EFFECT OF UNCOMMON EXIT LOCATION IN THE EMERGENCY EVACUATION OF TRANSPORT AIRPLANES

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INTRODUCTION

Aviation has evolved enormously since the era of early flights when the only worry was to maintain the aircraft airborne and controlled. Then, the next step was to make the flight safer, simpler and more efficient (McCormick 1995). The technology evolved due to a permanent effort done by the researchers, industries and aviation authorities (Anderson, 2002), in many areas, such as aerodynamics, propulsion, structures and avionics (Martinez-Val and Perez 2009). This endeavour has leaded to make commercial aviation the favourite of the public for medium and long distances. Although cost and speed have been two key drivers, to which environmental impact has been recently added, the underlying, permanent leitmotif of civil aviation has been safety (McIntyre, 2000; Krause, 2003).

Cabin safety has been one of the aspects considered within this scenario of research effort, since it is related to passenger survivability after crashes, emergency landings, etc. The ability to quickly evacuate the aircraft is an important survival factor after an accident. Thence, airworthiness authorities have established a set of requirements to ensure a minimum performance regarding evacuation. The potential scenarios are extremely varied and, therefore, the authorities have preferred to define a bench-mark based on a prescribed situation. The aircraft is full of volunteers, seated randomly, representing certain age-gender mix (EASA 2007, FAA 2008). Since the prescribed situation does not correspond to any specific accident scenario there is great debate about the pertinence of such requirement (OTA 1993, Hedo and Martinez-Val 2011), but it has the great advantage of being objective.

The rule, established in the 60s (Mohler et al., 1964), has evolved to encompass the developments in cabin materials, cabin crew training and evacuation means (Edwards and Edwards, 1990; Learmounth, 1993; OTA, 1993; Muir and Cobbet 1995, Goslin and Riches 2003). Currently, any new or largely modified derivative, transport airplane must show that all occupants can safely abandon the aircraft in less than 90 seconds, by means of a real emergency evacuation trial (EASA, 2007; FAA; 2008). The trials are costly and dangerous for the people taking part in them (OTA, 1993; Hedo and Martinez-Val, 2010). For this reason airplane manufacturers and civil aviation authorities have promoted the development of evacuation models that could be used for design and certification purposes. However, due to the lack of suitable software and data for model validation, the results have not been very promising. It is only in the last years when researchers are being capable of making meaningful contributions (Owen et al., 1998; Robbins and McKee, 2001; Galea, 2006; Xue and Bloebaum, 2008), although most models are of difficult handling or interpretation.

A few years ago, the authors of the present paper developed a new, agent-based simulation model with the specific aim of matching the conditions prescribed in the airworthiness requirements. The model, named ETSIA, was presented as the Doctor Thesis of the corresponding author (Hedo, 2009) and was tuned and validated with real data kindly offered by Airbus (Hedo and Martinez-Val, 2010). The model is capable of providing key information about the evacuation process and about how evacuation performance is related to cabin features (Hedo and Martinez-Val, 2011).

The objective of the present paper is to show the effect of uncommon exit arrangement in the evacuation process of narrow-body airliners, from the point of view of emergency evacuation certification, using the ETSIA model. Two main possibilities will be considered: large longitudinal shifting of the main embarking/disembarking doors; and suppression of some over-the-wing exits.

THE ETSIA MODEL

The ETSIA model is an agent-based computer model developed to simulate the evacuation trial of transport aircraft as it is performed in the certification process. It has been implement in Net Logo (Wilensky, 2007). As formerly indicated, the trial does not intend to reproduce any specific accident scenario but to provide a bench-mark for consistent analysis and assessment. In real life, the trial is performed only once for each aircraft, whereby the information provided is rather weak. Conversely, apart from the evident savings in time, money and risk, a simulation tool is capable of reproducing as many trials as desired, and the resulting information is much more interesting, both for the cabin designer as for the certification officer. The model has been described in detail elsewhere (Hedo and Martinez-Val 2010 y 2011), but will be summarised in the coming paragraphs.

Four submodels form the frame for the computer simulation: geometry, occupants, time and kinematics.

All geometrical information is managed by the geometrical submodel that handles all appropriate data about seats, aisles, exits, deployable slides, etc. The first step is to convert a detailed cabin plan, such as the one in Fig. 1, into a set of data gathering all required variables in the minimum computer memory (Hedo, 2009). Only one cabin is used for each aircraft version, typically in high density configuration. Once the cabin details are digitised, the available areas for people movement are converted into a grid of cells. The minimum discrete distance is 0.1m which is more than enough to accurately reproduce all cabin features. Occupants, passengers and crew members, are assumed to occupy a rectangular box of 0.5x0.3 m.

In the current status of the computer model only age and gender of passengers have been taken into account, for two reasons: first these are the only two attributes mentioned in the airworthiness requirements; and second, they are by far the most important characteristics according to literature (Muir and Cobbet 1995, Muir and Thomas 2003). Before each computer run, the simulated passenger population is distributed by age and gender, as indicated in the airworthiness regulations, and then randomly

assigned to a cabin seat. Crew members are considered to be in good physical conditions and, therefore, their attributes are similar to those of young men. Occupants' reactions times, marching speed, etc, are statistically distributed around mean known mean values for each category. Therefore, the computer screen will show six occupant categories (young men, senior men, young women, senior women, cabin attendants and flight crew members), identified by a different combination of hair and body colour (See Figure nº 2).
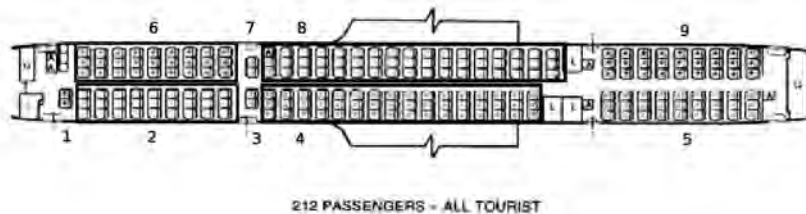

Figure nº 1. Planview of a B757 cabin with 8 exits (the numbers indicate the various seat zones (Seat blocks with similar layout and spacing)
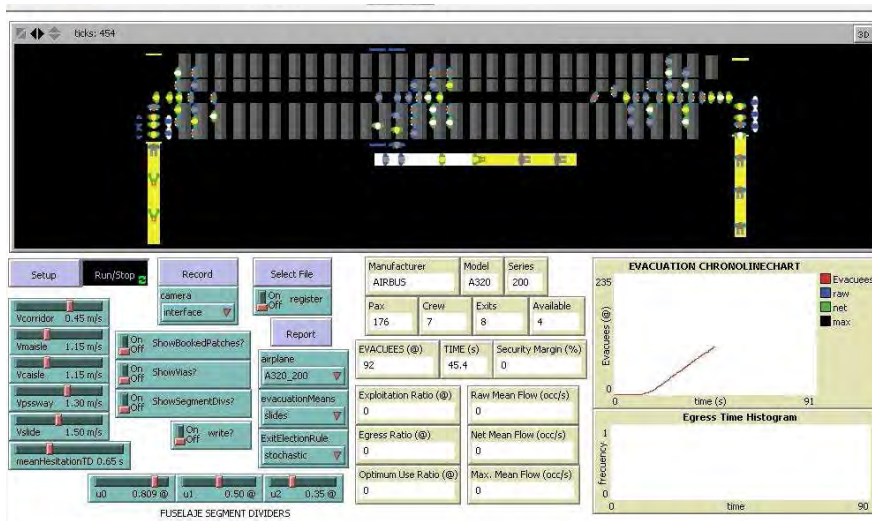

Figure nº 2. ETSIA model interface: computer screen during a simulated evacuation of the actual A320 cabin

With respect to the time submodel, time is considered as the background independent variable that continuously flows behind the scene and marks the rhythm and performance of the simulation. The time unit chosen in ETSIA is 0.1s; sufficient to simulate movement, hesitation, delay, etc. Any time point and time interval are defined against this background frame. Figure 3 shows the chronogram (a timeline of ordered subsequent time points) for the egress of a passenger. The evacuation takes place between the instant when the keyboard is hit to start the simulation and the

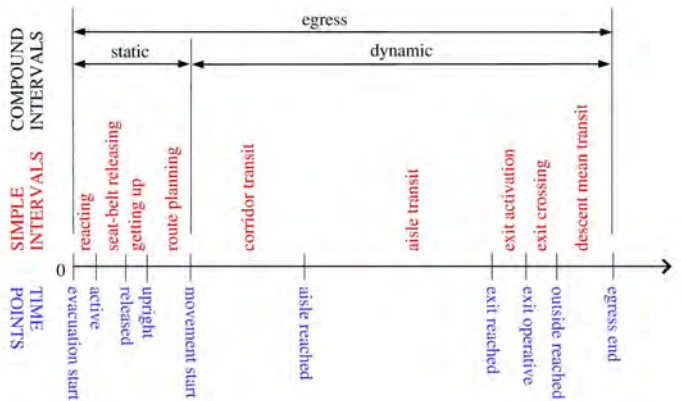time point when the last occupant reaches the ground in the computer screen.

Figure nº 3. Evacuation chronogram of a passenger egression

Finally, the kinematic submodel gathers all aforementioned features by means of the appropriate interfaces, and rules the movement of all occupants through the cabin and evacuation means. The kinematic submodel used by ETSA is a simple mathematical model able to reproduce all phenomena occurring in a certification evacuation demonstration.

The ETSIA computer model was tuned and validated with real data provided by Airbus (Hedo 2009, Hedo and Martinez-Val 2010). A series of consistency tests was performed to check the robustness of the whole model (Hedo and Martinez-Val 2011). The tests showed that the model was almost insensible to typical input data errors and stable with respect to the random nature of intervening variables (speed, reaction time, slide deployment time, etc).

In a previous research, twenty six narrow body airplanes were assessed with the ETSIA model, covering a broad spectrum: from regional turboprops (Fokker 50 or Saab 2000) to large, slender airliners (such as B757 or DC8-61). The results (Hedo and Martinez-Val 2011) showed the importance of two factors:

- seating capacity ratio; i.e. the ratio between the actual number of seats in the cabin and the maximum number of seats according to the exits (see Table 1). And
- emergency exit location; in particular its longitudinal distribution, taking into account that the two main exits are commonly placed at both extremes of the cabin for passenger embarking/disembarking and cabin servicing.

The results of that research indicated that the inappropriate longitudinal exit distribution was responsible for the long evacuation times of B757-200 with 10 exits and DC8-61. Airplanes with similar seating capacity ratio but better exit distribution or shorter average distance between exits behaved much better. Needless to say, all airplanes assessed were well below the

90s time limit, although one out of 1000 simulation runs of B757-200 with 10 exits went further than that limit for an extreme combination of very slow people at the beginning of some evacuation queues.

Exit type	No. passengers
A	110
B	75
C	55
I	45
III	35

Table nº 1. Evacuation capacity of exit types
Note: two close type III exits allow anevacuation capacity of 65 passengers

UNCOMMON EXIT LOCATION

As indicated above, all current airplanes have main doors at both cabin ends, for practical purposes. When they are used as emergency exits, provide a large passenger flow rate, but limited in efficiency for being fed by only one of its sides. That is particularly true if the door fits two lanes in the slide (as in types A and B).

The present research has chosen the A320 cabin to analyse the effect of uncommon exit location for various reasons: firstly, for it exhibits a commonly used arrangement (doors at the cabin ends and a pair of over-the-wing exits, as depicted in Fig. 4), used by many other designs; secondly, for it was the cabin used to tune and validate the ETSIA model, and all details are well known to the authors; and lastly, for the cabin does not showed any particular trouble in the 1000 simulation runs performed with it.

In the real emergency evacuation trial to certify the A320-100, its cabin had 179 volunteers (acting as passengers) plus 6 crew members (the crew members were real crew members, and had been trained for this particular cabin). Following the airworthiness requirements of the late 80s, the A320 exit arrangement was appropriate for 179 passengers, but the current regulations have raised the value to 195 passengers: 75 for a type B door (see Table 1), 55 for a type C door and 65 for two close over-the-wing exits; all exits present in both sides of the fuselage. The trial took 81.0 seconds and occurred without particular troubles. This last figure will be used for comparison with the new scenarios of shifted or suppressed exits.

Seven cases have been conceived to analyse the effect of uncommon exit location, ranging from rather radical arrangements to minor modifications. Whenever some location or position of exits is mentioned, it must be understood that the situation is fully symmetrical and the same exits are in both sides of the fuselage. To clarify the magnitude of the changes, let us say that the original type B door at the front end of the cabin was at 5.32 m from a certain arbitrary origin at the aircraft nose, and the rear type C door was at 29.64 m. This separation exceeds the 18 m limit between successive exits, but is acceptable for the presence of type III over-the-wing exits.
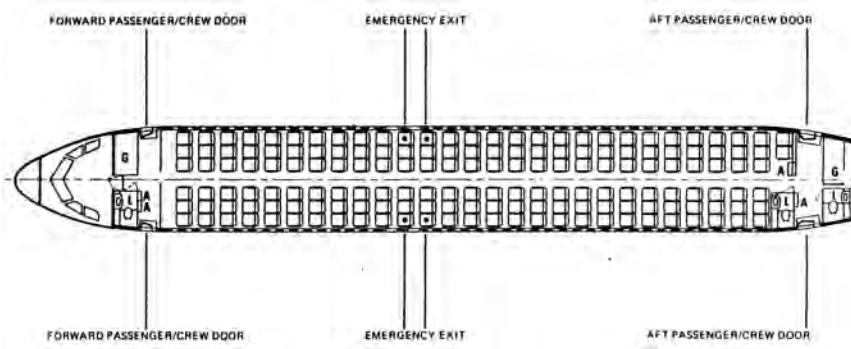
Figure nº 4. Plan view of a A320 cabin, showing the two cabin end doors
and a pair of over-the-wing exits, on each side of the fuselage

The exit arrangement in each one of the seven cases considered are listed in table nº 2. Since the idea of the present research is to analyse the effect of the location, all cases provided enough flow rate (according to Table nº 1) for the 179 passengers onboard. Scenarios V1a and V2a keep one or two of their exits at both cabin ends and do not comply with the 18 m rule (for the suppression of over-the-wing exits). In the real world this is not a problem for the designer may ask for an exemption, if the 90 s rule (the real important one) is respected.

Case	Exit types	Longitudinal position (from AC nose in m)	Evac. capacity (No. passengers)
V1a	A	5.3	220
	A	29.6	
V2a	A	10.6	185
	B	29.6	
V2b	A	10.6	185
	B	25.9	
V3a	B	10.6	185
	III	15.3	
	B	29.6	
V3b	B	10.6	185
	III	15.3	
	B	25.8	
V4a	C	10.6	195
	III	14.4	
	III	15.3	
	B	25.8	
V4b	C	10.6	195
	III	14.4	
	III	15.3	
	B	25.8	

Table nº 2. Type and location of exits in considered cases

Case V1a represents the situation of suppressing the type III exits, but enlarging the main doors at both cabin ends up to two type A doors, that might be sufficient to evacuate 220 passengers. Since this case is highly oversized from the point of view of the cabin capacity, in case V2a the rear exit has been converted to a type B door. Moreover, to diminish the effect of the long distance between both exits in case V1a, the front door has been

shifted rearwards to the coordinate where airlines commonly put the cut between business and tourist classes (let call it the BT transition position); equivalent to the space needed by seven high density rows. The distance between both exits is still larger than 18 m and so, case V2b, has shifted the type B rear door the distance equivalent to five high density rows.

To check other possibilities, case V3a has two type B doors; the first one shifted to the BT position and the rear one at the ordinary end of the cabin, but includes one type III over-the-wing exit. Case V3b is similar to case V3a except that the rear door is shifted five rows forward. Now Case V4a is very similar to the original cabin, but with the front door shifted rearwards to the BT position and in case V4b the rear door is shifted forward the aforementioned five rows.

To better understand the changes imposed by the aforementioned scenarios, Fig. 5 depicts case V2b. It is easy to check that both exits may be fed from both sides to improve the evacuation process. The red line in the middle of the cabin indicates the approximate partition between passengers heading to the front door and passengers going to the rear door. On comparing this figure with Fig. 2, it is easy to observe the magnitude of the changes in exit arrangement.
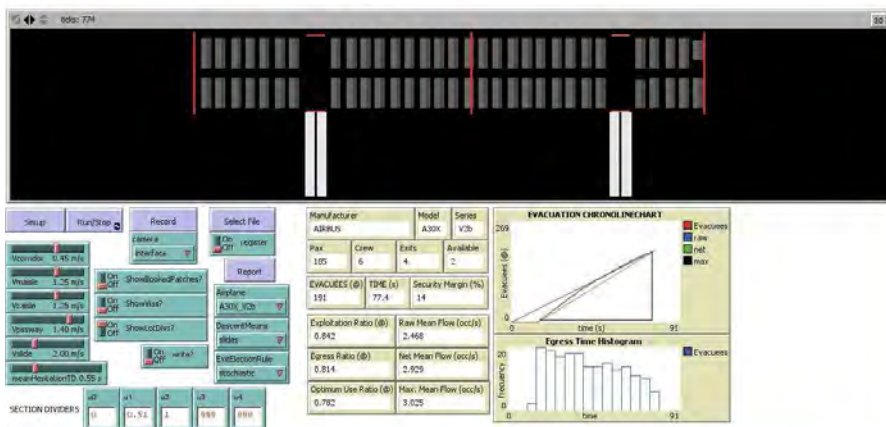

Figure nº 5. Empty cabin and results at the end of a simulated evacuation of case V2b (Chronolines and egression time histograms shown at the bottom right corner).

Each case has been simulated 1000 times. Therefore, the results have a strong statistical meaning. The results appear in figure nº 6. At first impression case V1a is the only one that behaves very badly (remember that the real certification trial took 81.0 s). Although the potential evacuation capacity is 220 passengers, widely exceeding the 179 figure, the exits are too distant and the passengers must travel a long way before reaching the exit. The average evacuation time is 91.3 s, and 917 runs out of 1000 overpassed the 90 s limit. All other simulated evacuations happened trouble-less.

Oppositely, cases V3b and V4b exhibited the shortest evacuations times with averages of 68.9 and 68.2 seconds, respectively. On looking at the details shown in Table 2 it seems that enlarging a type C to a type B door allows suppressing one of the over-the-wing exits to obtain very similar results.
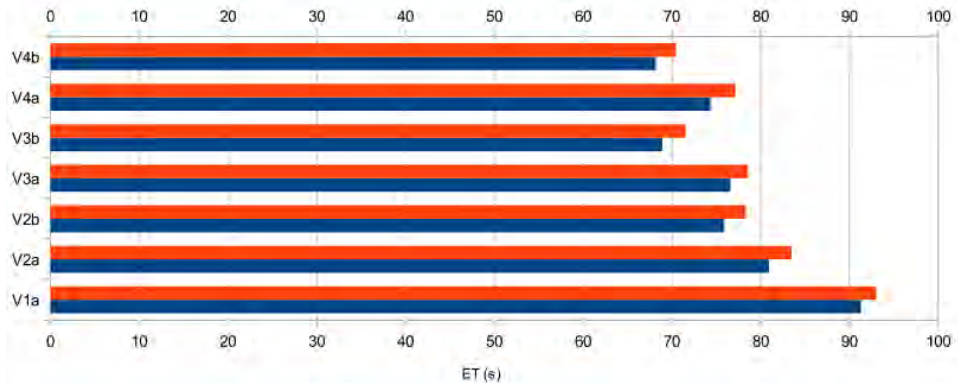

Figure nº 6. Mean evacuation time (blue bars, in seconds) and one-sided 95% confidence interval (red bars) of the A320 modifications studied

The in-depth analysis of the results provides more interesting information. For example, let us compare cases V1a and V2a. In both cases the evacuation capacity is well above the number of passengers. The distance between both exits is rather long, but the advantage of case V2a is that the front exit has seven rows ahead of the door and, consequently, 42 passengers feed the double lane slide much more efficiently. As a matter of fact, in case V1a 90 passengers take the fore exit and 89 the rear one, while in case V2a 108 passengers are evacuated through the front door against 71 that escape via the rear exit. Case V2a could be acceptable regarding the 90 s rule, but perhaps the extra structural weight for the type A door could be a burden from a designer viewpoint. The difference between cases V2a and V2b, 5.0 seconds, represents an additional evacuation time saving due to feeding also the rear door from fore and aft, apart from certain shortening in the mean evacuation path. On comparing cases V3a and V3b, the difference is larger, 7.7 s, for the presence of the intermediate type III exit improves the sharing and, therefore, improves the evacuation process.

CONCLUSIONS

The present study shows that the evacuation trial performed for airplane certification can be accurately simulated by a suitable computer model. Current hardware and software capabilities allow an almost perfect matching of real conditions, with the advantages of providing all relevant results at no meaningful cost and no personal risk.

According to the results obtained with the A320 cabin for several modified exit arrangements, the evacuation process depends much more on the appropriate location of exits than on its size. Moreover, when double lane slides (exits types A and B) are used, the evacuation efficiency

remarkably improves if the exit can be reached from both sides: i.e. the exit must not be placed at the end of the cabin, but having several rows of seats on both sides.

With a suitable location of the exits the designer could suppress one or two exits, out of four, with the corresponding savings in weight and equipment and providing faster evacuation than in the real certification trial.

Cabins with the front exit shifted rearwards to improve the evacuation would also provide better embarking of the aircraft by faster feeding the cabin. However, the forward shifting of the rearmost door could disturb the airplane servicing in intermediate stops, thus slowing the aircraft turnaround process.

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