

# Investigating Aircraft Evacuation Performance in Deteriorating Conditions

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**Abstract:** Accidents or serious incidents in aviation rarely result in a need to evacuate an aircraft. However, when the situation necessitates the action, the risk in terms of loss of life is significant. To ensure aircraft can be evacuated before passengers are overcome by smoke, fumes, and heat, the FAA requires all passengers to be deplaned in less than 90 seconds, with only half the exits accessible in darkness. In some situations, the number of exits can be further restricted, especially in the case of a fire post-impact. In this work we model the evacuation of the Airbus A220, with different exit configurations available. The benchmark maximum seat configuration of 125 seats was utilised. The evacuation modeling was undertaken in Pathfinder to compare to the industry requirement to evacuate all passengers in 90 seconds. The number and location of available exits were varied to determine their impact on the evacuation performance. The critical factor was found to be restrictions at the exits due to the single isle nature of the cabin configuration. This is an important design consideration for future aircraft types as we move away from the traditional tube and wing configuration.

**Keywords:** Aircraft evacuation, certification, safety, aviation, simulation, regulations

## Nomenclature

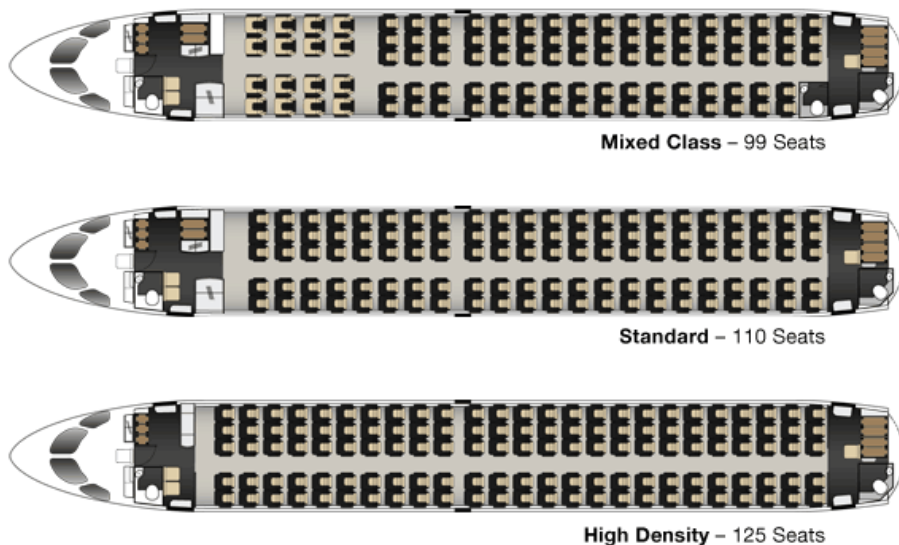
ICAO : International Civil Aviation Organization  
FAA : Federal Aviation Authority  
US : United States

## 1. Introduction

Of the 1277 official ICAO accidents from 2008 to 2019, 148 were categories that could immediately result in an aircraft evacuation. Of the evacuations which occurred in that period 18 resulted in further injury or loss of life. Therefore, in all aircraft accidents, 10 % result in evacuations, and 1.5 % result in further injury and/or loss of life during the evacuation. While there is limited data available highlighting current statistics, in the 8 years from 1988 to 1996, there were over 500 evacuations in the US alone (Hynes, 2000). If we consider the relative size of the global aviation industry (relative to the US), and the significant growth rate since 1996, the total number of global aircraft evacuations is likely to be at least an order of magnitude more. All these statistics demonstrate that a detailed understanding of evacuations in all situations is essential.

The FAA requires all passengers be evacuated from an aircraft in less than 90 seconds, with only half the exits available, and with minimal illumination (Martínez-Val and Hedo, 2000). Snelgrove (2020) highlights that this 90-second time requirement comes from studies undertaken by the FAA in the 1960's. These studies determined that a cabin engulfed in flames could be survived for up to two minutes. Factoring in other issues such as response, and time to inflate slides etc., the limit of 90 seconds was proposed. In general, it is important to understand how different parameters and factors will reduce survivability, beyond the initial limitation imposed historically (half exits with minimal illumination).

The methodology implemented in this work is similar to that of Choochart and Thipyopas (2020). This was done to compare the results of the software for a baseline comparison with Pathfinder. The previous work looked at an Airbus A330 whereas in this work we utilised an Airbus A220. The A220 was selected as Airbus' new ZEROe program has proposed a small blended-wing-body aircraft for less than 200 passengers, and the A220 represents the smallest conventional aircraft in the Airbus fleet. Seating configurations for the A220-100 are illustrated in Fig. 1. The seating configurations show a capacity between 99 to 125. The locations of the exits are also shown with three on each side of the aircraft, two at the front, two at the rear, and two over wing exits. Different combinations of exits were used to determine the impact of exit availability on the evacuation performance. Several trials were used for each exit configuration, to give a mean and confidence interval for each.



**Fig. 1.** An example seat map of the three Airbus A220-100 configurations with 99 seats, 110 seats, and 125 seats (Airlines Inform, NA).

## 2. Background

Validating the use of computer simulations in general, and specifically the Pathfinder model was key before any testing could be conducted. A common aspect in much of the literature was the costs and risks associated with testing evacuations in the real world. Published certification trials between 1972 and 1991 reveal 6% of participants sustained injuries from cuts and bruises up to a female participant who sustained permanent paralysis (Galea et al., 1998, Galea, 2006, Blake, 2003). Whilst in comparison to development costs, it may not seem expensive for an evacuation trial of a wide body aircraft to be conducted, the cost is in vicinity of \$USD 2 million (Galea et al., 1998, Galea, 2006, Blake, 2003). Also mentioned frequently is the inability for a certification trial to truly represent the evacuation capability of an aircraft. A single test does not provide confident information on cabin layout and only provides an artificial benchmark which does not reflect a real life emergency situation (Galea, 2006, Blake, 2003).

Most literature on using computer simulations returned a positive result that computer modelling is an effective and accurate method of certifying aircraft. Using the airEXODUS program and comparing it to the results of the trial test of a Boeing 737 with 55 passengers, showed a mean evacuation time that was 3.58% quicker for the airEXODUS software after 12 simulations with three different seating arrangements (Galea et al., 1998, Galea et al., 2001). A comparison of the same trial was conducted using the Pathfinder model and found a difference in mean egress time of 1.16%. Along with this, a Boeing 767 with 285 passengers and four exits showed Pathfinder results to be 3.12% faster than the trial (Choochart and Thipyopas, 2020). Using a real life evacuation trial and comparing to the well documented A380 evacuation trial time, the simulated egress times lie between 4.5% slower and 6.5% faster (Melis et al., 2020).

Another common theme was simulation drawbacks and how current evacuation models could be improved. A study which validated the airEXODUS software then went on to outline issues that need to be addressed for modelling to advance. It discussed the limited quantity of model verification, the inability for models to represent crew procedures, and the limited behavioural capabilities to simulate real accidents (Blake, 2003). Similar points were raised in other literature along with other drawbacks like a standardised framework not yet existing and the need for computer simulation trials to have their own set of regulations (Galea, 2006). A review of different simulation models, including airEXODUS and Pathfinder, found that before computer models can replace live certification trials it must first undergo strict validation testing (Togher and Barghuthi, 2018).

## 2. Methodology

Before any evacuation simulations could be run, the Pathfinder model had to be validated to ensure that the data collected from the simulation was viable. This involved multiple methods of validation as it is crucial to the research that the data is accurate, or at the very least, repeatable. Pathfinder was chosen on the basis that it

is free to use for academic purposes unlike many other software packages such as airEXODUS which is widely utilised but not provided for third party users. Unlike airEXODUS, Pathfinder has not been extensively tested, so validating the model was important.

The first step in validation was to review the literature which had used Pathfinder in their studies. A report on ‘The effect of airline passenger anthropometry on aircraft emergency evacuations’ (Melis et al., 2020) used the Pathfinder model and verified its ability to conduct evacuation simulation of narrow aisle passageways as seen on aircraft. Another study which used the Pathfinder model to investigate passenger evacuation from an A330-300 also compared the mean egress times to real world evacuation trials and to airEXODUS (Choochart and Thipyopas, 2020). In their work, through case studies of a Boeing 737 with 60 passengers and a Boeing 767 with 285 passengers, the mean egress time was comparatively 1.16% greater and 3.12% greater, respectively.

A flow chart to visually illustrate the validation methodology is shown in

. The first variable is the exit configuration used in the certification trial. The number of exit combinations ( $n$ ) can range from two for a twin exit aircraft up to 12,870 for the 16 exit Airbus A380. In this case, for this work, four different exit configurations were utilised. Additional loops can be added for different seating configurations, different types of aircraft, and different sizes of aircraft. The outer loop is the number of repeat trials, which in this work was ten random trials, where the passengers were randomly assigned different seats.

Pathfinder has the ability to specify the profiles of each individual passenger. Things such as anthropometry, movement speed, and responsiveness can all be altered and distributed appropriately. To create an initial profile and conduct some preliminary testing, two profiles were generated: male and female. Changing both profiles diameter and height to a normal distribution were the only changes made to the default Pathfinder settings in this initial work. For the males, height had a mean of 1.7554 m and standard deviation of 0.0619 m whilst width had a mean of 0.4541 m and standard deviation of 0.023 m (Hertzberg et al., 1954). Females had a mean height of 1.5728 m and standard deviation of 0.0573 m with a mean width of 0.3721 m and standard deviation of 0.034 m (Dawal et al., 2012).

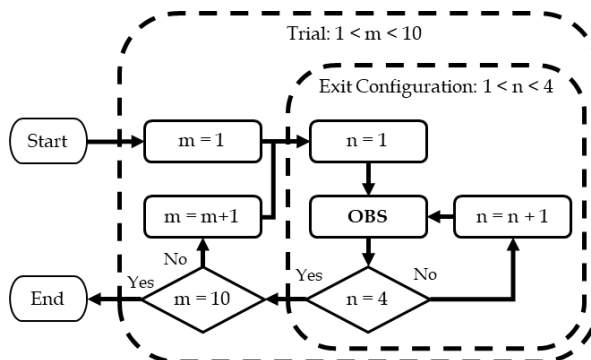


Fig. 2. The flow chart of testing variables.

The female anthropometric data may not be accurate as the sample pool was strictly from Malaysian university students who are typically smaller when compared to females of other countries.

Comfortable walking speed ranged from 1.272 m/s for women in their seventies to 1.462 m/s for men in their forties. Maximum speed ranged from 1.747 m/s for women in their seventies to 2.533 m/s for men in their twenties (Bohannon, 1997). More precise data will be utilised when the Pathfinder profiles are set up to match what is required in the FAA regulations in future research. Reaction times in an emergency situation in a group were  $(1.88 \pm 0.10)$  s and for an individual was  $(1.21 \pm 0.08)$  s (Bode et al., 2015).

### 3. Results and Discussion

The preliminary results included in this work are performed with only anthropometric data factored into the simulation whilst other Pathfinder variables remain at default. Fig. 3 illustrates a sample evacuation over several time periods ranging from the beginning of the simulation (zero seconds) through to forty seconds.

The simulations were repeated ten times for each aircraft exit configuration and a mean and standard deviation was calculated. The results are shown in Table 1. The results show, as expected, that the less exits that become available, there is a trend that shows an increase in evacuation times. More important is the spatial separation of the exits. That is, if a single pair of front exits were utilised (not simulated in this work), this would have an evacuation time similar to a single front exit. This is highlighted by the fact that the case with four exits (two front and two rear) is slower than the case with three side exits. Again, that is, the fact that the three exits have better spatial separation than the four exits, giving a better evacuation time.

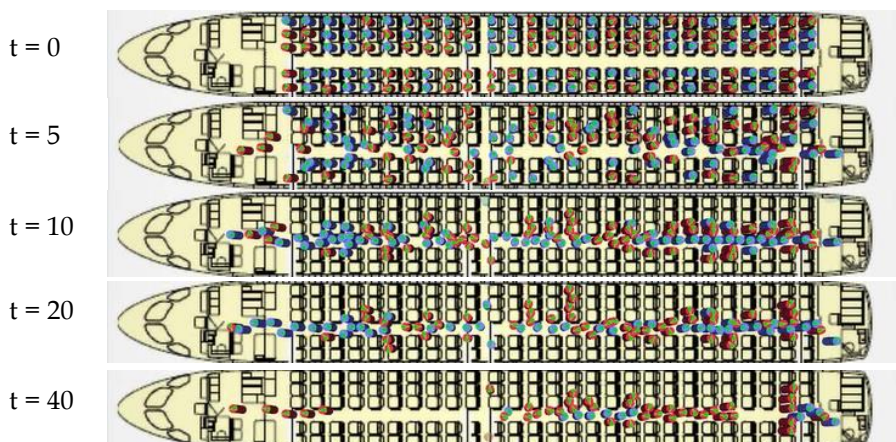
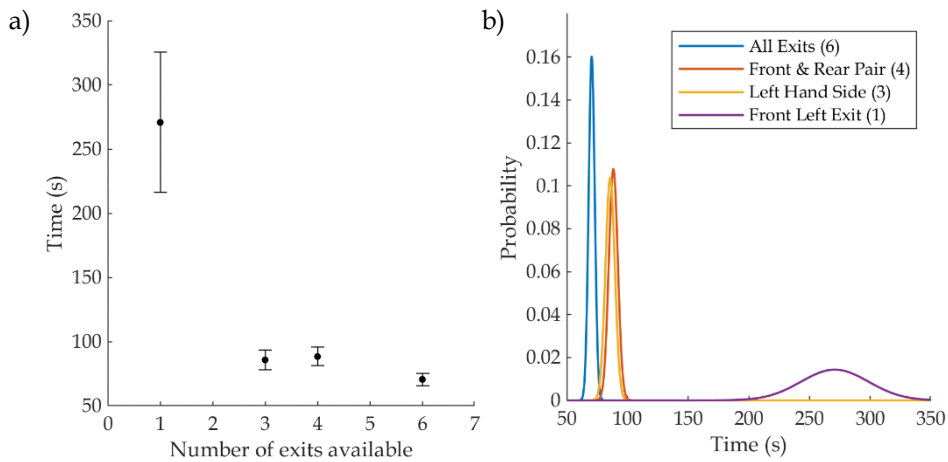


Fig. 3. Results of an A220 trial over time at intervals of 0, 5, 10, 20, and 40 seconds.



**Fig. 4.** Results from the study showcasing a) the scatter in evacuation for the number of available exits with 95 % confidence intervals and b) normally distributed probabilities.

<b>Table 1</b> Pathfinder evacuation results over all trials for the A220.	<b>Exit Configuration</b>	<b>Mean (s)</b>	<b>Standard Deviation (s)</b>
	All Exits (6)	70.52	2.490
	Front & Rear Pair (4)	88.34	3.700
	Left Hand Side (3)	85.72	3.850
	Front Left Exit (1)	270.8	27.87

Ultimately, the results of the validation study provide confidence in the use of the Pathfinder software for further work. Due to a lack of evacuation times available in the literature for the A220, the only conclusions that can be made relate to the potential certification of the aircraft. This means that as the A220 has passed evacuation certification it must have an evacuation time of less than 90 seconds with only half of the exits available. In simulating similar circumstances within the Pathfinder software, particularly for the case of only left-hand side exits available, a mean evacuation time of 85.72 seconds was achieved. This result would indicate that there is potential for the software to predict with reasonable accuracy, the evacuation times of the aircraft.

Moreover, the relatively small standard deviations from all the different exit configurations, as highlighted in **Fig. 4 a)** with 95 % confidence intervals and narrow distributions in **b)** indicates that the results of the simulation indicate high repeatability. Whilst only access to detailed evacuation data would allow for a more robust validation study of the Pathfinder software, these preliminary results provide confidence for future work to proceed with conservatism. Finally, of interesting note in the data, and as highlighted previously, is that an exponential decrease in evacuation time versus number of available exits can only be partially observed ( $R = 0.8662$ ). This is indicative of the fact that the absolute number of exits is not the primary factor in reducing evacuation time but the spatial separation of those exits is.

## 4. Conclusion

In conclusion, we have investigated the effect of aircraft and exit configuration of exit time for aircraft evacuations. This work is essential as accidents and serious incidents in aviation may result in a need to evacuate an aircraft, even if rarely. That is, when an evacuation is required, there is an increased risk of further loss of life. In order to minimise the additional risks during an event like a post impact fire, regulators and certifiers require all passengers to be out in less than 90 seconds, with only half the exits available in darkness.

Based on recent pushes to decarbonise aviation, there is the potential in the near term to see non-conventional aircraft configurations utilised. Specifically, Airbus' ZEROe program has a proposal for a small blended-wing-body aircraft. These non-conventional (not tube and wing) aircraft will need to consider the number and location of exits to ensure they meet the safety certification requirements. Interestingly, these results show that with multiple front exits, it may be possible to evacuate the aircraft with an aisle per exit at a rate that reflects the "all exits" case for a conventional tube and wing aircraft. That is, the primary bottleneck for the Airbus A220 was found to be the transit time with a single aisle. Given a blended-wing-body aircraft will inherently be shorter and wider, it will utilise more aisles, and if there are multiple closely spaced exits at the front of the aircraft, the 90 second rule may still be achievable. This might be easier to realise than front and rear exits configurations, and definitely easier than "over wing" exits (based on structural and fuel storage requirements).

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