Fire and evacuation analysis in BWB aircraft configurations: computer simulations and large-scale evacuation experiment

E. R. Galea, L. Filippidis, Z. Wang and J. Ewer
e.r.galea@gre.ac.uk
Fire Safety Engineering Group
University of Greenwich
London, UK

ABSTRACT

How long would it take to evacuate a blended wing body (BWB) aircraft with around 1,000 passengers and crew? How long would it take an external post-crash fire to develop non-survivable conditions within the cabin of a BWB aircraft? Is it possible for all the passengers to safely evacuate from a BWB cabin subjected to a post-crash fire? These questions are explored in this paper through computer simulation. As part of project NACRE, the airEXODUS evacuation model was used to explore evacuation issues associated with BWB aircraft and to investigate fire issues, the CFD fire simulation software SMARTFIRE was used. The fire and evacuation simulations were then coupled to investigate how the evacuation would proceed under the conditions produced by a post-crash fire. In conjunction with this work, a large-scale evacuation experiment was conducted in February 2008 to verify evacuation model predictions. This paper presents some of the results produced from this analysis.

1.0 INTRODUCTION

Very large transport aircraft (VLTA) pose considerable challenges to designers, operators and certification authorities. Capable of carrying more than 800 passengers, the A380 may be considered a VLTA however; it is nevertheless a conventional aircraft configuration and so falls within the realms of past operations and certification experience. The aviation industry's drive for increased efficiency is leading to the consideration of less conventional designs and even greater passenger capacity, such as the blended wing body (BWB or flying wing) passenger aircraft.

BWB designs being considered by project NACRE (New Aircraft Concepts REsearch) are capable of carrying in excess of 1,000 passengers on a single deck with 20 exits and eight longitudinal aisles. The configuration has multiple exits located in the rear of the aircraft and does away with the 'exit pair' concept inherent in conventional tube style aircraft configurations. Furthermore, BWB layouts will mean that cabin crew at exits will not be able to assess the situation at opposite exit locations making redirection of passengers difficult. Indeed, the restricted and complex visual access and complex spatial connectivity offered by these aircraft configurations make wayfinding by passengers and redirection by cabin crew difficult and challenging.

The BWB concept represents a significant departure from conventional aircraft design and as a result there are many challenging questions that need to be addressed. One of the most important areas concerns passenger egress safety. There are two fundamental questions that need to be addressed. The first is, how long will it take to evacuate a BWB aircraft? For a given passenger load, questions concerning seating arrangement, nature of longitudinal cabin partitions and longitudinal cabin aisles, the number, location and type of exits, nature of cross aisles linking each cabin section, 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.

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The second issue that must be addressed concerns the amount of time available to safely evacuate a BWB aircraft before non-survivable conditions develop. The industry standard evacuation certification regulations[1,2] require the aircraft manufacturer to demonstrate that the maximum complement of passengers and crew can be evacuated from the aircraft within 90 seconds through half the normally available exits. The rationale for using half the number of normally available exits is that a post-crash fuel fire is likely to make the exits on one side of the aircraft unusable[3]. The rationale for the prescribed evacuation performance requirement is that after 90 seconds, non-survivable conditions are likely to develop within a conventional aircraft cabin subjected to a post-crash fuel fire.

Within conventional aircraft the survivability time is driven primarily by the onset of flashover. Flashover is a critical point in post crash cabin fires where the fire rapidly grows to engulf the entire cabin4. The time to flashover is generally considered to mark the end of the survivability period for those passengers still within the cabin. While the 90 second requirement is questioned by some for conventional aircraft[3], it is clearly not necessarily applicable for BWB aircraft. Within BWB aircraft flashover is likely to occur within different time scales to that found in conventional aircraft and other fire hazards may play a more significant role in determining survivability than flashover. Issues such as how rapidly would smoke, toxic fire gases and heat spread through the BWB configuration and when would flashover occur need to be addressed. Thus the second of our key questions concerns, how much time is available before non-survivable conditions develop within the BWB subjected to a post-crash fuel fire?

To address these issues a series of evacuation simulations were undertaken as part of project NACRE using a specially modified version[5] of the airEXODUS aircraft evacuation model[6-8]. In addition, a series of large scale egress trials were conducted using a specially constructed BWB mockup to verify key airEXODUS predictions. To simulate the fire, the SMARTFIRE[9-13] computational fluid dynamics (CFD) software was used. Finally, the results from the fire simulation and the evacuation simulation were linked to investigate the evacuation in the presence of the developing fire. In this paper the findings from this work are briefly discussed.

2.0 airEXODUS EVACUATION SIMULATION SOFTWARE

The airEXODUS evacuation model is used to perform the evacuation simulations presented in this paper. airEXODUS[6-8] is designed for applications in the aviation industry including, aircraft design, compliance with 90-second certification requirements, crew training, development of crew procedures, resolution of operational issues and accident investigation. The EXODUS software takes into consideration people-people, people-fire and people-structure interactions. It comprises five core interacting sub-models: the passenger, movement, behaviour, toxicity and hazard sub-models. The airEXODUS software has been described in many other publications and so only a very brief discussion of the relevant components will be briefly discussed here.

The passenger sub-model describes an individual as a collection of defining attributes and variables such as name, gender, age, maximum unhindered fast walking speed, maximum unhindered walking speed, response time, agility, etc. These parameters assumed the default airEXODUS values which are derived from the industry standard certification trials. Cabin crewmembers can also be represented and require an additional set of attributes such as, range of effectiveness of vocal commands, assertiveness when physically handling passengers and the extent of their visual access within the cabin. The hazard sub-model controls the atmospheric and physical environment. It distributes pre-determined fire hazards such as heat, radiation, smoke and toxic fire gases throughout the atmosphere and controls the opening and closing times of exits. The hazard sub-model can read data generated by the SMARTFIRE CFD fire model. To transfer CFD fire hazard data the user must define a consistent set of zones within both the SMARTFIRE and EXODUS geometry. These zones are intended to represent regions in which the fire hazard data is expected to be near uniform i.e. exhibiting small spatial variation. The hazard data within SMARTFIRE is averaged over these zones to produce two values, a hazard value at an arbitrary nominal head height and a value a nominal knee height.

The TOXICITY sub-model determines the physiological effects on an individual exposed to the toxic and thermal environment distributed by the HAZARD sub-model. This is determined using the fractional effective dose (FED) and fractional irritant concentration (FIC) concept[6,14]. The airEXODUS toxicity model considers the toxic, irritant and physical hazards associated with elevated temperature, thermal radiation, HCN, CO, CO_2, low O_2, HCL, HBr, HF, SO_2, NO_2, Acrolein and Formaldehyde and estimates the time to incapacitation. Finally, when a passenger moves through a smoke filled environment their travel speed is reduced according to the experimental data of Jin[15]. All these effects are communicated to the behaviour sub-model which, in turn, feeds through to the movement of the individual.

As part of the earlier European Union Framework 5 project VELA[5], the airEXODUS evacuation model was modified to accommodate BWB type aircraft configurations. The model was modified in three areas:

- A novel scheme for passenger navigation was introduced based on wayfinding techniques used in building egress models.
- A modified model for passenger aisle swapping behaviour was introduced more appropriate for the BWB layout. When simulated passengers are subjected to slow moving queues in aisles they may begin to assess alternative routes within the cabin.
- A modified model to simulate cabin crew redirection procedures in BWB aircraft. Crew at a given redirection station use information concerning the congestion and passenger movement/behaviour within their corresponding visibility area to determine whether imbalances existed between the exits of which they were aware and hence whether passengers should be redirected.

3.0 SMARTFIRE FIRE SIMULATION SOFTWARE

A research version of the SMARTFIRE9 V4.0 software is used as the base model to perform the fire simulations in this study. The fire simulation model incorporated a range of sophisticated sub-models. A flame spread model including three ignition criteria1[3] is used to generate gaseous fuel at the interior burnable surfaces. The eddy dissipation combustion model[16] (EDM) is used to release heat due to gas fuel combustion. A multi-ray radiation model is used for the exchange of heat due to radiation and is essential for precisely predicting the spread of fire along solid surfaces. A toxicity model based on local equivalence ratio[10] is used to calculate the generation and spread of fire gases within the cabin. The calculation of smoke optical density utilises the mass optical density[12]. The parallel version of SMARTFIRE is used to simulate the large-scale fire scenarios. The fire model has been validated by successfully reproducing the C133 fire test conducted by the US Federal Aviation Administration[11].

4.0 BWB CONFIGURATION

As part of project NACRE many BWB configurations are being considered. In this paper we consider configuration FW1-1-1. The FW1-1-1 configuration is the base case from which all other NACRE

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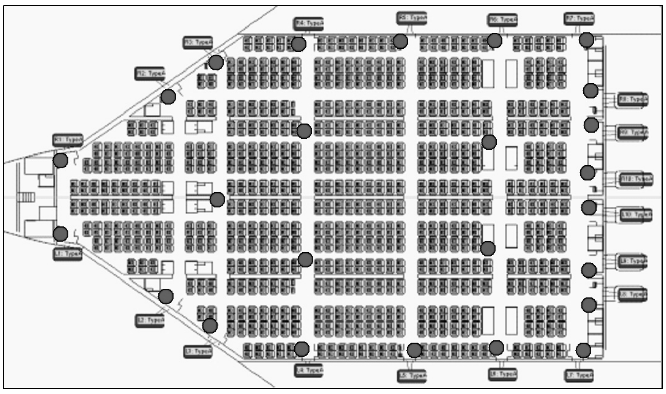

Figure 1. Cabin layout for FW1-1-1 showing location of cabin crew (circles) and exits.

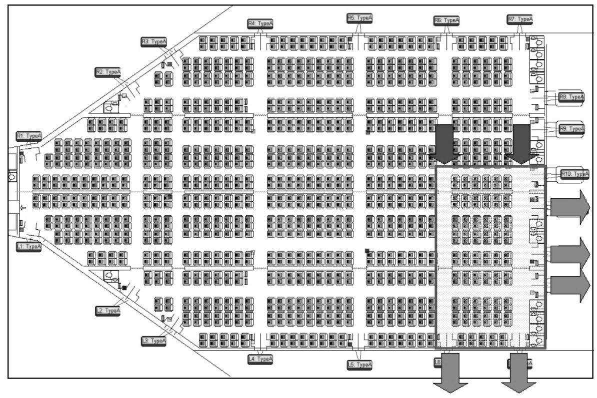

Figure 2. Section of full-scale cabin represented within the experimental mock-up.

BWB variants are generated. It is derived from the best design to emerge from the earlier VELA[5] project. The FW1-1-1 configuration consists of 1,020 passengers in a single class configuration, 25 cabin crew and 20 floor level Type-A exits (see Fig. 1). A member of the cabin crew is located at each of the exits with five additional cabin crew located within the body of the aircraft to assist in directing passengers to the various exits. This configuration resulted from considerable analysis of BWB evacuation scenarios in the earlier VELA project and is considered a base case and the first in a series of configurations which are being optimised for evacuation efficiency.

5.0 EVACUATION MODEL PREDICTIONS

As airEXODUS is a stochastic model, the simulated passengers will not necessarily make the same decisions if the simulation is repeated, it is thus necessary to run the model several times for each scenario. For the results presented here, the model was run ten times. The scenario considered here was a standard evacuation certification case where the exits on one side of the aircraft are considered unavailable. Thus of the 20 exits, 10 were made available on the left side of the aircraft. A standard opening time of 11·1sec was used for each of the Type-A exits.

Also, note that the times specified in this paper refer to out of aircraft times and not on-ground times as exit slide configurations have not yet been determined. For the above scenario the out of aircraft times ranged from 80·6sec to 92·8sec with an average of 85·9sec. While the minimum and average egress times are well under 90sec, we note that the maximum evacuation time is some 3sec over the maximum permitted time. It should also be recalled that these times represent out of aircraft times and not on ground times which may be some 3sec longer.

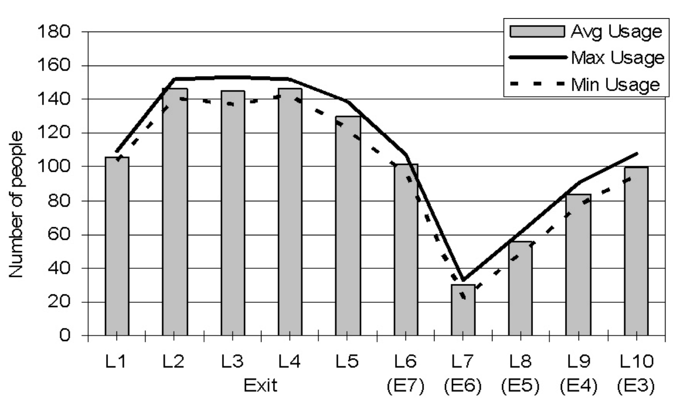

Figure 3. Exit usage, it is evident that exits at the back with the exception of L10 are underutilised.

From the exit usage results (see Fig. 3) it is evident that the exits located at the south east corner of the cabin experience very low passenger usage. The worst offenders are the corner exits L7 and L8 with an average of 30 and 56 passengers using these exits respectively. The passenger exit usage results also indicate that exits L2, L3, L4 and to a lesser extend L5 are over utilised. There is a clear trend that the exit capacity in the rear corner of the cabin cannot be fully utilised. This is thought to be for several reasons, firstly, to utilise L7 and L8 requires passengers to by-pass other functioning exits. Secondly, the location of these exits in the corner of the cabin means that they have a small natural catchment area of passengers for which these exits are their closest exits. Finally, the physical location in the corner provides poor visual access within the cabin. As a result it is difficult to reduce the heavy congestion in cross aisles 2-5 and the heavy usage of the forward exits (i.e. L2 to L6) (see Fig. 4). If we consider the ratio of the time wasted in congestion to the time spent in evacuating we find that in the average simulation, passengers spend on average 40% of their personal travel time caught in congestion. This indicates that a significant amount of time is lost to congestion in this scenario (see Fig. 4).

This trend in exit usage has been observed in all of the numerical predications for the various configurations examined. While the results appear to be consistent and plausible, it was not clear if this was an artefact of the evacuation simulation behaviour model or if it was a realistic result. In particular it was not clear if the crew redirection model and the passenger navigation model were producing realistic predictions. To investigate this further it was necessary to undertake experimental evacuation trials.

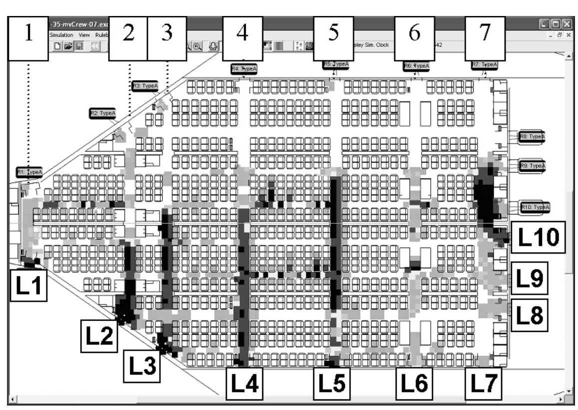

Figure 4. Population density plot at 40sec into evacuation, darker colour represents greater population density.

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Figure 5. View from Cameras 9 and 12 during Trial 1 Session 1.

6.0 LARGE SCALE EVACUATION TRIALS

The purpose of the experimental programme of work was to observe and quantify the evacuation behaviour and performance of passengers and crew in novel BWB configurations. The objectives of the experimental programme were to:

- Identify pax and crew behaviour unique to BWB geometries.
- Verify existing behaviours incorporated into aircraft evacuation models.
- Collect data for model calibration and fine-tuning.
- Collect data for model verification/validation.

Conducting full-scale trials involving over 1,000 people was prohibitively expensive and impractical and so it was decided to undertake large-scale trials using a portion of the BWB cabin. Furthermore, given the concern over the modelling of the rear part of the cabin, the trials focused on this part of the cabin (see Fig. 2).

The key issue of interest was identifying whether participants would redirect and bypass a usable exit while trying to evacuate. To accurately represent this behaviour within the mock-up it was estimated that 380 people would need to be utilised in the mock-up of this area. Note that in order to measure whether occupants are willing to bypass a usable exit there was no need to have all the test subjects seated within the mock-up. This realisation allowed the trials to be conducted with a much smaller cabin mock-up saving considerable construction costs. This required the construction of a geometry that had similar size and layout, including the aisles, exit number and location as well as the same geometry layout in the vicinity of the exits. In total some 88 participants would be seated in the mock-up and 146 participants would be brought into the mock-up via the two cross aisles feeding the mock-up section (see Fig. 2).

The cabin mock-up was constructed at Cranfield University who also recruited the trial participants under contract to the University of Greenwich. A series of four trials were conducted over two days with two groups of participants, 375 participants on the first day and 358 participants on the second day. Trials considered full and partial partitions, additional crew and a repeat of the full partition trial. The participants were aged between 20 and 50 and each cohort of participants was used in all four trials on each day. Data from the trials was collected using some 12 internal fixed mounted cameras (see Fig 5) and five external fixed mounted cameras. In addition, a special roving head mounted camera was used in each trial. On completing each trial, participants were also required to fill in a questionnaire. It is important to note that the trials were conducted in non-competitive conditions similar to those found in certification trials. Only the results from trial 1 session 1 are discussed here (trial with full partitions) however, these results are indicative of the findings from all the trials. It is also worth noting that a significant learning effect was detected in the repeat trials.

In comparing the exit locations used in the full-scale aircraft (and in the computer model) with those in the experimental mock-up, the designation L1 – L10 are used to represent the exits on the left side of the aircraft. In the mock-up, an E designation is used to describe the exits in the experiment. The link between the exits used in the experimental mock-up and simulation is as follows: L6 – E7, L7 – E6, L8 – E5, L9 – E4, L10 – E3 (see Fig. 2, Fig. 4 and Fig. 6).

A significant observation to emerge from the trials is that the exit usage distribution predicted by the airEXODUS software (see Fig. 3) is reflected in the results found in the experimental trial (see Fig. 7). In particular, the corner exit E6 (L7) is the most underutilised exit while the first back exit that the participants encounter, E3 (L10) is heavily used. There is a gradual decline in the number of people using the next exits along (E4 (L9) and E5 (L8)) culminating in the minimum exit usage for E6 (L7) in the corner. The number of people using the next

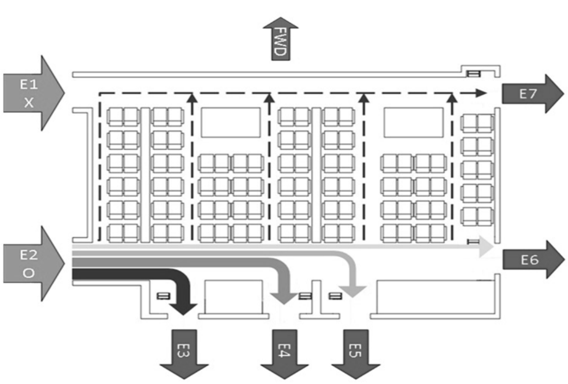

Figure 6. Cabin mock-up showing simulated exits (E3-E7) and inlet streams of participants (E1 and E2).

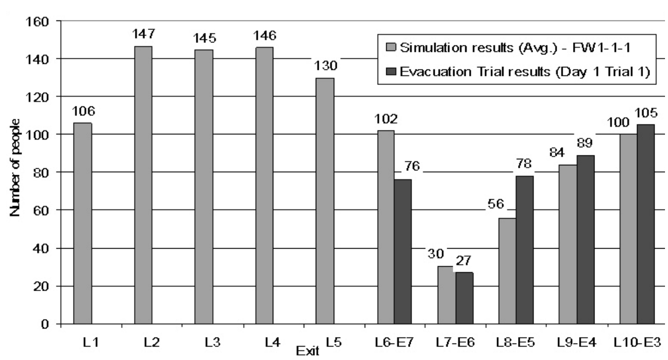

Figure 7. Comparison of exit usage between modelling predictions for full cabin and experimental results for cabin section.

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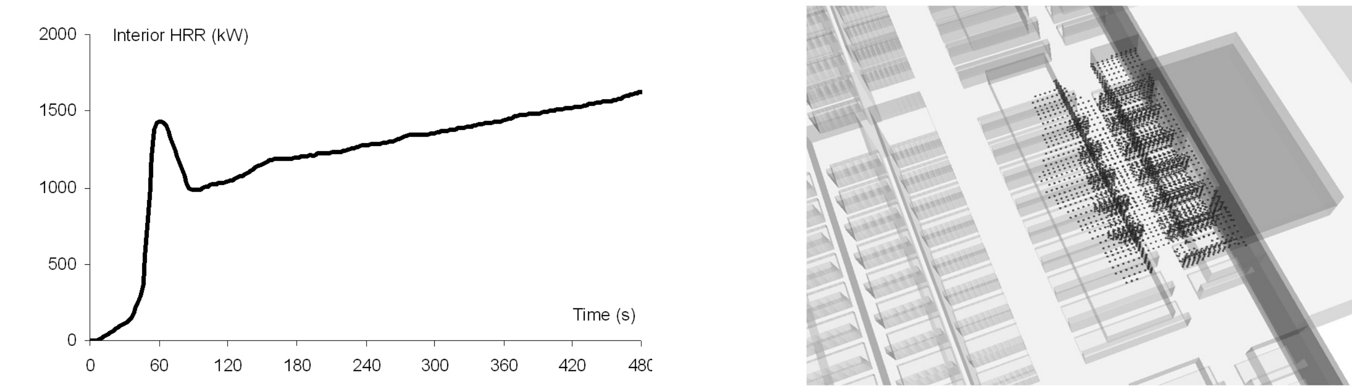


(a) HRR

(b) Burning locations at 480 seconds

Figure 8. Predicted interior (a) HRRs and (b) burning locations.

exit (E7 (L6)) then increases significantly. It should be noted that the modelling results depicted in Fig. 7 represent an average over 10 simulations while the experimental trial results represent the observations from a single trial. There is expected to be significant variation in exit usage for repeat trials which is not reflected in the trial results. This explains some of the differences between the predicted and measured exit usage values. It should also be noted that in the simulations there is a supply of passengers along the longitudinal aisles closest to the L6 (E7) exit that will also feed the exit. This will also contribute to the slighter higher number of people predicted to use the L6 (E7) exit.

From the participant questionnaires we note that only 5·7% (21) of the participants claimed that they could see all the exits. The least known exit from the start of the trial was E6 (26% (88) of participants could see the exit at the start of the trial) followed by E5 (29%) and E6 was also the exit that participants were least aware of DURING the trial (20% (71) of participants were aware of the exit) again followed by E5 (32%). The most know exit from the start of the trial and during the trial was E3 (49% (165)).

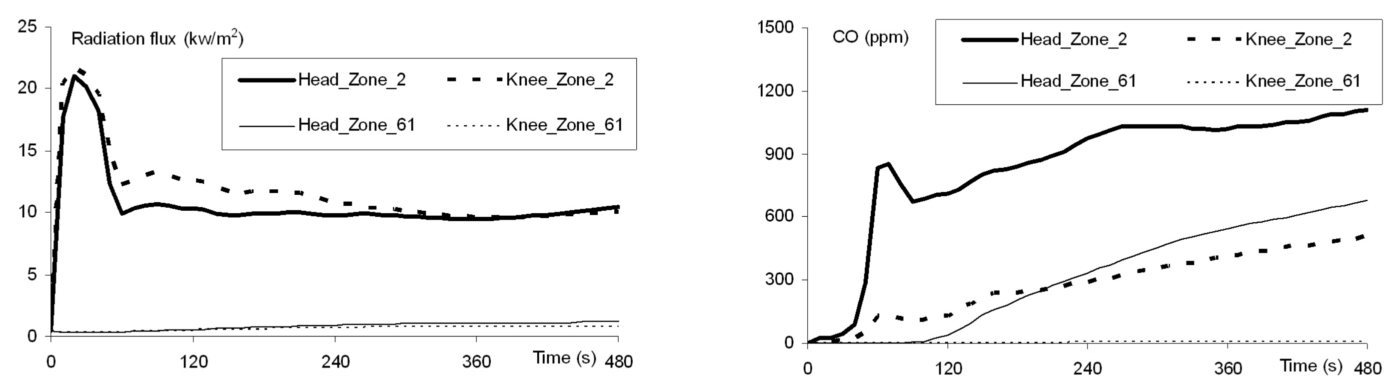
Knowledge of the existence of the various exits thus reflects their usage. The four most important reasons participants gave for not being able to see the exits, in order of importance were; partitions obscured view, passengers obscured view, exits too far away, didn't know where to look. Thus situational awareness and visual access are seen to be important factors in determining which exits are utilised during the evacuation. The exit by-pass that was noted in the trials is also of interest. If we consider the stream of people coming down the cross aisle closest to the rear three exits (145 participants, see E0 – E6 in Fig. 6) we note that 39·3% by-passed the first exit (E3), 6·9% by-passed the second exit (E4), 2·1% by-passed the third exit (E5) and no one by-passed the forth exit (E6). In comparison, airEXODUS predicts that 41·0% of the passengers will by-pass the first exit which is in good agreement with the experimental findings. We note that while just over a third of the participants are prepared to by-pass one exit, very few will by-pass more than one exit. The most important factors participants identified that influenced their choice of exit route, in order of importance were; nearest exit, first exit they saw and avoided heavily congested exits. It is interesting to note, that after having experiencing the first trial, avoiding heavily congested exits became the most important factor. All these observations support the logic of the decision making models within airEXODUS.

7.0 FIRE MODEL PREDICTIONS

7.1 Fire scenarios

In a post-crash aircraft fire, the fire is typically initiated outside the cabin usually due to a fuel spill. The fire then attacks the aircraft cabin gaining entry via ruptures to the fuselage due to impact damage, or burn through and ignites the interior materials. In the NACRE simulations, the external fuel fire source is located on the right side of the aircraft. Six different fire scenarios were investigated, all of which involved opened exits on the left side of the cabin during the entire fire simulation.

Scenarios 1 to 3 involved a fuselage rupture opposite the external fire of size varying from the equivalent of one, two and three Type-A exits respectively. The internal cabin partitions in these scenarios are full partitions. Scenarios 4-6 investigated the effect on cabin conditions and time to flashover of the following factors: height of partitions, material properties and an additional rupture located on the underside of the cabin. Here we report the results of Scenario 3, with the wide cabin rupture. The external fire had dimensions of 5·2m long by 2·5m wide and the fire reached a maximum heat release rate of 18MW after 8sec and burnt at this maximum rate for 10 minutes.



(a) Radiation Fluxes

(b) CO concentrations

Figure 9. Predicted radiation fluxes (a) and CO concentrations (b) in Zone 2 and 61.

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7.2 Fire simulation set up

The computational mesh used for the NACRE simulations consisted of approximately 650,000 cells. Mesh sensitivity studies suggesting that this mesh was adequate for these simulations. Different material properties for cabin walls, ceilings, monuments, seats, overhead bins and partitions are used in the flame spread model. Not all of the material properties were readily available and so some material data was derived from available data appearing in the public domain. When applying the EDM for the release of heat due to gas fuel combustion, the interior combustible materials are assumed to have the molecular structure of Phenolic foam[17], i.e. $CH_{1·1}O_{0·24}$. The yields of toxic gases are derived from the literature[17]. A parallel cluster consisting of seven processors was used for the simulations. This reduced the run time from 425 hours on a single processor to around 70 hours for a single 480 second fire simulation.

7.3 Simulation results

At flashover, the fire very rapidly changes from being localised to engulfing the entire volume. An important outcome of this analysis is that flashover is not observed within the first 480sec, which is much longer than the certification requirement of 90sec. This can be seen from the predicted interior HRRs in Fig. 8(a). The combustion behaviours over the entire simulation time do not display the rapid increase in values, which is the hallmark of flashover.

The seats close to the fuel fire are the first cabin fixture to be ignited. Later, the fire spreads to portions of the seats in front of and just behind the initially ignited seats. At 480sec, the fire mainly remains localised and confined to seats and overhead materials in the vicinity of the rupture as shown in Fig. 8(b). Clearly flashover is not the factor that will drive survivability in this type of scenario.

As seen in Fig. 8(a), the predicted (interior) HHRs reach a local maximum at approximately 60sec. At 60sec, severe fire hazards are mainly confined within the immediate vicinity of the rupture at head height (1·7m above the floor). Within the lower layer (0·5m above the floor), fire hazards such as temperatures and toxic gas concentrations are at very low levels in the vicinity of the rupture however, radiation fluxes are at untenable levels. After 80sec the hot fire gases have spread throughout the cabin section closest to the rupture. Temperatures at head height are around 100°C through most of the section. Hot fire gases begin to spill into the next cabin section with temperatures around 60°C in parts of the third longitudinal aisle. The atmospheric conditions in most of the cabin at around 90secs appear to be survivable. Only conditions in the cabin section immediately adjacent to the rupture pose a threat to life.

8.0 LINKED FIRE AND EVACUATION SIMULATIONS

In order to analyse the likely impact of fire hazards on the evacuating passengers, the NACRE cabin is divided into 67 zones for data output from the fire simulations. The fire hazard data in the upper layer (1·5m to 2m) and lower layer (0·3m to 0·8m) within each zone is a weighted average of variable values of all cells within the layer. This data at each time step is then exported to airEXODUS and used in the evacuation simulation, exposing the population to the evolving fire hazards.

Presented in Fig. 9 are the predicted radiation fluxes and CO concentrations at Zone 2 and 61. Zone 2 is in the section of longitudinal aisle immediately opposite the cabin rupture and hence the external fuel fire while Zone 61 is in the section of cross aisle adjacent to exit L4 on the opposite side of the cabin to the fire. As seen in Fig. 9(a), the radiation fluxes in both the upper and lower layers of Zone 2 reach hazardous levels of $10kW/m^2$ just before 10sec. The local CO concentrations peak at approximately at 60sec, which is 50sec after the radiation flux reaches critical values. This demonstrates that in the vicinity of the rupture, radiative flux is the key threat to survivability in Zone 2. In Zone 61 we note that the radiative fluxes and CO values are near ambient values up to 90sec after ignition and pose no threat to the passengers. The same conditions exist in the zone opposite L5. Thus conditions at two heavily used exits pose no threat to the passengers. As with the case without fire, the evacuation simulation was run 10 times. This produced an average evacuation time of 89·3sec compared with 85·9 sec without the fire. This modest increase in evacuation time is due to the presence of smoke within the cabin which reduces visibility and reduces travel speeds. While there is only a modest increase in evacuation times there are 12 predicted fatalities in this simulation. All 12 fatalities occur in the immediate vicinity of the rupture and all the fatalities are a result of exposure to radiative heat. The fatalities occur between 8 and 34 secs from the start of the simulation, with three fatalities occurring within the starting location and nine fatalities occurring in the aisle adjacent to the starting location. Given these conditions, it is felt that these fatalities are unavoidable, given their starting location and proximity to the fire.

In addition to the predicted fatalities, some 25 passengers are predicted to be injured due to heat exposure. Of these, three passengers are considered to have serious life threatening injuries. None of the survivors suffers from serious exposure to the toxic fire gases however, most of the survivors suffer from light exposure to HCl.

9.0 CONCLUSIONS

The experimental results highlight the importance of situational awareness and visibility in navigating a successful exit path within the complex layout of the BWB. Improving the passenger's knowledge of the cabin layout and the location of the exits and providing them with good visual access of the exits and aisles will be essential in achieving an efficient evacuation of complex BWB configurations. The experimental results also support the appropriateness of the exit selection behaviour implemented within the airEXODUS evacuation model and suggest that it is suitable for these types of applications.

The airEXODUS evacuation simulation suggests that the BWB with 1,045 passengers and crew can be evacuated in 80·6 sec to 92·8 sec with an average of 85·9sec. Improved performance can be expected by better utilisation of the rear and in particular the corner cabin exits. This may be achieved through improved passenger familiarisation with the cabin layout and improved visual access. However these times represent out of aircraft time and not the on-ground time as required by regulation. Fire simulations suggest that the BWB cabin exposed to an 18MW post-crash external fuel fire via a large cabin rupture does not flashover within the first 480sec. This suggests that, unlike conventional tube style aircraft, flashover is not the factor driving passenger survivability. When the SMARTFIRE fire simulations are linked to the airEXODUS evacuation simulation, thereby exposing passengers to the developing fire, the average evacuation time increases to 89·3sec. In addition, some 12 fatalities and 3 serious injuries are predicted. All the fatalities and injuries are the result of exposure to radiative heat and all are initially located in the immediate vicinity of the rupture. Smoke and toxic gases are not considered a serious threat in these scenarios. Given the location of the fatalities and the severity of the fire conditions, it is felt that these fatalities are unavoidable and are not inherently due to the cabin architecture.

Ultimately, the practical limits on passenger capacity and aircraft design are not based on technological constraints concerned with aircraft aerodynamics but on the ability to evacuate the entire complement of passengers and crew within agreed safety criteria. This work has demonstrated that the NACRE BWB configuration has the potential of satisfying such safety criteria and is arguably capable of providing an equivalent or better level of safety to today's conventional aircraft.

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