lower certification costs. In addition, the risks associated with the use of people for full-scale evacuation demonstrations would be removed. These benefits would not just be experienced by European citizens but in a global view by all travellers.

Whilst computer models provide a number of safety benefits, the need for partial testing of new cabin features using people is essential to provide confidence that models continue to accurately portray reality.

**Evacuation trials**

VERRES includes results of the first evacuation research trials of a large double-deck aircraft. These were intended to provide data for evacuation models, particularly related to the use of stairs in addition to exploring wider issues of VLTA evacuation. These exploratory trials were able to provide an indication of the many issues involved and provided useful pointers for future, more detailed investigations. It should be noted that a more complex interior allows more crew procedural options and passenger behaviour may be less predictable with implications for crew training.

New VLTA cabin features such as multiple aisles/cross-aisles would need further experimental investigation. Features such as stairs need a careful characterisation for understanding their use in the event of evacuation and VERRES has been able to explore a number of aspects of stair operation. Particularly useful was the collection of passenger movement rates on the stairs during the trials. Passengers were also noted to make heavy use of the central handrail while both descending and ascending the stairs. 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 influenced 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.

**Managing large numbers of passengers**

A major VLTA evacuation issue would be more passengers for cabin crew to manage (although in total, the proportion of cabin crew to passengers would be expected to stay the same), possibly with large slides and crowd management at the foot of the slides becoming more significant in importance. Concerning the passenger exit hesitation times for the high sill height, the trials produced inconclusive results. Whilst 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 was clear that the extreme caution of the cabin crew positioned at the exits and the lack of (panic) motivation of the passengers exerted a strong influence on the data produced.

The management of large numbers of passengers in a more complex cabin interior than current aircraft is an issue. The need for improved situational awareness for cabin crew has been considered and improved communication systems for them may be worthy of further investigation. These could be visual information display systems perhaps placed at exits or portable systems to allow crew to share information regardless of location. These tools may enable better command and control procedures to be developed for the cabin crew.

The communication of safety information to passengers is likely to continue to be difficult to successfully achieve. Providing situational awareness to passengers in a more complex VLTA interior will be a challenge and improved techniques may be required.

**Research recommendations are made to:**

1. Conduct further experimentation and computer simulation on the use of stairs (and handrails) in the evacuation process for accident/incidents and precautionary evacuations. The VERRES trials provide an indication of some of the passenger movement issues but more trials would be required to establish conclusive results. The purpose would be to formalise the use of stairs and stair management.

2. Continue to develop and eventually demonstrate (through parallel application with certification trials – both historic and new) a framework for the use of aircraft evacuation simulation for certification purposes.

3. Continue the development of aircraft evacuation modelling technology to enhance existing behavioural capabilities, in particular in the area of crew-passenger interaction and passenger behaviour in real accident scenarios; e.g. ability for passengers to climb over seats and their behaviour in fire/smoke environments.

4. Collect data on the passenger exit hesitation time distribution associated with representative VLTA upper deck exits to better characterise the performance of these exits and for use in computer simulation.

5. Gain a greater knowledge of passenger behaviour and passenger- crew interaction in an emergency within a VLTA through experiments (plus the use of software models noted in recommendation 3) in order to maximise evacuation efficiency.

6. Assess the importance of exit visibility. This should include the evaluation of new materials and intelligent systems to make the location and status of the exit more apparent to passengers (and crew).

7. Review the use of upper-deck slides for large numbers of passengers in accident/incidents and precautionary evacuations with the purpose of maximising evacuation efficiency and minimising injuries.

8. Conduct experimentation on enhanced crew communication (with the flight crew and between cabin crew) in accident/incidents and precautionary situations (attention should be paid to the crew organisation and communication means).

9. Conduct research work on the improvement of the passenger safety information delivery process (safety objectives, media and timing).

10. Conduct experimentation on cabin crew location significance (special attention should be paid to panic mitigation and passenger flow redirection).

Note that the research teams in the consortium employed complementary analyses of data for the trials undertaken for the study and the efficacy of this methodology should be considered for future studies.

**Cabin crew training recommendations are made to:**

Ensure that VLTA cabin crew training addresses specific issues that may be more demanding in VLTA. In particular they must be able to manage evacuating a large and complex interior through effective communication with passengers and other cabin crew. It may be necessary to develop skills with new systems offering enhanced communications and situational awareness The management of passengers on and around stairs will be important, together with the effective management of passengers at the foot of slides. Some of these skills may be developed through the use of computer simulations.

The developments commenced here will play a vital role in the safe evacuation of future Very Large Transport Aircraft

## Glossary

| | |
|---|---|
| AASK | Air Accident Statistics and Knowledge (Greenwich University/CAA database) |
| BWB | Blended Wing Body |
| CAMI | Civil Aerospace Medical Institute (Oklahoma City) |
| FSEG | Fire Safety Engineering Group (Greenwich University) |
| IMO | International Maritime Organisation |
| MR | Mental Representation |
| SHEBA | Ship Evacuation Behaviour Assessment facility |
| VERRES | Very Large Transport Aircraft Emergency Requirements Research Evacuation Study |

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