A User-Operated Model to Study Strategy in Aircraft Evacuation

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A computer model is described to study strategies used by passengers evacuating a burning aircraft Two baseline cases are presented to demonstrate the model In the first case, in a simple scenario, strategies were found to change from even movement to the nearest exit to others farthest from the fire In the second case a test studying the effects of obstacles on passenger movement nonlinear effects were found that may increase the time required to escape The presence of obstacles created bottlenecks and, in some cases, isolated whole sections of the passenger cabin, making it impossible to escape This occurred even though exits were still available for escape, but passengers could not reach them

Nomenclature

n_t = total number of passengers
$time_f$ = total time to evacuate through doors
$time_l$ = time to open doors

Introduction

AIRCRAFT accidents can result in impact survivable crashes, followed by fuel and cabin fires The aircraft environment following the crash affects the time required to safely evacuate passengers Obstacles, fuselage integrity heat, toxic gases, fire spread, passenger management by crew, and passenger conflicts are just a few of the variables that can determine evacuation time A method to simulate evacuation on a quantitative basis in such an environment may help in interpreting accident histories

New aircraft cabin materials and structures are continually being developed to improve safety A quantitative evaluation may assess their relative merit in increasing survival Com puter simulation of the evacuation of passengers in the crash environment is a method that can provide some of this in formation A first generation simulation model called FIREVAC[1] has been developed by the University of Dayton Research Institute FIREVAC is an evacuation model that estimates the number of passengers safely evacuating a burning aircraft It allows for degradation in passenger performance due to exposure to cabin atmospheric conditions such as heat and toxic gases FIREVAC is now being used to analyze data obtained from full scale fire tests with state-of the art and advanced cabin materials The tests have been run at the NASA, Houston and FAA, Atlantic City, test facilities to assess the value of introducing advanced materials into cabins based on their impact on the fire environment and their contributions to increased survival in a burning aircraft In addition, where possible, it will be used to predict aircraft accident histories

One assumption in the FIREVAC model is a choice of passenger strategy Strategy is represented as an "optimal exit path." At present, a passenger's exit path at any time is determined from the passenger's present position and "distance" to the closest exit perceived as open Time is now the measure of "distance " Other factors may be added later to redefine the parameter distance In its present form, this evacuation pattern may prove representative for some cases but not be representative in the complex situation caused by a fire Any algorithm assumed for an evacuation pattern, such as the "optimal exit path," should be substantiated Ob viously, the best method is to obtain data derived from real passengers in an aircraft accident to substantiate the algorithm This is not always possible Another method is that used by the FAA in Oklahoma City. The FAA tries to study evacuation with actual test subjects in an evacuation simulator Other studies may provide data based on aircraft certification tests, but for a nonfire condition All of these alternative methods provide some data base but are limited with respect to fire studies numbers of test subjects and the convenience of running great numbers of tests Another method to enlarge the data base may be the use of a computer simulation for evacuation that is user operated

A first generation model has been developed at the NASA Ames Research Center to study the feasibility of using this approach for evacuation in fires The model is called STRATVAC STRATVAC has been demonstrated to a number of members of the flight safety community and has been favorably received STRATVAC has been developed to study potential escape patterns and strategies and to try to develop statistics for behavior given a particular aircraft configuration and an adverse condition In its present form STRATVAC is limited in conveying the sensory effects of fires but can convey some of the visual and psychological aspects inherent in an unknown and changing environment The addition of sound and/or color with the graphics package is now under consideration to enhance the concept of danger. Behavioral statistics obtained from STRATVAC will be compared with evacuation tests The present paper, however only includes a brief description of evacuation and the model Some initial results are included to exemplify the charac teristics of the model and its use

Model Development

STRATVAC is a completely user operated model designed to study each passenger's strategy given a simulated fire condition STRATVAC is written in FORTRAN 77 and contains graphics subroutines to portray the aircraft layout and the passenger's location and location of the adverse condition One graphics subroutine uses a Selanar graphics board and another, DISSPLA software available from ISSCO The graphics may be projected on a wide screen so that a number of users can review the display simultaneously

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In addition, evacuation directions could be elected using joysticks or voice actuation as commands The aircraft layout is a simplified representation of a wide body jet (Fig 1) The cabin is divided into first and tourist class sections and includes eight exits, four directly opposite each other on each side of the aircraft The fuselage is surrounded on four sides by an external field in which a simulated fuel fire can develop Penetration of the fuel fire into the cabin can occur at a number of points along the fuselage wall and/or at the exits A simulated fire may also occur in the cabin, independent from the fuel fire Fire can spread from one location to another at different rates in four directions, right left, tail, and pilot A "draw" determines if the fire will spread in a particular direction based on limiting thresholds Another draw determines the number of times this procedure is repeated in a unit of time The draw is compared to arbitrary thresholds or those generated by a beta distribution function The beta function is a function of the time from the start of the fire and is a convenient way to simulate a birth and decay fire history The threshold functions can be different for fire spread in the fuel or cabin fire

Passengers are assumed to be buckled in their seats at the start of the evacuation Passenger actions included in the model are 1) releasing seatbelts and rising; 2) moving through seats; 3) moving through aisles; 4) waiting for doors to be opened; and 5) jumping out of doorways

The time required to perform these actions is shown in Table 1 The time for each operation is assumed a constant for every passenger and is estimated based on times reported by the FAA, Oklahoma City,[2] for test subjects in an evacuation simulator, and on a review of videotapes (United Airlines 767 Videotape of Certification Tests, 1982) of evacuation from aircraft during certification tests The results show that moving through an aisle is faster than moving through a row of seats or jumping out of a doorway Releasing seatbelts and rising and opening doors are the slowest operations

In the model, obstacles can be introduced into the cabin These obstacles can be randomly distributed throughout the aircraft based on a percentage of the total number of locations in the cabin The obstacles cannot be moved and act as blocks to passenger movement

The model also senses passenger conflicts with each attempted move When two or more passengers attempt to move into the same vacant location, the conflict is sensed and is resolved by prompting the user to choose a move to another location or the option of gambling for the location The losers of the gamble remain in their old locations; the winner moves into the vacant location Another conflict that is sensed and resolved occurs when other passengers attempt to move into a location occupied by a delayed passenger Again, the conflict may be resolved by choosing other locations to move to or by gambling for the location If the passenger elects to gamble, the results of this gamble lead to several possibilities: Passengers may not move at all, may interchange places, or may be bumped into some contiguous location, including out an exit

During the use of the model the test subjects have only limited knowledge about their environment At the beginning of the test, they are allowed to review the entire aircraft layout before any fire develops and before obstacles are in place This action is akin to reviewing the safety card in an aircraft From that point on, their view of the aircraft becomes limited to only their immediate environment in the cabin and outside the aircraft As they move through the cabin this view is updated

Although a test case has not been included in this paper the model also has an option to study crew management Up to six crew members can be assigned to different locations in the aircraft Each can recommend evacuation directions to ten passengers in the immediate area surrounding the crew member Before passengers are prompted to move, they are informed of the recommended direction identification, and location of the crew member making the recommendation The passenger then may or may not elect to follow the recommendation Thus, a study can be made of the crews' and passengers' reactions based on the use of the crew management option

Background

Examining the assigned average time for each passenger action in the model, one can estimate an evacuation pattern in a noncrash evacuation for comparison to the simulated fire environment During the time it takes the crew to open the doors and deploy slides, passengers have released their seatbelts and risen and have tried to move to the aisles Passengers close to the aisles will fill these aisles within 6 to 10s while the doors are being opened Passengers in seats removed from aisles will move closer to the aisle, waiting to enter the aisle queues before the doors open Thus, there will be a holding pattern of up to 10 s

Table 1 Passenger evacuation actions

Action	Time, s
Release seatbelts and rise	~ 5 0
Move from one seat to another	~ 1 0
Move from one aisle location to another	~ 0 25
Await door opening	~10 0
Move out an exit	~ 1 0[a]

[a]Exits over a wing take ~2 0 s

Table 2 Baseline demonstration of passenger movement strategy[a]

Move numbers	Passenger movement	Passengers electing that specific movement,%
1 3	Move into aisle	100
	1) Move to nearest exit away from fire	81 8
4	2) Move to nearest exit farthest from fire	18 2
5	No change in types of moves compared to 4	
	1) Move to nearest exit away from fire	54 5
6 7	2) Move to nearest exit farthest away from fire	45 5
8 15	No change in type of moves compared to 6 7	
	1) Move to nearest exit away from fire	54 5
	2) Move to nearest exit farthest away from fire	36 4
16	3) Move to next exit farthest from fire	9 1

[a]Fire began in the door (exit 5); passenger occupied window seat Data based on individual actions of 11 subjects tested separately (Configuration 1)

Table 3 Effect of randomly distributed obstacles on number of available exits

	No of available exits	
Cabin space blocked, %	Configuration 1[a]	Configuration 2[b]
0	8	8
10	7	8
20	6	6
30	4	6
40	4	5
50	3	4

[a]Aisle widths at exits 1 2 7 and 8 are double width; aisle widths at exits 3 4 5 and 6 are single width [b]Aisle widths for all exits are double width.

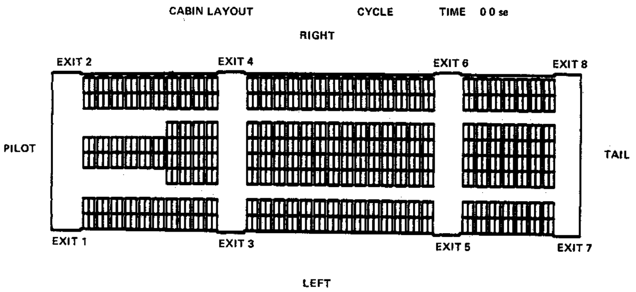

Fig 1 Aircraft layout

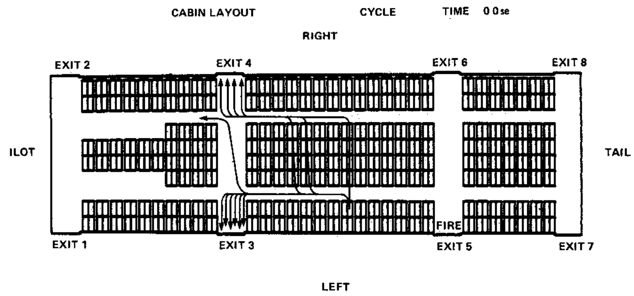

Fig 2 Evacuation test results

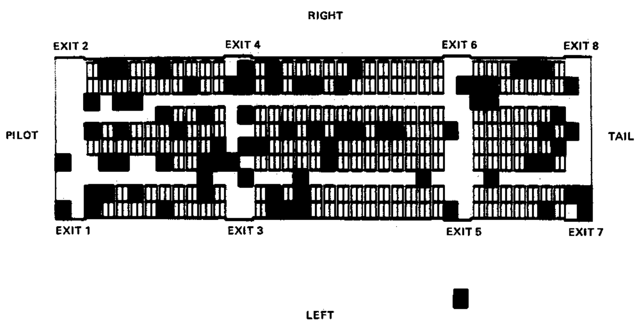

Fig 3 Effect of blockage on escape routes

Because moving out of an exit is slow compared to moving along an aisle toward an exit, jumping out the exit can prove to be the rate determining step in evacuation A rough estimate of evacuation time for this case can be obtained by assuming: 1) a load of 256 passengers (n_t); 2) jumping out of an exit takes 1 s and is the rate determining step (no wing exits); 3) a 10 s lag to fully open doors ($time_l$); 4) no obstacles; 5) two passengers escaping at once from the same exit; 6) equal loading on each exit; and 7) eight exits Then

$$n_t = \text{number of exits} \times \text{rate/exit} \times \text{time}_f \tag{1}$$

and the total time to evacuate is

$$\text{total time} = \text{time}_f + \text{time}_l \tag{2}$$

Using this equation for the case where all exits are available the time to completely evacuate the cabin would be approximately 25 s If half the exits are available, an average passenger load per exit for a wide body jet might be around 64 people This is similar to a condition for certification tests In this case, the evacuation would take approximately 42 s A few additional seconds would be required to move down slides and run to safety For the case where two exits are over a wing, the passenger distributions are not equal If all the exits are available

$$n_t = 256 = 6 \text{ exits} \times \frac{2 \text{ passengers}}{1 \text{ s exit}} \times \text{time}_f + 2 \text{ exits} \frac{1 \text{ passenger}}{1 \text{ s exit}} \times \text{time}_f \tag{3}$$

where $\text{time}_f = 19$ s and the total time $= 29$ s The passenger distribution here consists of about 19 passengers queued at each wing exit and about 36 at the other exits For the case where half the exits are available and there are two wing exits

$$256 = 2 \times 2 \times \text{time}_f + 2 \times 1 \times \text{time}_f$$

where $\text{time}_f = 43$ s and the total time $= 53$ s or a distribution of about 43 passengers at each wing exit and 86 at the other exits

Thus in an orderly optimum, and nonfire environment that may represent an initial phase of evacuation in some crashes, the pattern might be quickly represented as simple queues at the exits. This may not be true however for the fire environment results Two simple cases were run with a simulated fire environment to demonstrate the kinds of information the model generates and to act as baseline cases for comparing other, more complicated test cases

The first case used 11 subjects, one at a time Each individual had no prior knowledge of the simulated aircraft environment or of any of the other test subjects' results In this sample case when one subject was tested there were no obstacles blocking seats or aisles but there was a hypothetical fire condition in the cabin All operations could be performed at the *same* speed The fire spread from exit 5 along the left side of the aircraft and across the cabin The results of the study are shown in Fig 2 and Table 2. At first most of the subjects chose to move to the exit nearest to them away from the fire (exit 3) and to the nearest exit farthest from the fire (exit 4) As the fire progressed the ratio of these two strategies changed Only about half still moved to the nearest exit (exit 3); the remainder moved to the nearest exit located farthest from the fire (exit 4) In one case, an exit even farther from the fire was chosen (exit 2); obviously fire spread affects the choice of exit In subsequent tests the effect of introducing other parameters, such as different operation times passenger conflicts, obstacles etc will be studied and compared to this baseline case

In another sample case the effect of obstacles on potential escape routes was studied for two cabin configurations Table 3 shows the effect of randomly distributed obstacles on the number of exits available for escape As expected the number

Table 4 **Passenger loading per exit as related to obstacles**

		No of passengers per exit at indicated percentage of cabin blockage					
Exit	Aisle width	0%	10%	20%	30%	40%	50%
			Configuration 1				
1	Double	32	32	20	22	11	2
2	Double	32	32	20	22	11	6
3	Single	32	32	20	n/a	n/a	n/a
4	Single	32	32	n/a	n/a	n/a	n/a
5	Single	32	n/a	n/a	n/a	n/a	n/a
6	Single	32	32	94	39	30	15
7	Double	32	32	9 5	11	11	n/a
8	Double	32	32	9 5	n/a	n/a	n/a
% Passengers capable of escape[a]		100	91 9	82 4	72 1	59 2	49 6
% Passengers capable of escape through exits		100	89 6	76 8	48 5	41	17 1
			Configuration 2				
1	Double	30	21	27	15	17	n/a
2	Double	30	21	27	15	17	0
3	Double	30	21	27	15	5	5
4	Double	30	21	n/a	n/a	n/a	n/a
5	Double	30	21	27	25	10	1
6	Double	30	21	27	25	n/a	n/a
7	Double	30	21	n/a	n/a	n/a	n/a
8	Double	30	21	27	25	3	3
% Passengers capable of escape[a]		100	90 3	79 7	68 6	57 6	47.0
% Passengers capable of escape through exits		100	89 2	84 6	73 5	30 1	8 0

[a] Obstacles may also be interpreted as injured passengers; an obstacle in any seat at the beginning of evacuation is assumed to be an in capacitated passenger unable to escape All other passengers are assumed to be capable of escaping

of exits available is directly related to the number of obstacles present Half of the space in the aircraft blocked by obstacles results in about half the number of exits blocked This proportion is not true for the average passenger loading per exit Table 4 shows passenger loading per exit as a function of the number of obstacles In this case, passenger loading can change dramatically as a function of blockage and con figuration of the width of the exit aisles In configuration 1, the width of the exit aisles was double at the ends of the cabin and single toward the center For configuration 2, all exit aisles were double width For configuration 1 at 20% blockage, the average loading on exit 6 far exceeds the load on other exits For configuration 2, more common in wide body jet design, the wider aisles result in more evenly distributed passenger loadings on the exits with an increase in blockage The effect of blockage is even more apparent if possible escape routes are plotted on the cabin layout As the number of blocks increase, escape routes become narrower and bottlenecks occur This is shown in Fig 3 for configuration 2 In some cases whole sections of the cabin become isolated and lose every possible escape route, even though a large number of exits are still technically available for escape

Conclusion

A model has been developed to study passenger evacuation strategy in aircraft accidents involving fire In simple baseline tests with the model, it is apparent that strategies may vary even given a simple aircraft fire environment Therefore, realistic evacuation models should anticipate varying strategies The effects of blockage on evacuation have also been studied Blockage has a nonlinear effect At small blockage ratios, the time to evacuate may be severely affected by bottlenecks and isolation Further use of the model for comparative testing of the effects of other parameters is in progress

Acknowledgment

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References

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