NASA CONTRACTOR REPORT 166511

A Computer Simulation of Aircraft Evacuation with Fire

V. E. Middleton

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A Computer Simulation of Aircraft Evacuation with Fire

Victor E. Middleton
University of Dayton Research Institute
Dayton, Ohio

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National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

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ABSTRACT

A computer simulation has been developed to assess passenger survival during the post-crash evacuation of a transport category aircraft when fire is a major threat. The computer code, FIREVAC, computes individual passenger exit paths and times to exit, taking into account delays and congestion caused by the interaction among the passengers and changing cabin conditions. Simple models for the physiological effects of the toxic cabin atmosphere are included with provision for including more sophisticated models as they become available. Both wide-body and standard-body aircraft may be simulated. Passenger characteristics are assigned stochastically from experimentally derived distributions. Results of simulations of evacuation trials and hypothetical evacuations under fire conditions are presented.

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SECTION 1

INTRODUCTION

University of Dayton Research Institute (UDRI) scientists have developed a computer model, FIREVAC, to simulate passenger evacuation from a generic aircraft, with provision for a post-crash scenario including fire.

1.1 MODEL OBJECTIVE

The model objective is support for the study of:

1) The effects of fire-induced toxicants on time required for passenger evacuation and, hence, probability of passenger survival;

2) the effects of aircraft design and materials on time required for passenger evacuation (both with and without fire); and

3) evacuation procedures.

1.2 MODEL ORGANIZATION

The model has three logical modules. They are:

1) Cabin Environment Module (CEM) - The CEM describes a two-dimensional cabin environment as a function of time. Environmental factors include cabin configuration (placement of seats, aisles, doors) and the effects of fire (temperature and concentrations of toxic gases). Possible future additions to this module would provide for a three-dimensional environment (the addition of height to the present length and width), as well as the inclusion of smoke and crash debris.

   The present computer code implements the CEM by reading data files which provide the time-dependent cabin description. These data files can be either derived from test data or the output of mathematical models of fire such as MacArthur's (UDRI) DACFIR model developed for the FAA (see Reference 1).

2) The Human Factor Module (HFM) - The HFM calculates the physiological effects of fire-related toxicants on human escape behaviors.

The approach taken is the use of a human response factor which is used to modify passenger movement parameters and which varies with the history of cabin conditions. This response factor is currently calculated using the concept of a "Fractional Incapacitation Dose", following the ideas of Sarkos and Crane (see References 2 and 3). The fractional incapacitation dose represents a passenger's accumulation of toxicants (heat, gases) as a fraction of the dose required to incapacitate that passenger. Effects of the separate toxicants considered are assumed additive.

3) Passenger Egress Module (PEM) - The PEM simulates passenger movement. Each Passenger is assigned an "optimal" (see section 4.2) exit route through the aircraft configuration and proceeds along this route subject to interaction with other passengers and ambient conditions. Exit routes can be updated to reflect the changes in the cabin environment, as relayed from the CEM. Passenger movement behavior will change as dictated by the HFM. Passenger position is displayed by "snapshots", graphical output representing the aircraft interior as a function of time.

Figure 1 shows the interaction between the three logical modules in terms of the data flow between them. The model is a clock-driven simulation; that is, at given time increments the cabin environment, passenger physical condition, and passenger positions are updated. Note that the update increments need not be the same for all phenomena, e.g., passenger positions can be calculated more often than the cabin atmosphere is updated. (See Appendix A, card type A for detailed definition of update time parameters.)

The next three sections of this report will examine the three logical modules in detail.

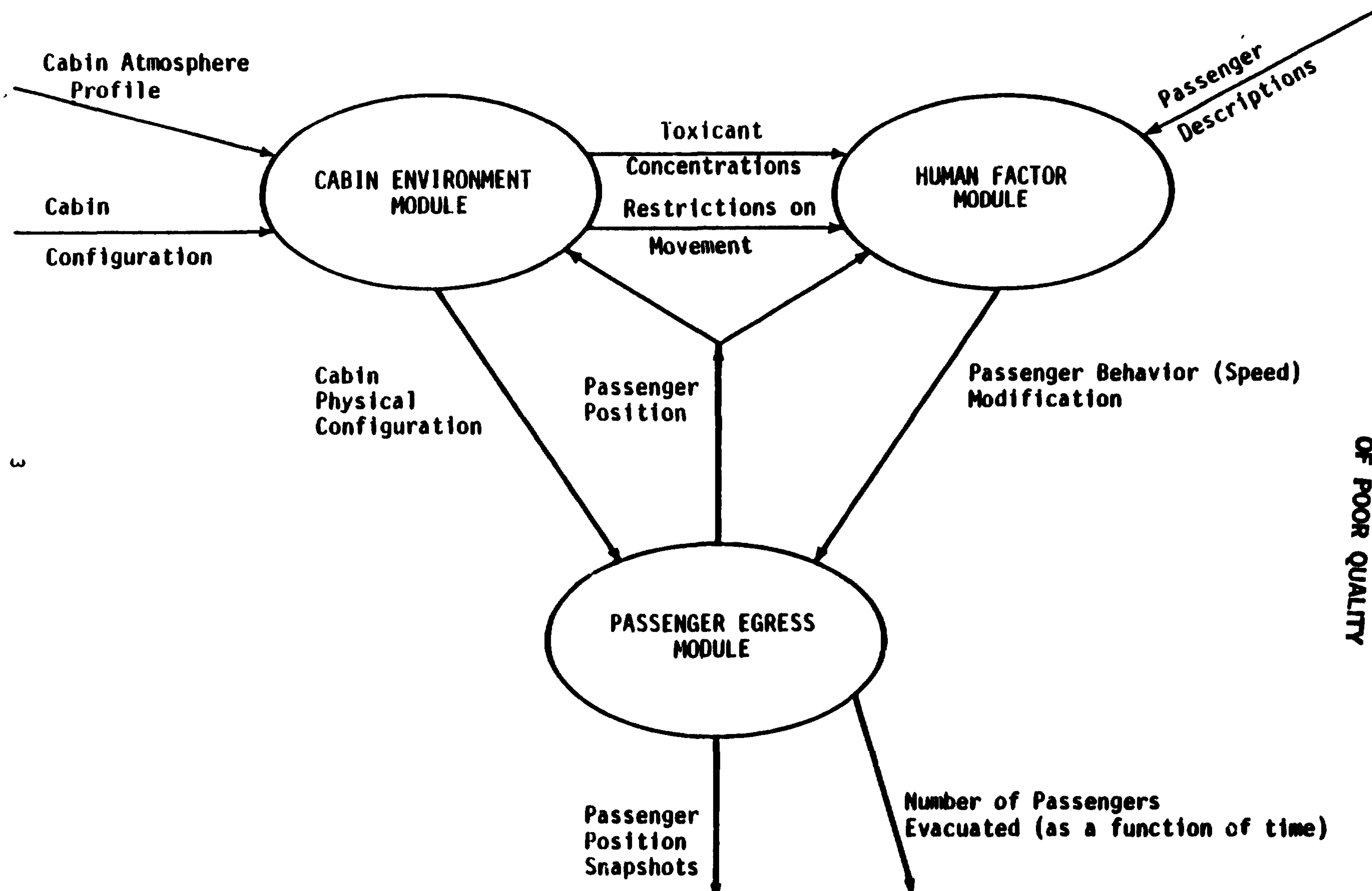

Figure 1. Data Flow Between Logical Modules of FIREVAC.

SECTION 2

CABIN ENVIRONMENT MODULE

As can be seen from Figure 1, the CEM processes two primary data structures, the cabin configuration and the cabin atmosphere profile. The section will describe the computer implementation of the CEM in terms of the breakdown of the primary data structures into their component parts and the processing functions which operate on those components.

2.1 THE CABIN CONFIGURATION

The cabin configuration model inputs describe the aircraft as a set of nodes or boxes. These nodes can represent seats, aisle space, exit doors, aircraft skin or exit slides. Each node is assumed large enough to hold a single passenger. Node location is defined with a two dimensional row-column coordinate system. Typical aircraft configurations are shown in Figures 2 and 3. The numbered nodes represent seats with passengers, e.g., row 2, column 3 is the seating (initial placement) assignment for passenger 1 in both Figures.

Nodes are classified according to the type of space they represent (i.e., seat node, aisle node, etc). Passenger speed is then defined in terms of the time required to traverse a given node type.

For each distinct node type the model requires the mean and standard deviation, the maximum and the minimum time of passenger movement through that node type. Individual passenger node movement times are stochastically assigned by assuming normal distributions within maximum and minimum (see section 3). The model has been exercised using time data supplied by J. Gillespie of the FAA as described in Reference 4. The test case was a DC-9 evacuation, the data based on a test demonstration with 144 subjects conducted August 2, 1975.

The values for interior node types (1-3) were not obtained from the DC-9 evacuation. To quote from the above referenced Gillespie report (p.7)

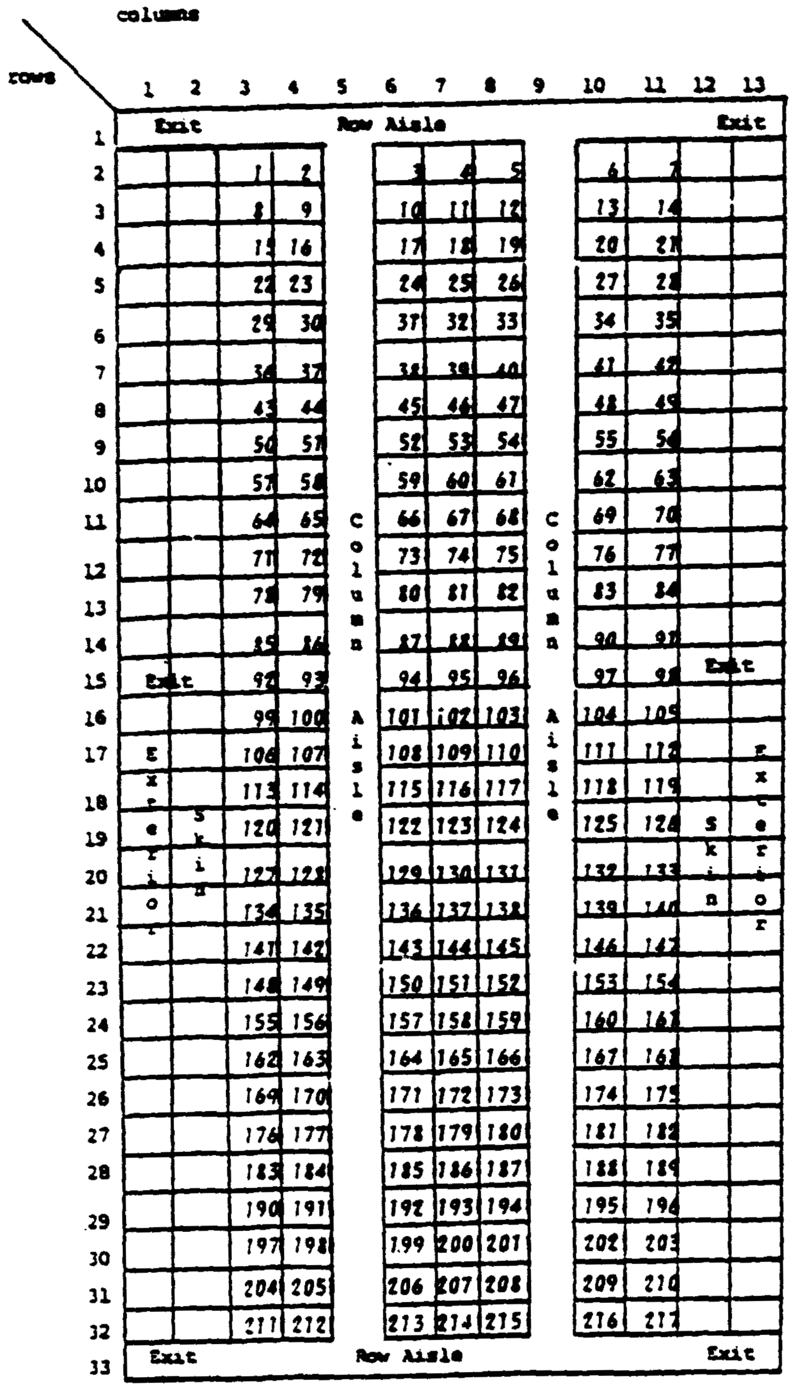

Figure 2. Sample Aircraft Configuration
with Passenger Placement.
(B767-200)

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rows \ columns	1	2	3	4	5	6	7	8	9	10
1	Exit			Row Aisle					Exit	
2			1	2		3	4	5		
3			6	7		8	9	10		
4			11	12		13	14	15		
5			16	17		18	19	20		
6			21	22		23	24	25		
7			26	27		28	29	30		
8			31	32		33	34	35		
9			36	37		38	39	40		
10			41	42		43	44	45		
11			46	47	C	48	49	50		
12	E		51	52	o l	53	54	55		E
13	X		56	57	u	58	59	60		X
14	T		61	62	m n	63	64	65		T
15	E	S	66	67		68	69	70	S	E
16	R	K	71	72	A i	73	74	75	K	R
17	I	I	76	77	s l	78	79	80	I	I
18	O	N	81	82	e	83	84	85	N	O
19	R		86	87		88	89	90		R
20			91	92		93	94	95		
21			96	97		98	99	100		
22			101	102		103	104	105		
23			106	107		108	109	110		
24	Exit		111	112		113	114	115	Exit	
25	Exit		116	117		118	119	120	Exit	
26			121	122		123	124	125		
27			126	127		128	129	130		
28			131	132		133	134	135		
29			136	137		138	139	140		
30			141	142		143	144	145		
31			146	147		148	149	150		
32			151	152		153	154	155		
33	Exit		Row Aisle			156	157	158		
34			159	160		161	162	163		
35			164	165		166	167	168		
36			169	170		171	172	173		
37			174	175		176	177	178		
38						Row Aisle			Exit	

Figure 3. Sample Aircraft Configuration with Passenger Placement. (DC-9, Series 180)

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> Data on passenger movement within the aircraft are based upon tests done at CAMI with sixteen test subjects one at a time as they rose from their seat, proceeded to the aisle, and moved down the aisle to the exit. Therefore, this data does not include any interference effects between passengers as they move into the aisles. It has been noted that bottlenecking occurs at the exit doors in test cases run with the data. It was impossible to obtain passenger movement data inside the aircraft from available evacuation films.

Relevant data in seconds is as follows:

NODE TYPE	$\bar{X}$	S	MAX.	MIN.	NODE DESCRIPTION
1	.253	.03	.3	.2	row aisles
2	.253	.03	.3	.2	column aisles
3	.933	.106	1.3	.75	seat
4	.96	.33	2.0	.5	Type I exit doorway
5	2.33	1.42	7.	.7	Type III overwing doorway (smooth flow)
6	1.54	.0	2.5	.6	Type I exit slide
7	2.97	.0	4.2	1.1	Type III overwing slide (smooth flow)
8	1.72	.87	5.6	.7	Type III overwing exit door (erratic flow)
9	2.09	.0	4.0	1.4	Type III overwing exit slide (erratic flow)

Where $\bar{x}$ = Mean time through node (sec).

s = Standard deviation of time-through-node distribution (sec).

Max. & Min. = Maximum and minimum times through node (sec) (i.e., we use a clipped Gaussian distribution.)

Gillespie makes a distinction between smooth and erratic flow for the overwing exits because passengers had to be forced by crew members to maintain reasonable traffic flow to one of the overwing exits. It should be noted that in our data sets S = 0 for the exit slides (nodes type 6, 7, 9) whereas the Gillespie data includes the experimental data for standard deviations. Our rationale is the assumption that passenger behavior on the exit slides is more a function of gravity than of those passenger physical characteristics which determine behavior interior to the cabin.

Also required as input is the mean time to open a door. The data used were:

Type I exit	= 10.4 secs.
Type III overwing exit - smooth flow	= 12.8 secs.
Type III overwing exit-erratic flow	= 15.8 secs.

The model has two variables to describe exit status: IXITPP and IXITRL. The first of these defines passenger perception of the exit status, i.e., whether the passenger believes the exit will be open when the passenger reaches it and, hence, is a good exit target. The second provides the physical reality of exit status, i.e., whether a passenger can actually egress through a given exit. IXITPP is used in the determination of passenger exit path and IXITRL is used in the simulation of passenger movement (see section 4).

The input variables which comprise the cabin configuration are listed on the B and C card types in Appendix A.

2.2 THE CABIN ATMOSPHERE PROFILE

The cabin atmosphere is defined as a set of toxicant values (temperature, toxic gas concentrations) which are a function of both time and cabin position. Variation in time is achieved by updating the toxicant values at set intervals (as defined by an input parameter). Variation as a function of cabin position is achieved by assuming each cabin node has its own atmosphere, that is, a complete set of toxicant values is assumed for each cabin node.

Toxicant values are derived from an input file which represents a series of sample readings of those values at various cabin locations. This input file can contain experimental data or the output from a mathematical model of fire. In either case, the input file may not provide the complete cabin atmosphere; sample reading times may not coincide with model atmosphere update times, and there is no guarantee that each cabin node will represent a sampling location for each (or any) toxicant.

This means the model must expand on the data provided by the atmosphere input file and approximate whatever values may be missing. Each model atmosphere update performs a two-step approximation process. The first step provides temporal variation, the second spatial variation. This two-step process mirrors the format of the atmosphere input file. Each input file is organized into data sets. Each data set contains one reading for each toxicant at each of that toxicant's sampling locations. Each reading in a given data set is assumed to have been taken at the same time, as measured from clock time = 0 for the model scenario. (Note that clock time = 0 is not necessarily the start of passenger movement. See Section 4 for details of passenger movement).

Data sets are assumed to be in chronological order. At any time during the simulation (in particular at atmosphere update times) the model is presumed to have read (and stored in memory) two data sets; the first representing a time less than or equal to the simulation clock time, and the second greater than that clock time. Variation in time for the sampling point values is achieved by linear interpolation between appropriate values of the two data sets. This is the first step of the cabin atmosphere approximation process. It provides a temporally complete profile of toxicant values at toxicant sampling locations.

The next step in the cabin atmosphere approximation process is to find values for each toxicant at each cabin node for the given simulation time. We use a weighted average of some (or all) the sampling points. This method was chosen for ease of implementation and for the generality it offers. It requires no assumptions as to the locations or number of sampling points.

For a given toxicant:

Let P_i $i = 1, n$ represent the sampling points

Let P represent a point of interest

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Let V_i represent the toxicant value (temperature, gas concentration, etc.) at P_i. The problem is to calculate a value, V, for the point P. Let d_i represent the distance from P to d_i, (i.e., if P is cabin node (n_p, m_p) and $P_i = (n_{p_i}, m_{p_i})$ then $d_i = \{(n_p - n_{p_i})^2 + (m_p - m_{p_i})^2\}^{1/2}$.)

If $d_i = 0$ for any i then P is a sample point and no approximation is required. Otherwise, let:

$$V = \sum_{d_i < R} \frac{\frac{1}{(d_i)}}{a} V_i$$

where:

R defines the region of approximation (i.e., if $d_i > R$ then V_i does not contribute to V)

and $a = \sum_{d_i < R} \frac{1}{(d_i)}$.

Note that as the distance from P to P_i decreases or increases, the value V_i makes a correspondingly lesser or greater contribution to the weighted average V.

The function, $1/d_i$, used above is not the only choice of weighting factor, and was selected for simplicity in the absence of any criteria to favor another choice. Should future experience recommend another function (as for instance $1/d_j^2$) the model could easily be changed.

Note in the above if there is only one sampling point, P_i, within the region of approximation, then $V = V_i$. In this instance we have merely taken the value of the closest point. If P is on a line between two points P_i and P_j and those are the only two points within the region of approximation, then the above is equivalent to linear interpolation.

We currently have two sets of cabin atmosphere data. The first of these is derived from FAA C-133 Fire tests as described in reference (see

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Reference 2) (see Fig. 4). We have used this data to provide an atmosphere for wide-body simulations (specifically in a Boeing 767). Unfortunately, this data is given for only a single sampling location. More complete data is available from a series of NASA fire tests (see Reference 5). This data was used to provide multiple sampling point data for both temperatures and gases. Fig. 5A shows the test configuration with data collection points and Fig. 5B shows the corresponding model sampling point locations for a DC-9 cabin configuration.

FAA C-133 Fire Tests (Sarkos, 1982)

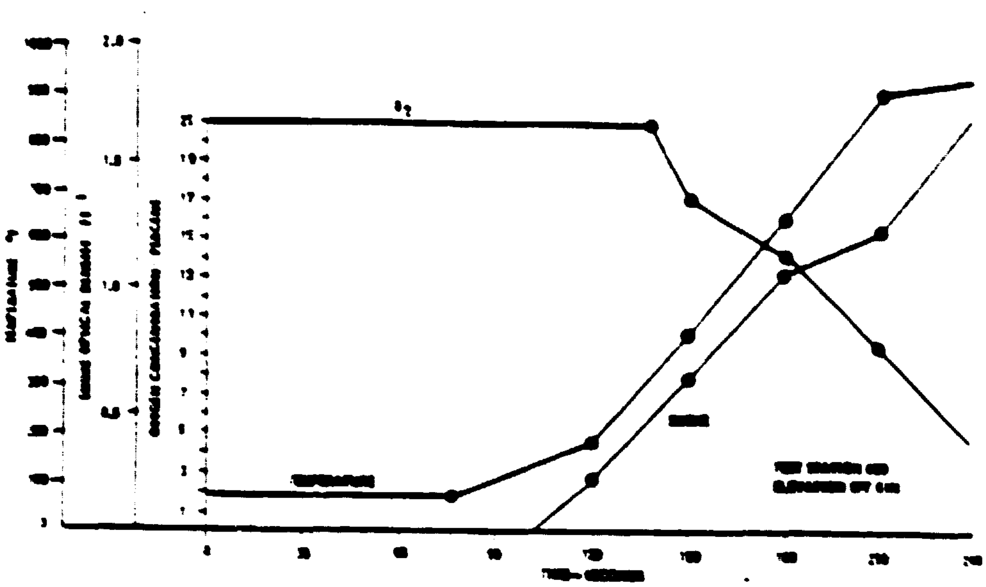


Figure 4(a). Hazards in Aft Cabin Produced by Burning Interior Materials.

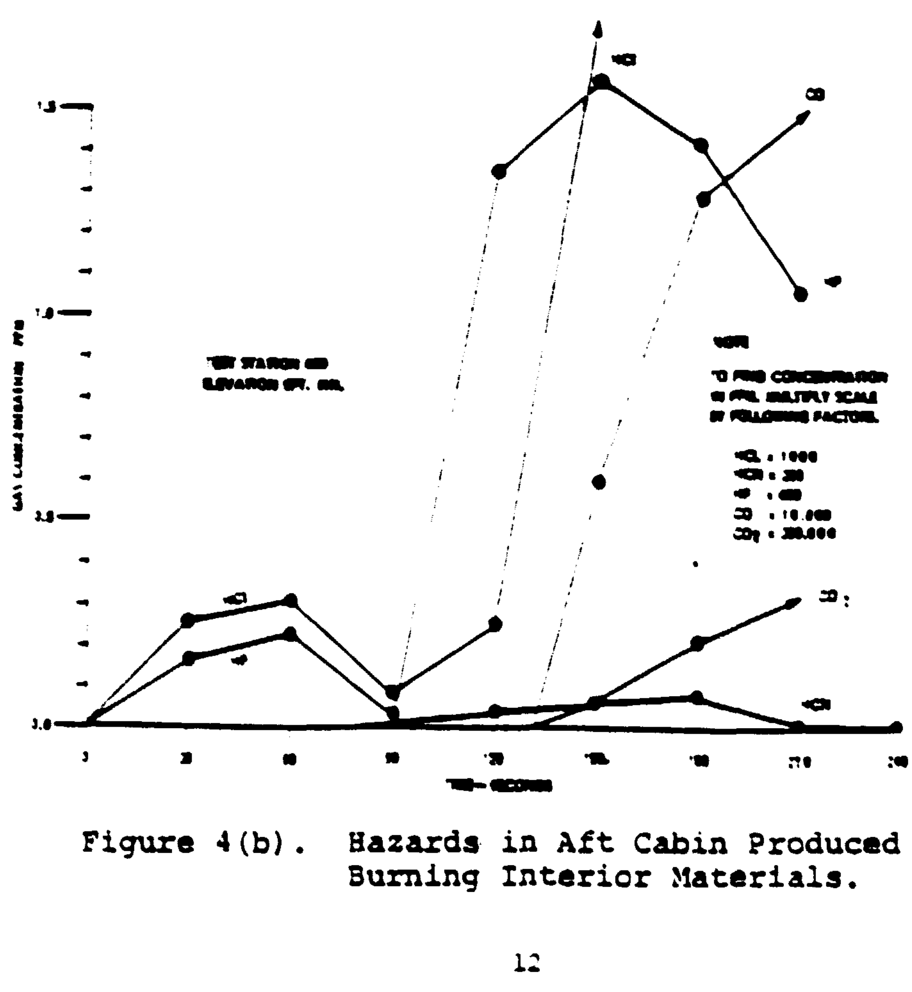
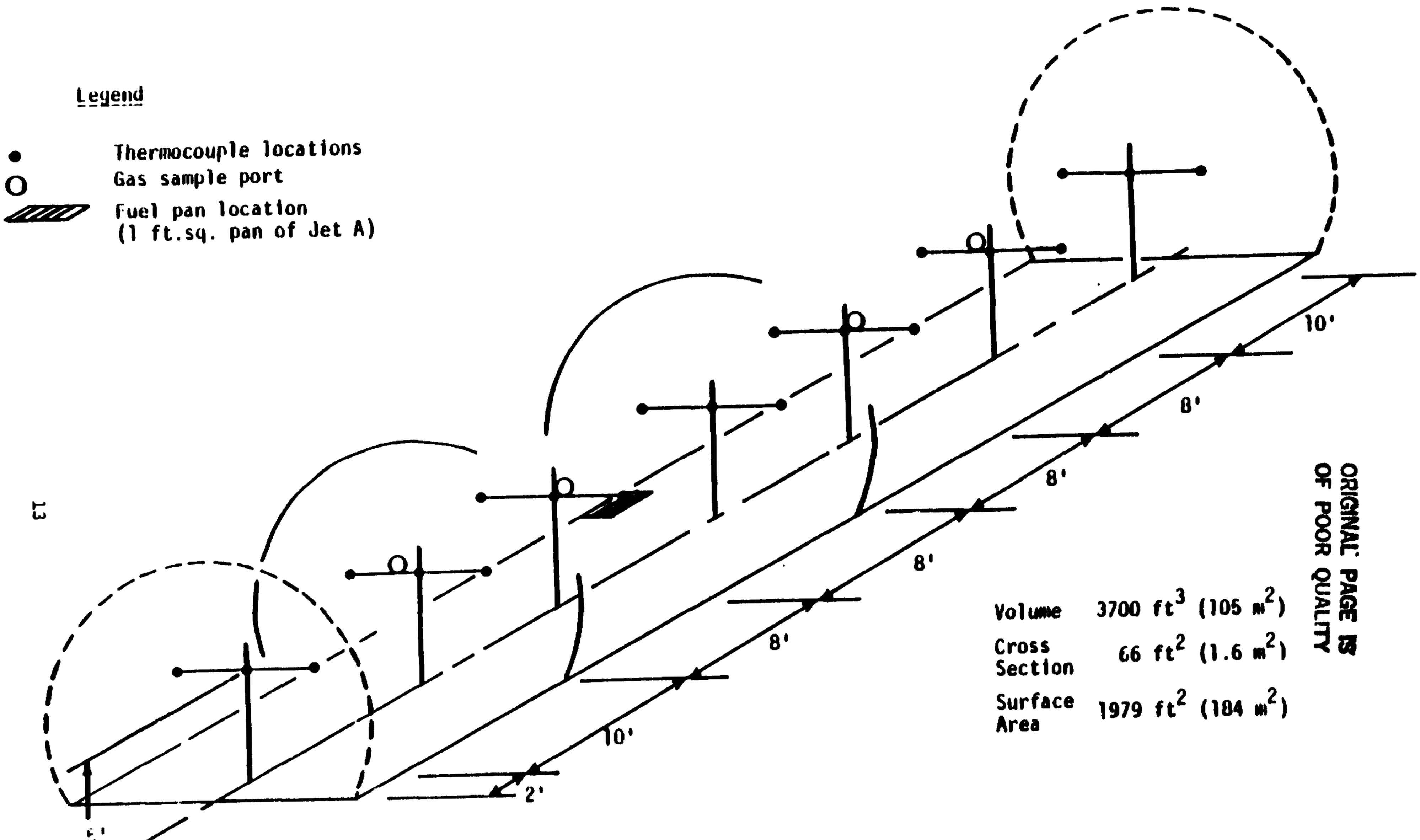


Figure 4(b). Hazards in Aft Cabin Produced by Burning Interior Materials.



(a) 56 ft Cabin Used in NASA Houston Tests (not to scale).

Figure 5. Placement of Cabin Atmosphere Measurement.

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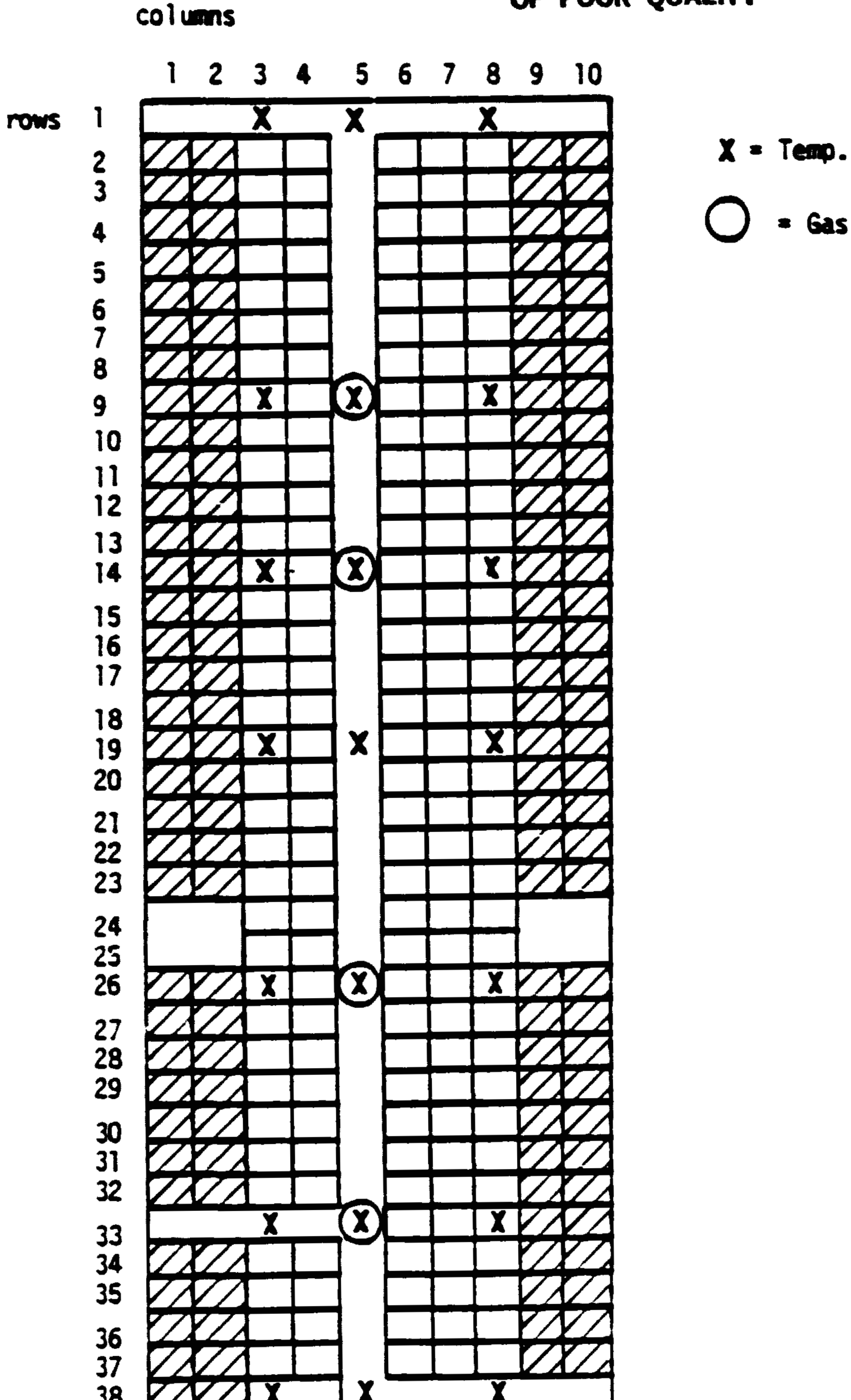

(b) FIREVAC Representation of
Test Cabin.

Figure 5. Continued.

SECTION 3

THE HUMAN FACTOR MODULE

As figure 1 shows, an HFM input is the toxicant data of the CEM, and the HFM output is time required for passenger movement, as degraded by the effects of those toxicants. The CEM produces an atmosphere for each node in the aircraft. At given time intervals (as determined by an input parameter) the HFM examines each passenger, updating his human response factor with respect to the toxicants present in the node he currently occupies. That human response factor is then used to modify his speed by altering both the time required to travel through all node types and his reaction time - the time required to notice a target node is vacant. (See section 4 for the details of node-to-node movement).

3.1 THE FRACTIONAL INCAPACITATION DOSE

The human response factor, R_H, is related to F_D, the concept of a fractional incapacitation dose (see References 2 and 3) by:

$$R_H = 1 - F_D.$$

As explained by Sarkos et. al. (Reference 2), the F_D concept is a hypothetical human survival model whose purpose is to assess the relative importance of each cabin fire hazard:

> The survival model described ... is hypothetical. Its main purpose is to provide a means of predicting the time-of-incapacitation within a fire enclosure, based on measurements of elevated temperature and toxic gases concentrations which change, in some cases substantially, with time. Thus, it is a tool for reducing a fairly large number of somewhat abstract measurements into a single, cogent parameter: time-of-incapacitation or the hypothetical time at which an individual can no longer escape from a fire environment. How well the model relates to actual escape potential is unknown and, realistically, cannot be determined. It is known that segments of the model are deficient for lack of available information. For example, no data exists on the effect of irritant gases (e.g., HCL, HF) on acute human escape potential. (FAA has sponsored new research at Southwest Research Institute to determine "the threshold concentration for escape impairment by irritant gases (HCL and acrolein, initially) using a nonhuman

primate model and a relevant behavioral task that can be extrapolated to man.") Thus, the HCL and HF incapacitation doses utilized in the model are simply based upon extrapolation from threshold limit values (TLV's) for an 8-hour work environment. Confidence in the model is greater for the prediction of the <u>relative</u> escape time between tests on different material systems than on the prediction of <u>absolute</u> escape times. (From Reference 2, pp. 6-7)

The chief virtues of the F_D concept from the point of view of our model are:

1) The fact that it does reduce a large number of abstract measurements into a single parameter, and, hence, one that can be easily applied to passenger behaviors; and
2) The fact that it allows for the cumulative effects of the atmosphere, thus allowing the passenger's short-term toxicant exposure history to affect his probability of survival.

The UDRI implementation of the F_D concept makes the assumption that F_D yields not only the time to incapacitation, but also a measure of partial impairment, e.g., $F_D = 0 \Rightarrow$ no impairment, $F_D = 1 \Rightarrow$ complete incapacitation, $F_D = .5 \Rightarrow$ 50% incapacitation, i.e., passenger speed is decreased by a factor of 2.

The present computer implementation defines F_D as:

$$F_D(t) = \sum_{n=1}^{N} \left| \frac{T_n^{3.61}}{Q_o} + \sum_{i}^{M} \frac{C_{i,n}}{D_i} \right| \Delta t_n$$

where:

$F_D(t)$ = the Fractional Incapacitation Dose accumulated at time t

Δt_n = the time increment (in minutes) for the n^{th} interval (not necessarily the same for all n)

N = the number of time increments to time, t

i.e., $t = \sum_{n=1}^{N} \Delta t_n$

T_n = the temperature (°C) at time $t = \sum_{k=1}^{n} \Delta t_k$

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$Q_o = 4.1 \times 10^8$ statistically derived proportionality constant (see Reference 2)

D_i = the incapacitation dose of the i^{th} constituent (ppm*sec)

$C_{i,n}$ = the concentration at the i^{th} constituent (ppm)

The constituents currently under consideration are:

CO	$D_i = 1.44 \times 10^6$	(ppm*sec)
HF	$D_i = 6.84 \times 10^4$	"
HCL	$D_i = 1.44 \times 10^5$	"
HCN	$D_i = 2.88 \times 10^4$	"

Note that the above equation assumes that all effects are additive. If an individual could simultaneously absorb the incapacitiation dose of two different toxicants the equation would give him an F_D equal to 2; however, the computer implementation of the equation imposes an upper limit of 1 on any individual's F_D.

Note, furthermore, that this form of F_D does not take into account individual passengers' respiration rates or body masses. Also, there is no consideration of oxygen deprivation or the physiological and/or psychological effects of smoke. Future model enhancement should provide for further deterioration of passenger speed due to the blinding effects of dense smoke.

3.2 MODIFICATION OF PASSENGER BEHAVIOR

At present, passenger speed (defined as time to move through a node) is initially assigned stochastically, using a set of random Gaussian deviates. For each passenger P, his speed of movement is determined by first randomly selecting a value Z_p from a standard normal distribution (mean 0, standard deviation 1). Each node type, n, has its associated $\bar{X}_n$ and S_n, the mean and standard deviation or the time required to move through that node (as defined by the CEM). Then $t_{n,p}$ (the time required for the pth passenger to move through the n_{th} node) is initially:

$$t_{n,p} = \bar{X}_n + Z_p S_n \text{ , if } tmin_n \leq X_n + Z_p S_n \leq tmax_n$$

and if:

$\bar{x}_n + Z_p S_n < tmin_n$ then $t_{n,p} = tmin_n$

$\bar{X}_n + Z_p S_n > tmax_n$ then $t_{n,p} = tmax_n$

where:

$tmin_n$ is the minimum time allowed for movement through a type n node and $tmax_n$ is the maximum such time. This restriction on the range of $t_{n,p}$ is required to avoid the aberrations which could arise from blindly fitting a continuous normal distribution to experimental data (e.g., If $\bar{X}_n = 2.33$, $S_n = 1.42$, then $Z_p = -2$ would give t = .51 without a minimum range restriction, whereas, $tmin_n = .7$ results in $t_{n,p} = .7$ and avoids negative time of movement).

The initial values for $t_{n,p}$ are assigned under the assumption that $F_D = 0$ and, hence, $R_H = 1$. At each HFM update interval, the values for $t_{n,p}$ and each passenger's reaction time are divided by R_H. Hence, when $F_D = 0, t_{n,p}$ is unchanged; when $F_D = 1$, $t_{n,p}$ is infinite and the passenger is unable to move.

SECTION 4

PASSENGER EGRESS MODEL

The PEM completes the cycle of module interaction illustrated by Figure 1. It accepts data on cabin conditions from the CEM and data on passenger behavior from the HFM, uses that data to simulate passenger movement, and returns passenger position data to both the CEM and the HFM as well as producing the model's graphical and summary outputs.

The simulation of passenger movement assumes that at any given time each passenger has a known exit path, a sequence of nodes beginning with the passenger's current position and terminating with an exit. Each passenger is examined each update of the PEM to determine whether that passenger satisfies the criteria for movement into the next node of his exit path.

4.1 PASSENGER MOVEMENT CRITERIA

For each PEM update for each passenger, p, the simulation logic requires variables:

T = current time according to simulation running clock

N_{in} = row, column location of node currently occupied by p

N_{to} = row, column location of p's target node (next node in p's exit path)

T_{empty} = time N_{to} was vacated (i.e., simulation clock time at which the last passenger to occupy N_{to} left)

T_{in} - time required for p to move though N_{in} (sec's)

T_{to} - time required for p to move through N_{to} (sec's)

$T_{lastmove}$ = time of p's last move (clock time)

REACT = time required by p to notice that N_{to} is empty (sec's)

$STATUS_n$ = the passenger number of the current occupant of node n, e.g., $STATUS_{N_{in}}$ = p. $STATUS_n$ = 0 if node n is empty, i.e., p will be unable to move unless $STATUS_{N_{to}}$ = 0.

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Passenger p is considered to have had enough time to move when:

1) $T - T_{lastmove} \geq (1/2)\ T_{in} + (1/2)\ T_{to}$; and

2) $T - T_{empty} \geq REACT$

This technique assumes movement is from the center of the node currently occupied to the center of the target node. Condition (2) provides a simulation of reaction time delay.

As a result, the model shows passengers in a tightly packed queue moving in a shuffling fashion, where movement is jerky and the movement of a given passenger is dependent on that of passengers in front of him. Passengers in less crowded quarters are modeled as accelerating to their speed of movement and maintaining that speed. This is because in that case, target nodes have few passengers in them as blockers and, hence, condition (2) is met virtually every time condition (1) is met.

Both the time required to move through nodes and REACT are modified in the HFM by the human response factor. At present, REACT is an input parameter and a single value is assumed initially for all passengers. Given experimental data, this single value could be replaced by a mean, standard deviation, maximum and minimum as with passenger node times. The REACT parameter also requires further study to determine proper values for the simulation of panic situations, in which passengers would probably be pushing and shoving, and hence, packed more densely in their exit queues than would be the case in an orderly evacuation.

When passenger p has an empty target node, N_{to}, and is found to have enough time to move, the nodes adjacent to N_{to} are examined for other contenders, other passengers who also meet the above given criteria for movement into N_{to} at the current simulation clock time. If any other contenders are found, priority is given to the passenger who has been waiting longest for the given target node. This procedure could easily be replaced in the computer implementation if another priority scheme is found to yield a more realistic simulation. Other possible decision procedures which have been considered are:

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1) Speed - fastest passenger has right-of-way;
2) Size - biggest passenger has right-of-way;
3) "Chivalry" - male passengers allow female passengers right-of-way;
4) "Parental Agressiveness" - passengers identified as carrying small children have right-of-way; and
5) Random draw.

In terms of the simulation objectives, the priority scheme used is not as important as such model parameters as passenger speed or REACT, because the priority scheme has more effect on which passengers escape than it does on how many escape.

4.2 PASSENGER EXIT PATHS

The assumption is made that at any time in the simulation, each passenger is following a set path to egress, rather than looking ahead only one move at a time. In order to have the passenger's movement respond to cabin conditions, these set exit paths are updated periodically. In order for such updates to make sense, the choice-of-path is dynamic; it reflects changing conditions as reported by the CEM.

The model's exit path algorithm allows for determination of an "optimal" route from a passenger's present node position to the closest exit perceived as open by that passenger. The path is optimal in the sense that the algorithm calculates a "distance" from the passenger to all possible exits and chooses the closest one (as defined by that "distance"). The algorithm's flexibility lies in the number of ways in which it is possible to measure the desirability of a path; at present, the time of movement from one node to the next; and the difficulty (or impossibility) of moving through blocked nodes is considered.

The exit route is selected by viewing the aircraft as a digraph (directed graph). The node centers are graph vertices and the paths from one node to the next are viewed as edges. Finding the exit path is, thus, the problem of finding the shortest path from a specified vertex (passenger's present position) to another specified vertex (open exit).

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The algorithm used is due to Dijkstra (see for example Reference 6) and makes use of the length, $d_{i,j}$ (or distance or weight) of the directed edge from vertex i to vertex j. This length or distance will determine the desirability of moving from one node to another and can be defined in a number of ways. The only restrictions, the algorithm places on the definition of $d_{i,j}$ are:

$d_{i,j} \geq 0 \quad \forall i,j$

$d_{i,i} = 0 \quad \forall i$

$d_{i,j} = \infty$ if there is no edge (or path) from i to j

The current model implementation defines the metric $d_{i,j}$ for each passenger, p, in terms of that passenger's node movement times. The presence of other passengers in nodes along a potential exit path is considered a possible impediment and affects $d_{i,j}$ by adding a term designed to represent the delay created by waiting for those passengers to move.

The form used is:

$$d_{i,j} = (1/2)\, T_{i,p} + (1/2)\, T_{j,p} + T_{j,b}$$

where:

$T_{i,p}$ = time required for passenger p to move through node i

$T_{j,p}$ = time required for passenger p to move through node j

$T_{j,b}$ = 0 if there is no passenger in node j; time required for the blocking passenger (the passenger in node j) to move through node j.

A sample calculation is shown in Figure 6. In both cases a and b passenger 1 is determining his closest exit. Nodes A1 - A6 represent aisle nodes, through which passenger 1 can move in .25 sec.; nodes S1 - S6 represent seat nodes, through which the passenger can move in .9 sec., and nodes E1 and E2 represent exits (of the same type), with 1.0 sec. as required time of movement. In case a, passenger 1 is assumed alone in the portion of the aircraft represented. The digraph representation shown is labeled with the values for d between each at the nodes represented. As shown, the closest exit to

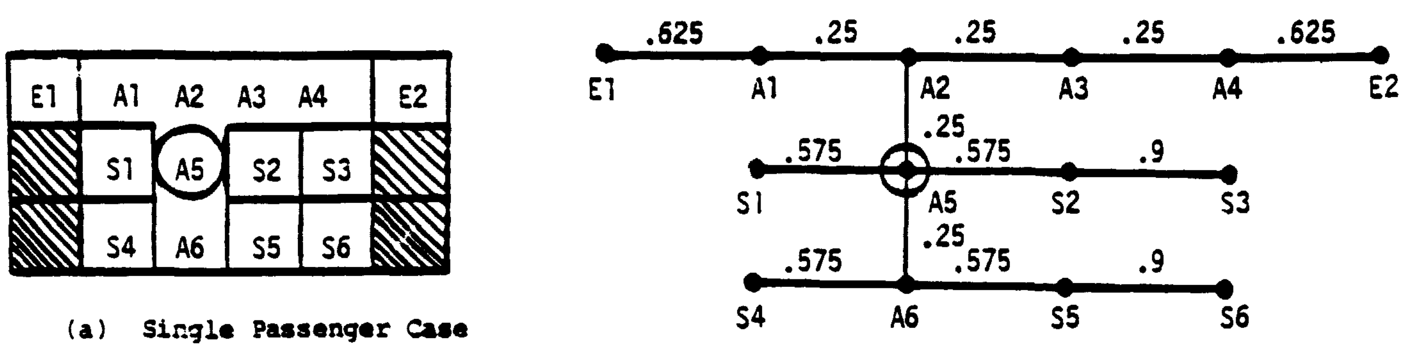
Aircraft configuration
with passenger 1 in A5
whose movement times are:

through S. (seat node) = .9 sec.
A. (aisle node) = .25 sec
E. (exit node) = 1.0 sec

Digraph representation

Here 1's exit path to
E1 A5 A2 A1 E1 has
distance 1.375

Exit path to E2
A5 A2 A3 A4 E2 has
distance 1.375



(a) Single Passenger Case

If a passenger, 2, is added in node A1 with movement times
through S. = 1.0 sec
A. = .3 sec
E. = 1.5 sec, then the apparent distance (from 1's perspective) from A2 to A1 changes as shown below.

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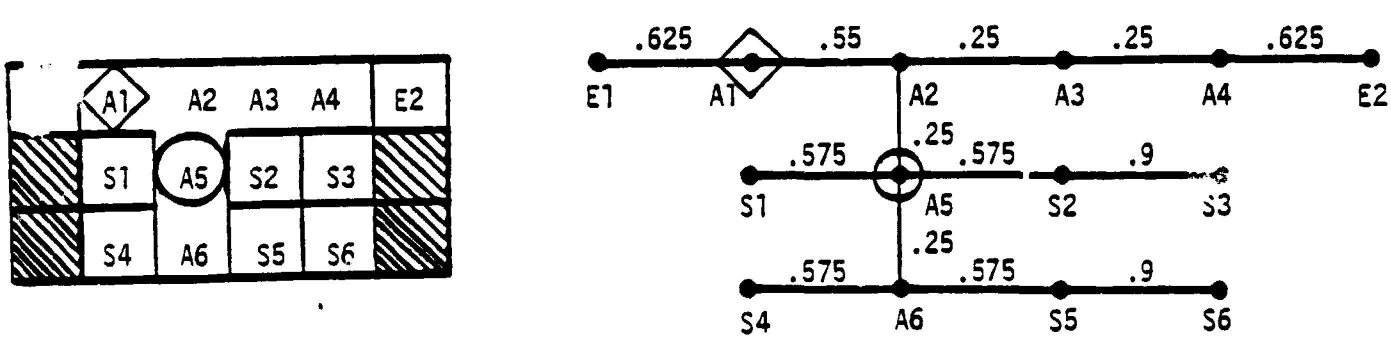
Hence 1's exit path to E1
now has distance 1.425
whereas the distance to E2
is unchanged.



(b) Two Passenger Case

LEGEND: ◯ = passenger 1
◇ = passenger 2

Figure 6. Illustration of Exit Path Distance Calculations.

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passenger 1 is E1 and his exit path is A5A2A1E1. In case b, a second, slower passenger is added in node A1. This changes passenger 1's perception of the distance from A2 to A1 by .3 seconds - the time required for 2 to travel through node A1. Now passenger 1 believes E2 is the closest exit, and his exit path is A5A2A3A4E2.

The current method for choosing a path is, of course, not perfect. Measuring of the effect of impediments by adding other passengers' lines of travel was chosen for its simplicity and will not, in general, provide an optimal distribution of passengers among available exits. The rationale behind using the blocking passenger's time of movement as a time delay is based on the assumption that the passenger under consideration will have to wait for the blocking passenger to move. This assumption is most valid when the blocking passenger is close to, and slower than, the passenger under consideration. If the blocking passenger is far enough away or fast enough, the other passenger may never get close enough to him to have to wait for him. On the other hand, it can be argued that if a passenger sees another passenger in his path, he will view this as presenting a delay.

More importantly, at present, the choice of path does not account for any avoidance of fire or fire-related toxicants. Note that the algorithm does not require that $d_{i,j}$ be symetric, i.e., that $d_{i,j} = d_{j,i}$. This means that movement towards the fire could be discouraged and movement away from the fire encouraged. Future versions of the computer program should include some consideration of the temperature difference between nodes. More analysis is required to find the best way to do this. At present, the metric is time-based; the concept of distance is considered in terms of the time the passenger believes is required to cover the distance to each unit. While it is easy to put a numerical factor into the computer code to alter $d_{i,j}$ as a function of the temperature in nodes i and j, it is not trivial to determine what realistic values for that numerical factor should be. Similarly, a factor for confusion as a result of either smoke or panic or both can easily be inserted into the computer, but, again, determining an appropriate factor is not trivial.

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Efficient use of the exit path algorithm requires methods to determine how often exit paths should be updated. It would be possible to perform updates after every passenger move or other change in the cabin environment, but this would greatly increase model run time. At present, there are two mechanisms for driving exit path updates. The first is an input parameter (see card type A, Appendix A) which specifies a constant time interval between exit path updates for all passengers. Usually, if the interval between updates is short, significant alterations of exit path occur for only a small minority of the passengers on any given update. This means a lot of computer time is used recomputing paths which have not changed. To solve this problem, a second method for updating exit paths is provided. This consists of identifying certain nodes in the aircraft configuration as decision nodes. When a passenger moves into one of these nodes his exit path is recomputed. Decision nodes are places where a passenger has a choice of ways to go, e.g., row and column aisle intersections. (See card type B in Appendix A for input descriptions).

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SECTION 5
CONCLUSION

The UDRI FIREVAC does not represent a finished product. There are two broad areas of activity required before the model can be depended upon to fulfill its stated objective. These areas can be described as model validation and model feature refinement. The model validation work is the more important of the two; in fact, it is probable that the pursuit of the model validation will suggest the direction of model refinements.

5.1 MODEL VALIDATION

Software testing activities have the dual goals of model verification and validation. We consider verification to be the process whereby the computer code is verified to faithfully implement the mathematical model of the simulation, i.e., where we insure the code is doing what we thought we told it to do. We regard validation as the process whereby we insure that the model produces an acceptable approximation of the real world behaviors it is intended to simulate. In this framework, model development is viewed as a building process in which we continually attempt to improve our approximation of the real world behaviors, expand upon the number and kinds of behaviors simulated, or both.

The present version of FIREVAC has undergone considerable verification testing, but very little validation testing. The primary reason for this is lack of data. Cominsky (see Reference 7) presents a data base resulting from a review of impact survivable post crash fire accidents. In only a few of these is there any data relating to egress rates, and in none of them is there any breakdown of speeds of movement with respects to features of the aircraft configuration other than exit chosen. As described in Section 2, even the CAMI tests do not provide adequate data on speed of movement within the cabin. The situation with regard to data on how various toxicants combine to degrade passenger movement is even worse. A realistic validation scheme for the FIREVAC model must first concentrate on validating the egress simulation in the absence of fire. We must attempt to obtain data for such validation from manufacturers' certification tests, by analysing videotapes and whatever other sources of information are available. The FIREVAC model was purposely designed to be heavily dependent upon input parameters which describe passenger movement. With enough data, we should be able to adjust these parameters to obtain a "good" evacuation simulation, where "good" is defined as replicating egress rates from emergency evacuation tests.

The problem of validating the post crash fire scenario is much more involved. First, analysis of such accidents does not lend itself to classification. Each accident has so many unique features that a generic class of parameter descriptions cannot be formulated, i.e., each accident must be treated as a special case. Extant descriptions of fire spread, cabin debris, passenger conditions, etc. are inadequate. Furthermore, the model's human response factor and F_D concentrations are only crude representations of toxicant effects. Even so, the model can provide a <u>relative</u> measure of hazard for different post fire crash scenarios.

5.2 MODEL FEATURE REFINEMENTS

At present, we envision refinements and the inclusion of additional capabilities in each of the model's three modules. Activities under consideration include:

CEM

1) Smoke could be included as a function of both time and cabin position.
2) Fire scenario input needs refining. This could include the analysis of data from the NASA Houston fire tests (see Reference 5) to refine the approximation of cabin atmosphere data for all cabin nodes from the test data, and exploring the possibility of using more sophisticated fire models to produce input. We should note that the techniques of sophisticated fire models (e.g., Notre Dame's UNDSAFE) which are PDE (partial differential equation) solvers, require amounts of computer time and space

which preclude trying to incorporate those techniques in our model. We see the development of sets of "representative situations" from test data and/or PDE models as our best alternative.

3) Inclusion of crash-related cabin debris could be included.

HFM

1) The F_D calculation outlined in Section 3.1 could be augmented considering each passenger's body mass and respiration rate. This would result in:

$$F_D(t) = \int_0^t \left[\frac{T^{3.61}}{Q_o} + \frac{R_v}{M_b} \sum \frac{C_i}{d_i} \right] dt$$

where $F_D(t)$ is the fractional incapacitation dose at time t, (-)
T is the ambient gas temperature (C)
Q_o is an empirical constant (Crane) ($c^{3.61}$-sec)
C_i is the ambient concentration of the ith toxic gas (ppm)
R_H is the passenger response factor (-)
M_b is the body mass in gm
R_v is the respiration rate in ml/sec
d_i is the incapacitation dose in PPM ml/gm.

2) The F_D calculation could be replaced with the concept of a short term lethal limit. Passenger incapacitation would be assumed instantaneous upon absorption of a specified lethal dose of any toxicant.

3) Replace an additive F_D with the maximum fractional incapacitation dose of the individual toxicants as absorbed at time t.

PEM

1) We need to obtain and evaluate data from emergency evacuation tests and use the results to better define passenger speed parameters.

2) We have to improve the choice of exit path process. This includes altering the distance function to reflect the presence of fire and smoke as well as incorporating some sort of confusion factor due to panic. Also required is refinement of the exit path update criteria; when should a passenger change his mind about choice of exit?

3) We need to consider the imposition of delays caused by panic or confusion.

4) The possibility of a change in contender priority logic (as discussed in Section 4.1) maybe desirable.

Model improvements such as those listed above should be given priority as a function of their promise for support towards the model objective. The model objective itself should be refined to determine how the model is to be used, and what the specific purposes of exercising the model are.

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APPENDIX A

USER INFORMATION

The FIREVAC model requires several different types of input data and produces a variety of outputs. In the interests of modular structure the computer program has been designed to read from, and write to, different logical units. Each logical unit is associated with a VAX 11/780 file, and each VAX file can be considered to contain a distinct type of input or output data. Figure 7 shows a sample VAX command file, a list of the steps required to run FIREVAC on a VAX. The procedure illustrated in Figure 7 assumes that an executable version of the FORTRAN code is in memory (in this case that version is called FIRESND). It further assumes that the required input files are available. The input files are assigned to the FORTRAN input device numbers 11-16 (FOR011 - FOR016). The specific variable formats for each file are included below. Briefly, the input files are:

1) A control file, assigned to FOR011.
   The control file contains model control parameters such as model cycle time updates. See Table 1 below.

2) An aircraft configuration file, assigned to FOR012.
   This file contains the physical description of the aircraft with definitions of each node (e.g., seat, aisle, etc.). See Table 2 below.

3) A passenger position file, assigned to FOR013.
   This file defines the number of passengers and their initial locations. See Table 3 below.

4) An aircraft atmosphere file, assigned to FOR014.
   This file contains the cabin atmosphere profile. This file is required even if the simulation is to be run without an atmosphere. The model requires the number of toxicants and toxicant sampling points - which would be set to 0 in the no atmosphere case. See Table 4 below.

```
$!      Input Files:
$ASSIGN DATA:CTRL180A.DAT      FOR011   ! DC9--SERIES 180 case.
$ASSIGN DATA:AC180OWCL.DAT     FOR012   ! FIRE3ND, atmosphere.
$ASSIGN DATA:PASS180.DAT       FOR013
$ASSIGN DATA:H14A.DAT          FOR014
$ASSIGN GROVE:PHYSINDAT.DAT    FOR015
$ASSIGN DATA:GDEV.DAT          FOR016
$!      Output Files:
$ASSIGN PATH180.OUT     FOR021
$ASSIGN SNAP180.OUT     FOR022
$ASSIGN ATMOS180.OUT    FOR023
$ASSIGN PLOT180.OUT     FOR024
$ASSIGN SUMRY180.OUT    FOR025
$RUN FIRE3ND
```

Figure 7. VAX Command File to Run the FIREVAC Simulation.

TABLE 1

CONTROL FILE

INPUT DATA DESCRIPTION

Record	Variable Name	Type	Cols.	Format	Units	Description
	** READ IN SUBROUTINE CNTRIN (from FOR011) **					
A-1	ISIMST	Integer	1-6	I6	millisec	Passenger egress simulation start time. Used to initialize TOFLM : Passenger time of last movement.
A-2	SIMEND	Real	1-6	F6.0	sec.	Simulation end time. Maximum allowable clock time.
A-3	IDELTA	Integer	1-6	I6	millisec	Clock update increment. Usually set to 10 (.01 sec.s) as this is an order of magnitude smaller than the fastest passenger movement times.
A-4	ISNPTM	Integer	1-6	I6	millisec	Time interval between output snapshots.
A-5	IATMDT	Integer	1-6	I6	millisec	Time interval between atmosphere update calls. The aircraft atmosphere is assumed constant between updates. Should be set to a value greater than the expected simulation termination if no fire-related atmospheric effects are being simulated.
A-6	IDTSPD	Integer	1-6	I6	millisec	Time interval between passenger condition (HFM) updates. Should also be set to a value greater than the expected simulation termination time for the no-fire (no atmosphere) scenario.

TABLE 1

CONTINUED

A-7	JPSDBG	Integer	1-7	I6		Debugging parameter. Used to print atmospheric effects on the JPSDBGth passenger. If no such output is desired, should be set to 0.
A-8	IXITUP	Integer	1-6	I6	millisec	Time interval between passenger exit path updates. Warning-- this parameter has a large effect on program run time.
A-9	REACT	Real	1-6	F6.0	secs.	Initial passenger reaction time. This value is degraded for each passenger as cabin conditions dictate.
A-10	IDSCRB	Char	1-82	72A1	-	Run description of current simulation.

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TABLE 2

AIRCRAFT CONFIGURATION FILE

Record	Variable Name	Type	Cols.	Format	Units	Description
			** READ IN SUBROUTINE ACIN (from FOR012) **			
B-1	IACTYP	Char	1-10	10A1	-	Aircraft type.
B-2	MWIDE	Integer	1-3	I3	-	Length of aircraft (in number of nodes).
	NLONG	Integer	4-6	I3	-	Width of aircraft (in number of nodes).
B-3	JCNDX	Integer	1-3	I3	-	Column numbers in which aisles are located. Last entry = 0.
B-4	IRNDX	Integer	1-3	I3		Row numbers in which aisles are located. Last entry = 0.
B-5	(One type B-5 card should be read in for each of the MWIDE x NLONG aircraft nodes i.e., NR should vary from 1 to NLONG as NC varies from 1 to MWIDE.)					
	NR	Integer	7-9	I3	-	Row number of current node.
	NC	Integer	12-14	I3	-	Column number of current node.
	NTYPE	Integer	17-18	I2	-	Current node's specific node type: 1 = row aisle 2 = col aisle 3 = seat 4 = exit, type A 5 = exit, type A DW 6 = slide, type A 7 = slide, type A DW 8 = skin/exterior NTYPE goes into NDETYP(NR,NC).

TABLE 2

CONTINUED

	NCB	Integer	21-22	I2		Current node's general node class: 1 = aisle 2 = seat 3 = skin 4 = exterior 5 = exit 6 = slide NCB goes into NCABE(NR,NC).
B-6	NUMNDE	Integer	6-8	I3	-	Number of node types in this simulation.
B-7	XBAR(IN)	Real	1-7	F7.4	-	(IN=1,NUMNDE) Average speed of passengers traveling through node.
	S(IN)	Real	9-15	F7.4		(IN=1,NUMNDE) Sample standard deviation for node.
	TMAX(IN)	Real	17-23	F7.4		(IN=1,NUMNDF) Maximum speed through node.
	TMIN(IN)	Real	25-31	F7.4	-	(IN=1,NUMNDE) Minumum speed through node.
B-8	NDECPT	Integer	1-3	I3	-	Number of decision points.
B-9	(A B-9 record is read for each decision point (NDECPT))					
	IDECPT (NDECPT)	Integer	1-3	I3	-	Row location of decision point.
	JDECPT (NDECPT)	Integer	4-6	I3	-	Column location of decision point.

TABLE 2

CONTINUED

Record	Variable Name	Type	Cols.	Format	Units	Description
	** READ IN SUBROUTINE EXITIN (from FOR012) **					
C-1	NEXITS	Integer	1-2	I2	-	Number of exits in the aircraft.
C-2	(One type C-2 card should be read in for each exit (I=1,NEXITS))					
	LOCRX(I)	Integer	1-3	I3	-	Row location of exit.
	LOCCX(I)	Integer	4-6	I3	-	Column location of exit. Note that this value should be either MRGTXT or LEFTXT.
	IXITPP(I)	Integer	7-9	I3	-	Passenger perception of exit status: 0 = open, 1 = closed.
	TOPEN(I)	Real	12-18	F7.3		Time it takes for exit to be opened.

TABLE 3

PASSENGER POSITION FILE

Record	Variable Name	Type	Cols.	Format	Units	Description
			** READ IN SUBROUTINE PASSIN (from FOR013) **			
D-1	IACTYP	Char	1-10	10A1	-	Aircraft type. Note that this should match record B-1 of the aircraft information file.
D-2	NUMPAS	Integer	1-3	I3		Number of passengers in the aircraft for this simulation.
D-3	IPASS	Integer	1-3	I3	-	Passenger number.
	NR	Integer	5-7	I3	-	Initial row location of passenger.
	NC	Integer	9-11	I3	-	Initial column location of passenger. Note that these values should probably indicate a seat location as described on card type B-5 i.e. NEDTYP(NR,NC) = 3

TABLE 4

AIRCRAFT ATMOSPHERE FILE

Record	Variable Name	Type	Cols	Format	Units	Description
			** READ IN SUBROUTINE ATMBIN (from FOR014) **			
E-1	NGASES	Integer	1-4	I4	-	Number of gases to be considered by this simulation
		(E-2 and E-3 cards are repeated for each of the 10 gases)				
E-2	NAMGAS(I,10)	Char	1-10	10A1	-	Name of each gas. Note that order of gases specified must remain consistent with the order used to input gas concentration values below. (I=1,10)
E-3	GASIDC(10)	Real		F13.6	PPM*sec	Incapacitation dose constants (PPM*SEC) for each gas.
E-4	NTEMPT	Integer	1-4	I4	-	Number of temperature sampling points.
		(An E-5 card is repeated for each of the 10 gases.)				
E-5	NGASP(I)	Integer	5-64	I4	-	Number of sampling points associated with each individual gas.
E-6	INAME	Char	1-20	20A1		Description of data comment. Used to delimit values for different toxicants in the atmosphere profile input file
E-7	TIMOLD	Real	1-10	F10.0	secs	Time coordinate for all old temperature and gas concentration values. Should be <= SIMST.

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TABLE 4

CONTINUED

(E-8 thru E-10 cards are required only if NTEMP(>0)

E-8	INAME	CHAR	1-20	20A1	-	Description of data comment used to distinguish temperature values in the data file.
E-9	(Card type E-9 is repeated until all temperature sampling points are input. (I=1,NTEMPT) Data for 4 data points is assumed on each card--i.e., format is 4(I4,I4,F10.0))					
	ITMPT(I)	Integer	1-4 19-22 37-40 55-58	I4	-	Row coordinate of each temperature sampling point.
	JTMPT(I)	Integer	5-8 23-26 41-44 59-62	I4	-	Column coordinate of each temperature sampling point.
	TMPOLD(I)	Real	9-18 27-36 45-54 63-72	F10.0	deg.s C	Old (for purposes of linear interpolation) temperature at IPTth sampling point.
E-10	RADTMP	Real	1-10	F10.0	node*	Radius of influence for temperature values (unit length = node length or width)

(E-11 thru E-13 cards are repeated for each of the 10 gases.)

E-11	INAME	Char	1-20	20A1	-	Description of data comment, used to distinguish value for different gases in the data file. This description is usually the name of the gas. Note that order in which gas information is input must remain consistent.

* Unit = node length or width; i.e. each node is assumed to be a unit square.

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TABLE 4

CONTINUED

E-12 (Card type E-12 is repeated until all sampling for IQth gas are described. Data for 4 data points is assumed on each card--- i.e., format is (I4,I4,F10.0).)

	IQABPT (IPT,IQ)	Integer	1-4	I4	-	(IPT=1,NOABPT(IQ)), IQ=1,NOABES) Row coordinate of IPth concentration sampling point for IQth gas.
	JQABPT (IPT,IQ)	Integer	5-8	I4	-	(IPT=1,NOABPT(IQ)), IQ=1,NOABES) Col coordinate of IPth concentration sampling point for IQth gas.
	QABOLD (IPT,IQ)	Real	9-18	F10.0	PPM	(IPT=1,NOABIQ(IQ)), IQ=1,NOABES) Old (for purposes of linear interpolation) concentration of Ith gas at IPTth sampling point.

(NOTE: Old temperature and gas concentration values are read in with location of sampling points. New values are assumed to be at same sampling points in same order.)

E-13	RADQAB(IQ)	Integer	1-10	F10.0	node*	Radius of influence if IQth gas.

* Unit = node length or width; i.e., each node is assumed to be a unit square.

TABLE 4

CONTINUED

Record	Variable Name	Type	Cols	Format	Units	Description

** READ IN SUBROUTINE ATMBRD (from FOR014) **

(F-1 thru F-6 type cards are repeated for each time (temperature, gas concentration) where the last time should be greater than or equal to anticipated run termination time.)

Record	Variable Name	Type	Cols	Format	Units	Description
F-1	INAME	Char	1-20	20A1	-	Description of data comment.
F-2	TIMNEW	Real	1-10	F10.0	secs.	Time coordinate for all 'new' temperature and gas concentration values.

(F-3 and F-4 type cards are required only if NTEMPT > 0.)

Record	Variable Name	Type	Cols	Format	Units	Description
F-3	INAME	Char	1-20	20A1	-	Description of data comment.
F-4	TMPNEW(I)	Real	1-10 11-20 21-30 31-40 41-50 51-60 61-70 71-80	8F10.0	deg. C	(I=1,NTEMPT) New value for Ith item temperature sampling point. Order of values should be the same as in TMPOLD

(F-5 and F-6 type cards are repeated for each of the 10 gases and are required only if NOABEB >. There should be one F-5 type card for each gas for which NOABPT(IG) > 0. The F-5 card should be followed by as many F-6 cards as are required to provide values for all sampling points.)

Record	Variable Name	Type	Cols	Format	Units	Description
F-5	INAME	Char	1-20	20A1	-	Description of data comment.

TABLE 4

CONTINUED

F-6	QARNEW (IPT, IQ)	Real	1-10 11-20 21-30 31-40 41-50 51-60 61-70 71-80	8F10.0	PPM*	(IPT=1, NOAGPT(IQ)); IQ=1, NOAGES) New value for IQth gas concentration for IPTth sampling point. Order of values should be same as in gas old.

*PPM = parts per million

5) A passenger description file assigned to FOR015.
At present this file is not used. It is intended to provide detailed passenger descriptions (e.g., sex, age, body mass, respiration rate) as model features requiring such data are implemented.

6) A file of Gaussian deviates assigned to FOR016.
This file provides a normal distribution of passenger characteristics (speed) for the present model implementation. See Table 5 below.

Model output files are:

1) Passenger movement details, assigned to FOR021.
This file is intended primarily for debugging purposes. It lists every passenger move on a node-to-node basis. Debugging switches in the model can be set to greatly expand this file, giving exit path information or examining the results of individual subroutine calls.

2) Snapshot output; assigned to FOR022.
This is the graphical representation of the aircraft interior and passenger positions (see Figures 8 to 16 of Appendix B)

3) Atmosphere output, assigned to FOR023.
This is a record of the cabin's interior atmosphere. Here again, the volume (and amount of detail) can be controlled by debugging switches.

4) F_D vs time plot data, assigned to FOR024.
Provides a set of data points with time as the abscissa, and the fractional incapacitation dose of a selected passenger as ordinate. This output can be used to generate a plot of F_D vs time.

5) Simulation summary output, assigned to FOR015.
This gives the time of evacuation for each passenger, the number of passengers evacuated through each exit and last passenger's time out for each exit. See Figure 17 in Appendix B.

TABLE 5

GAUSSIAN DEVIATES FILES

Record	Variable Name	Type	Cols	Format	Units	Description
		** READ IN SUBROUTINE INDSPC (from FOR016) **				
		(G-1 Cards are repeated until NDEV Gaussian deviates have been read in. At present NDEV = 250.)				
G-1	R	REAL	1-2	5(F12.0)	-	Gaussian deviates
			13-24			
			25-36			
			37-48			
			49-60			

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APPENDIX B

SAMPLE OUTPUT

This appendix contains a comparison of a no fire scenario with a fire scenario. The airplane considered was a DC-9 5180. For the fire scenario the atmosphere data used was taken from test case 24 of reference 5. This output is not intended as a prediction of actual evacuation, but is provided solely to illustrate typical model output. Figures 8 to 16 show passenger placement for both scenarios at 20 second intervals. Figure 17 shows a comparison the summary outputs for both cases. The exit numbering scheme used is shown in Figure 8.

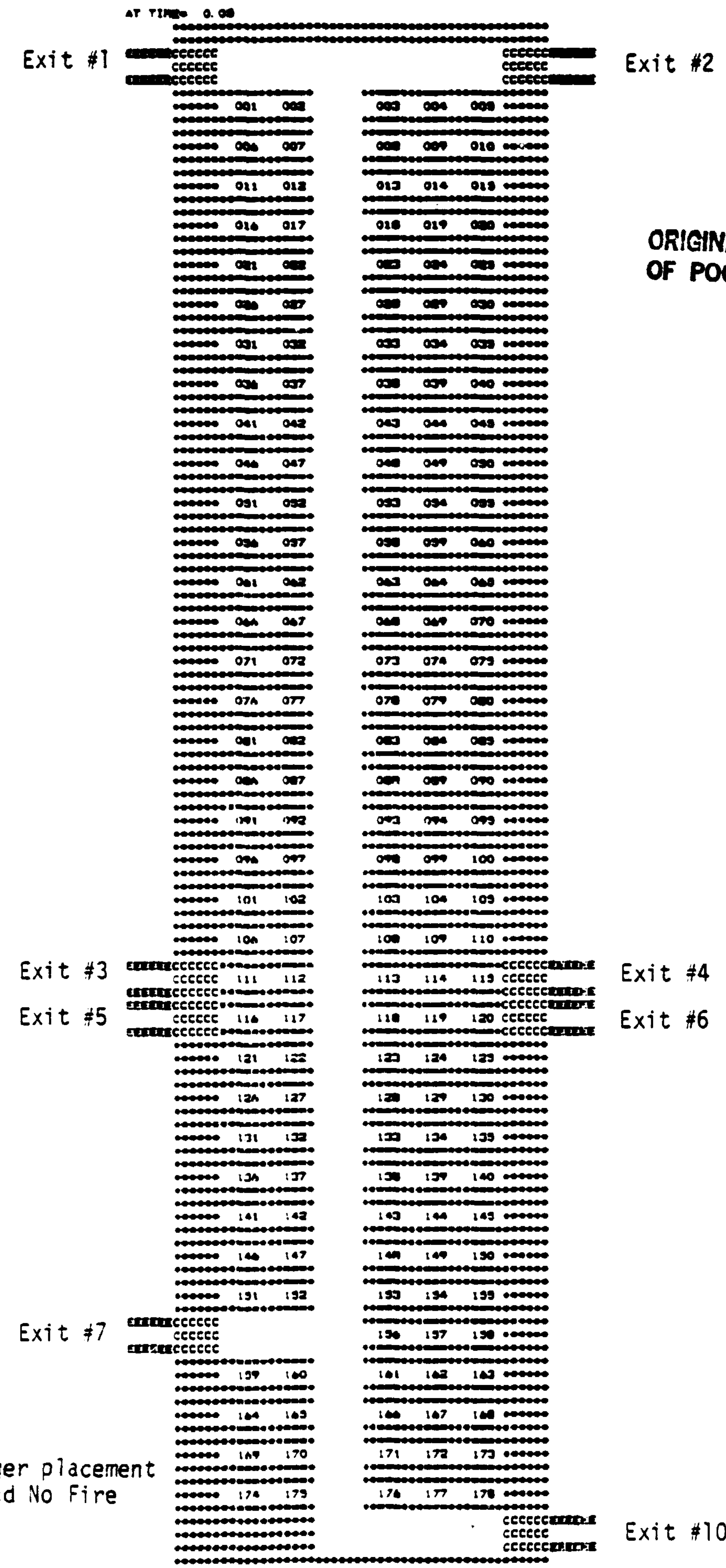

Figure 8.
Initial passenger placement in both Fire and No Fire Scenarios.

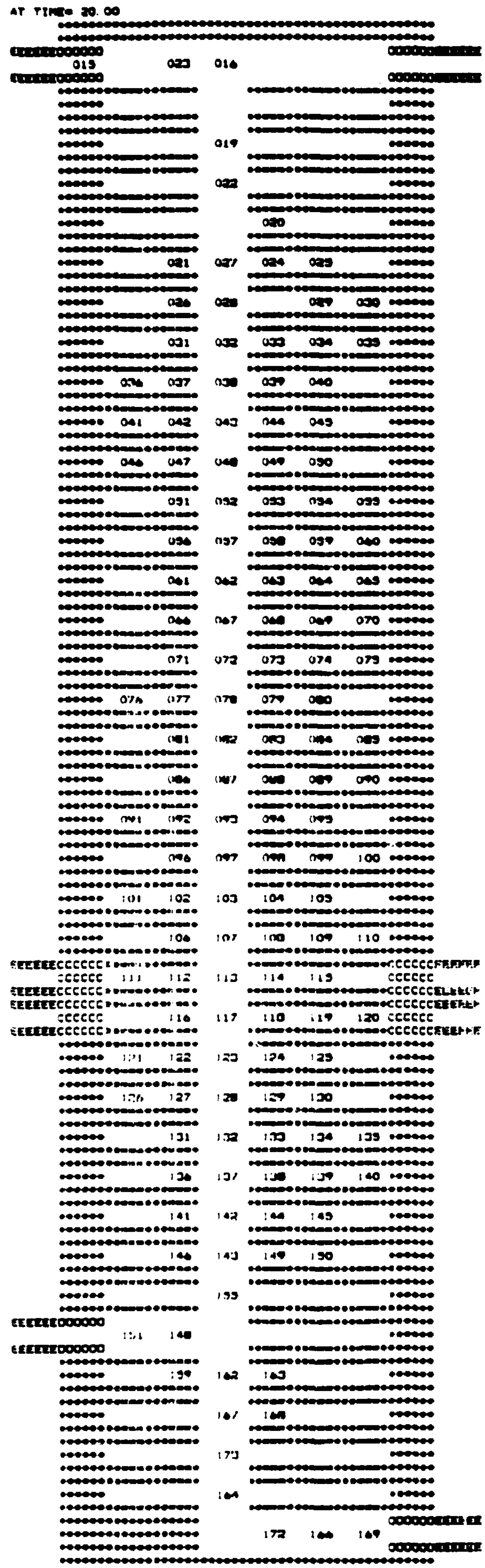

Figure 9.
Passenger placement at
t = 20 seconds
No Fire Scenario.

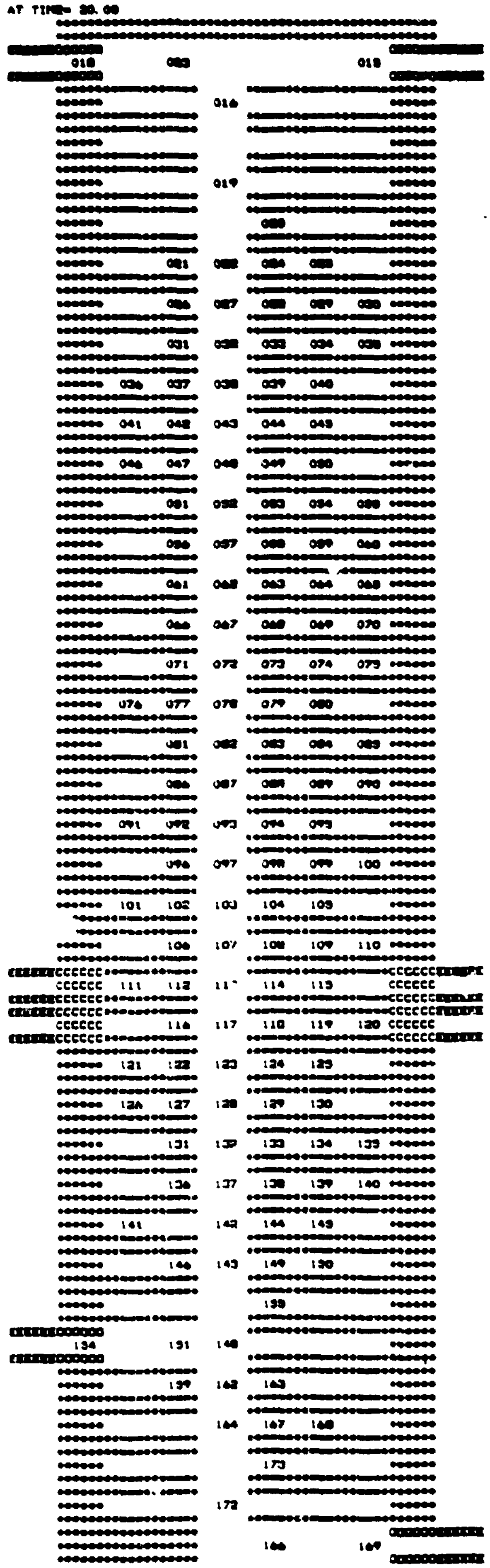

Figure 10.
Passenger placement at
t = 20 seconds
Fire Scenario.

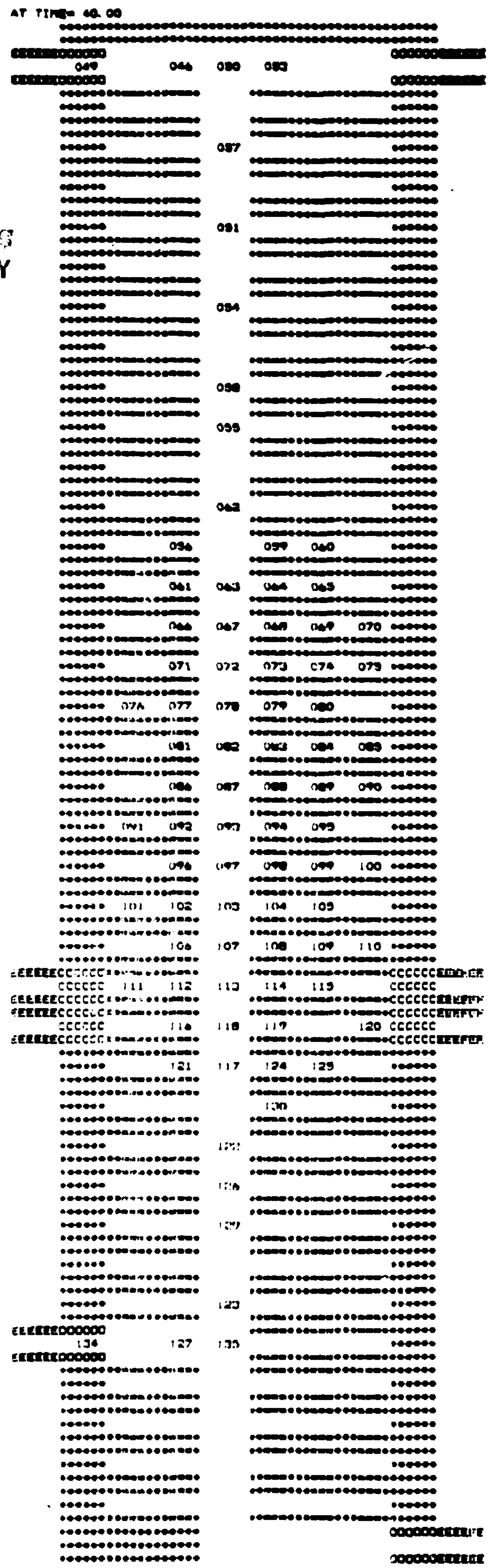

Figure 11.
Passenger placement at
t = 40 seconds
No Fire Scenario.

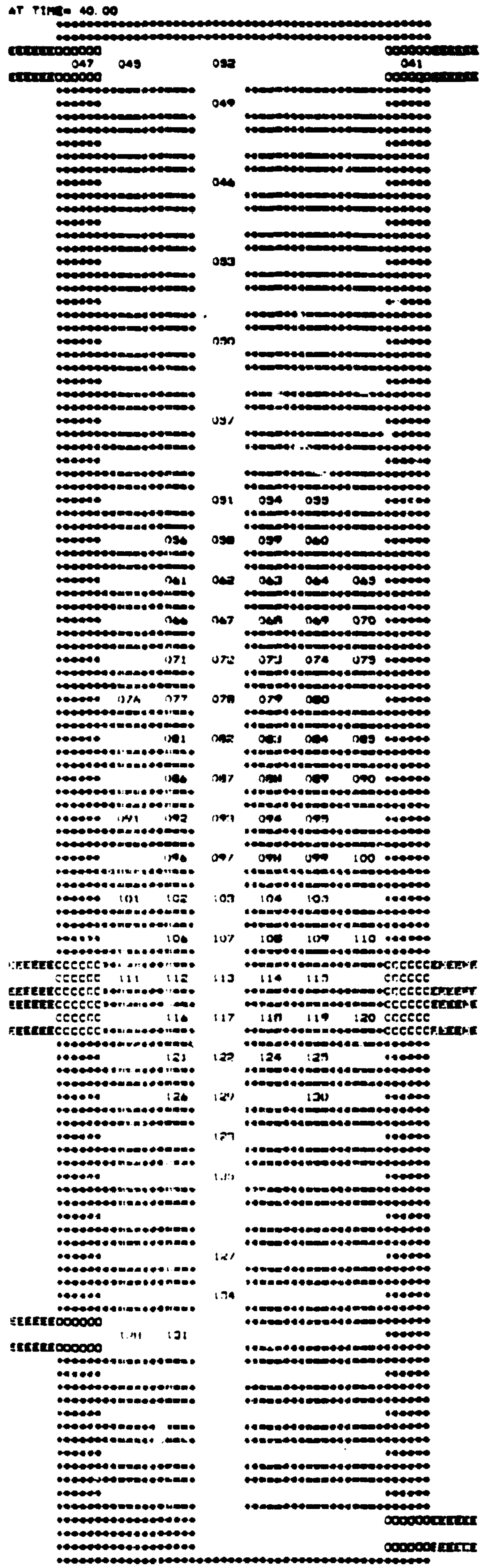

Figure 12.
Passenger placement at
t = 40 seconds
Fire Scenario.

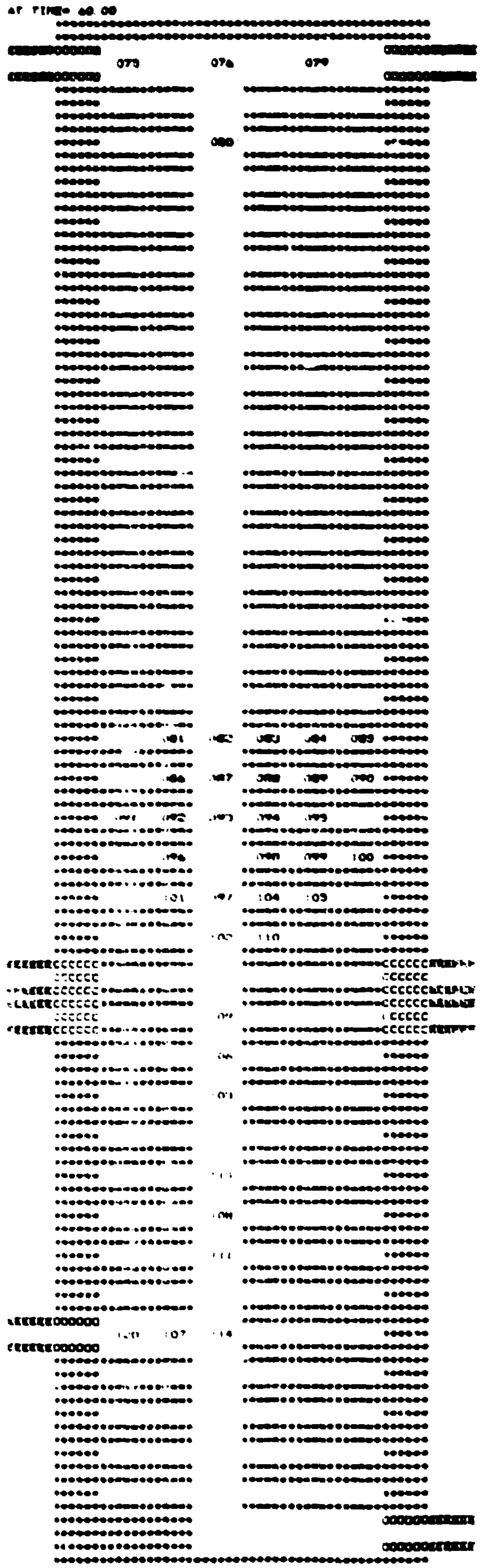

Figure 13.
Passenger placement at
t = 60 seconds
No Fire Scenario.

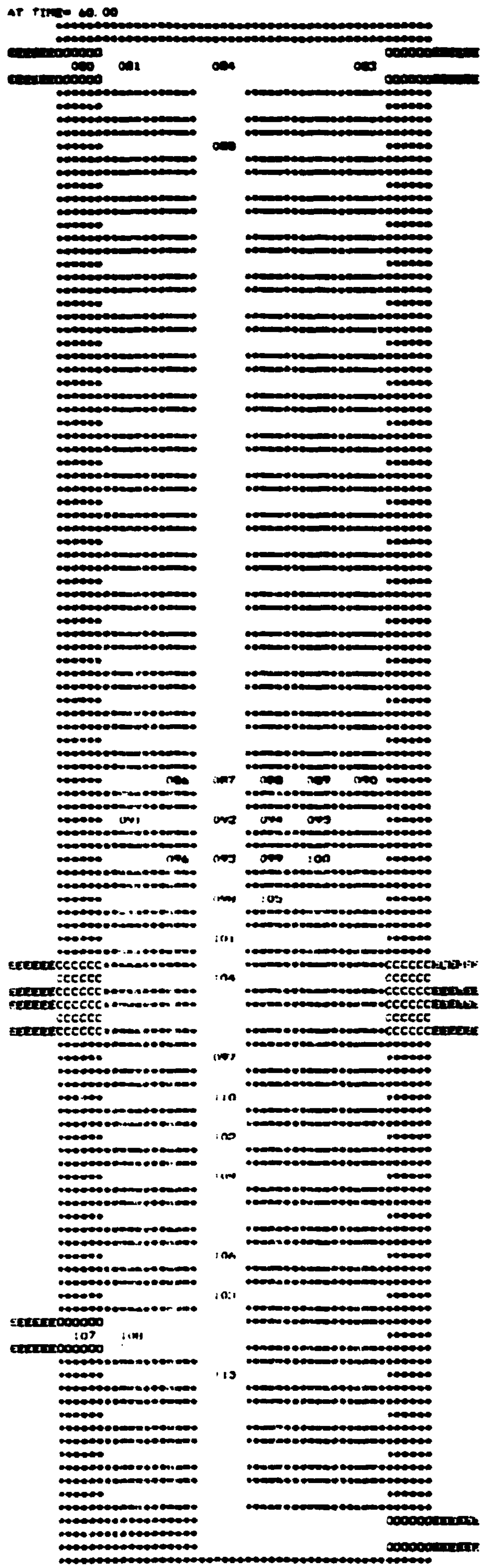

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Figure 14.
Passenger placement at
t =60 seconds
Fire Scenario.

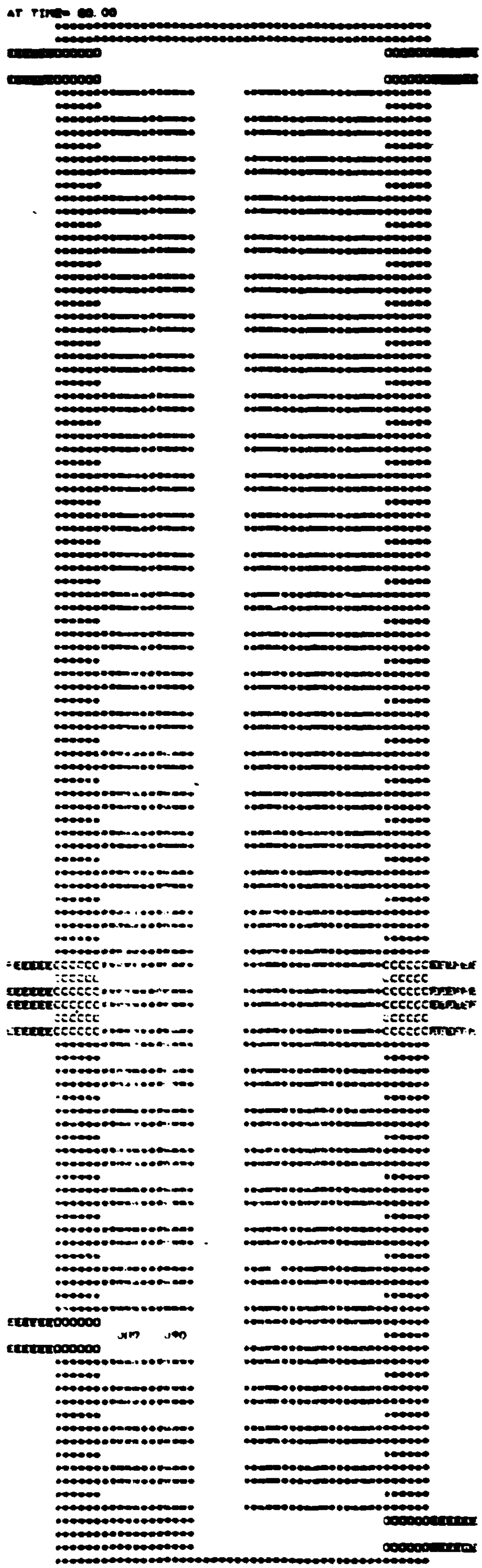

Figure 15.
Passenger placement at
t = 80 seconds
No Fire Scenario.

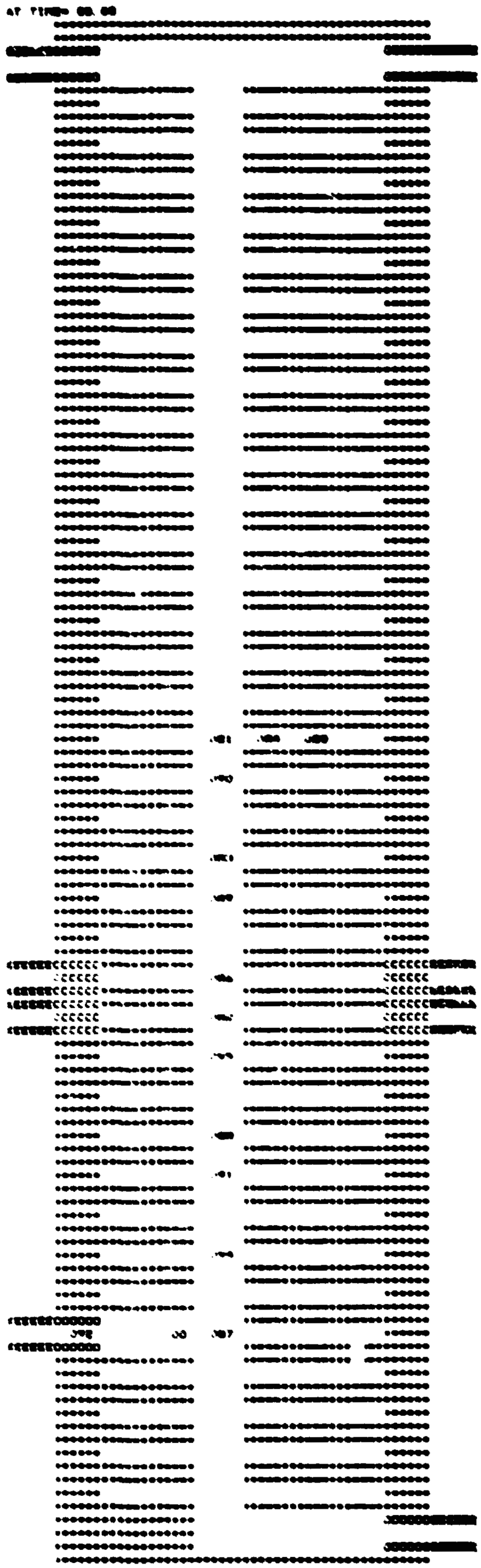

Figure 16.
Passenger placement at
t =80 seconds
Fire Scenario.

EXIT	NO. OUT	TOTAL TIME
1	48	63.603 SEC.S
2	32	63.462 SEC.S
7	83	95.865 SEC.S
10	15	30.124 SEC.S

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SIMULATION START= 0 MILLISECONDS DELTA T= 50 MILLISECONDS
ACCELERATION FACTOR= 0.250
DC-9 S180
DC9 S-180 FIRE3ND COMPLETE ATMOS (IATMDT=IDTSPD=5 SEC.S)

(a) Fire Scenario (Atmosphere and Human Factor Updates Every 5 seconds).

EXIT	NO. OUT	TOTAL TIME
1	46	63.823 SEC.S
2	39	64.023 SEC.S
7	76	83.453 SEC.S
10	17	64.140 SEC.S

SIMULATION START= 0 MILLISECONDS DELTA T= 50 MILLISECONDS
ACCELERATION FACTOR= 0.250
DC-9 S180
DC9 S-180 FIRE3 No Atmos. (IATMDT=9's/IDTSPD=9's/IXITUP=100000)

(b) No Fire Scenario.

Figure 17. Comparison of Exit Times Between a Fire and No-fire Scenario.

APPENDIX C

MODEL SUBROUTINES

This appendix provides the details of the model's subroutine structure. The model is first divided into its specific processes and then each process is in turn broken down into its components until the model is described in terms of its individual FORTRAN subroutines.

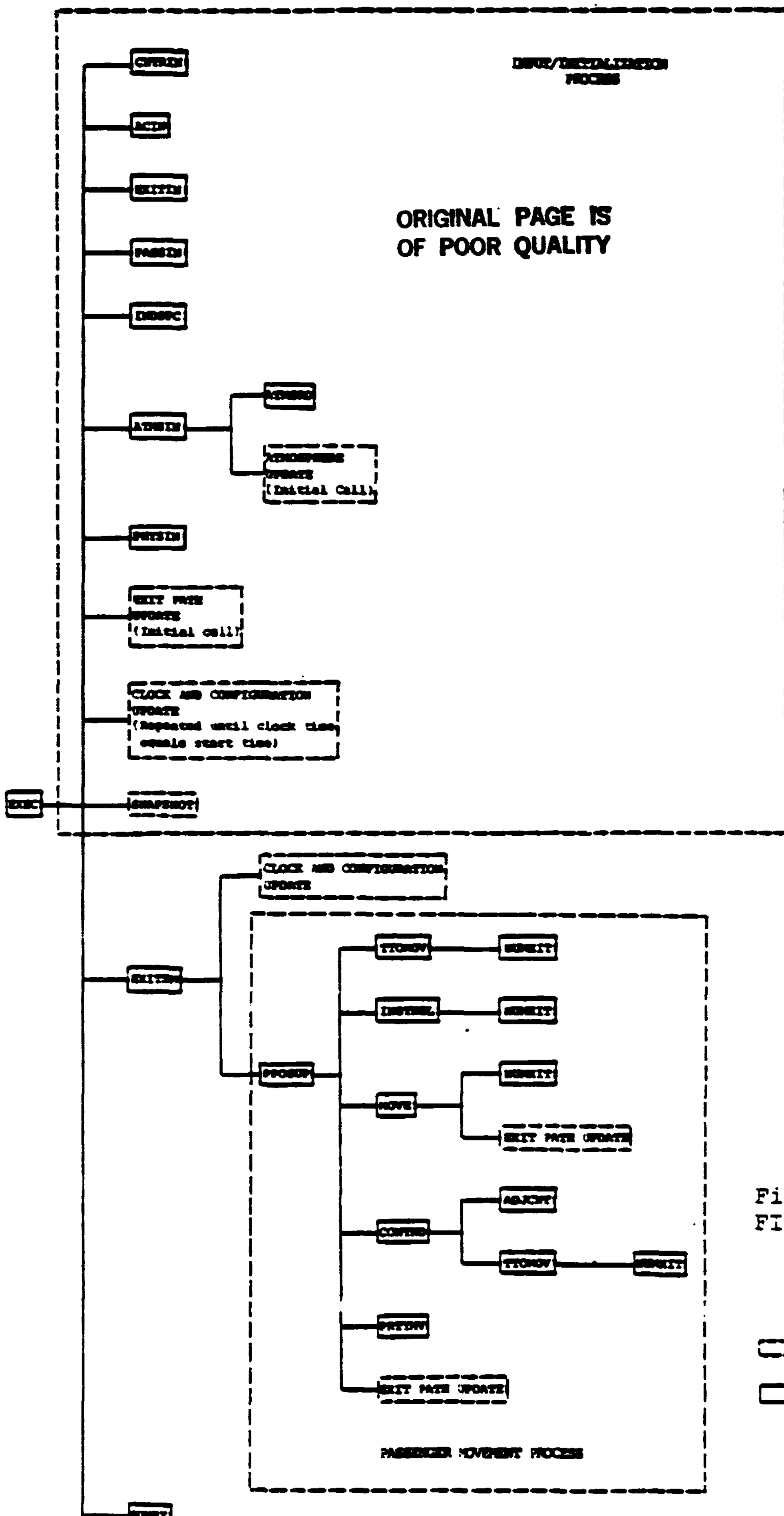

Figure 18.
FIREVAC Calling Tree.

LEGEND

= Process (a group of subroutines)

= Subroutine

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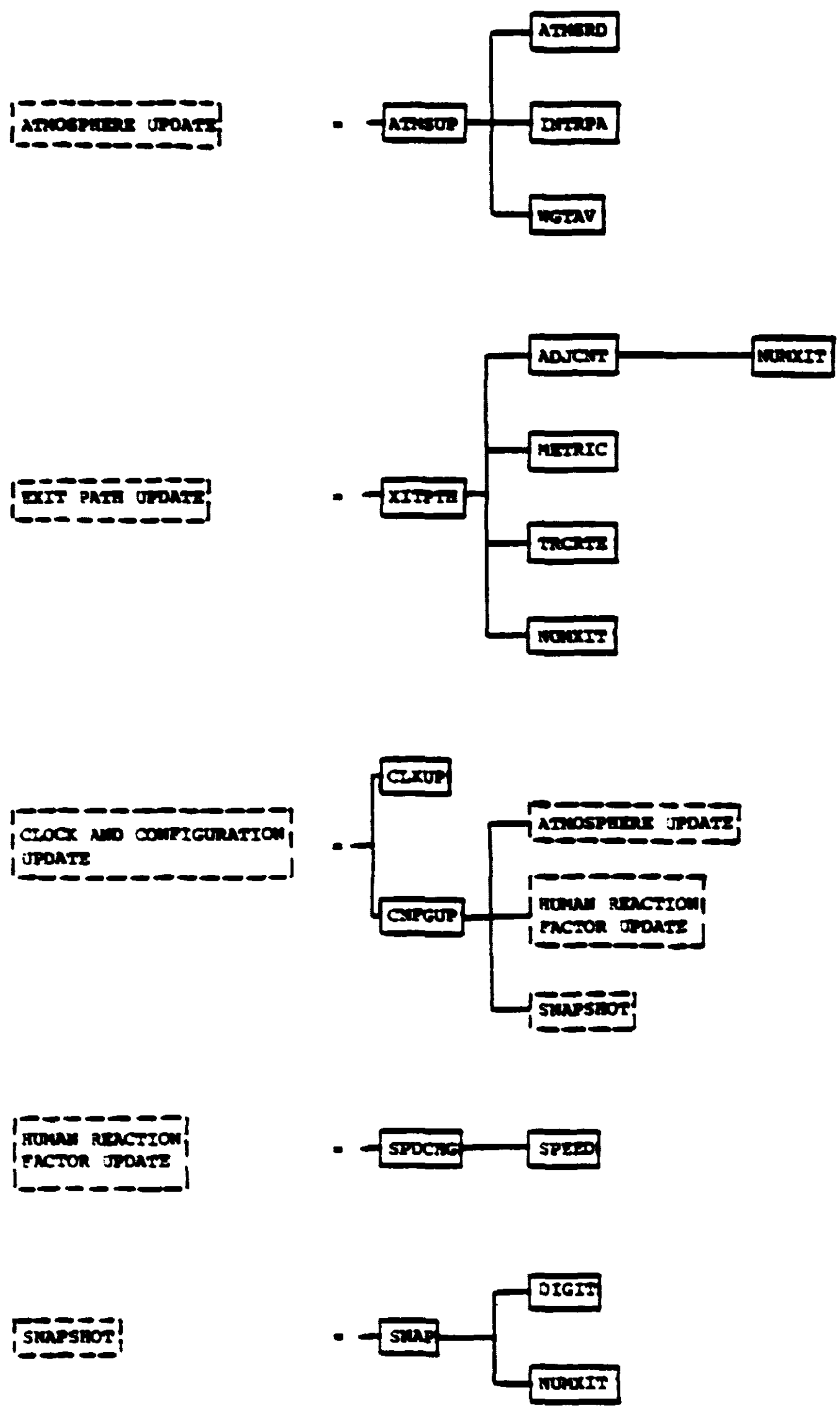

Figure 18. Continued.

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FIREVAC VERSION 5 PROCESSES

Atmosphere Update	Calculates cabin atmosphere from input atmosphere profile.
Exit Path Update	Determines "optimal" exit path for a given passenger.
Clock and Configuration Update	Keeps running sumulation clock controls. CEM and HFM updates.
Human Reaction Factor Update	Calculates human reaction factor and adjusts passenger speeds.
Input/Initialization	Reeds in required aircraft and passenger data. Sets initial values for the model's dynamic variables.
Passenger Movement	Simulates passenger movement from seated position to exit.
Snapshot	Produces graphical output showing cabin interior and passenger position.

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FIREVAC VERSION 5 SUBROUTINES

ACIN	Aircraft input routine reads aircraft configuration data, type, width, length aisle locations, etc.
ADJCNT	Finds all nodes which are adjacent to a given node and which can be occupied by a passenger.
ATMSIN	Atmosphere input/initialization routine. Reads in profile of atmospheric conditions and initializes other atmosphere related variables..
ATMSUP	Updates the atmospheric conditions inside the aircraft for a given time. Used first to set initial cabin atmosphere parameters then called during the sumulation to update them. Calculates toxicant concentrations to reach node in the aircraft cabin..
ATMSRD	Reads one "new" set of toxicant concentrations from atmosphere input profile.
CLKUP	Clock update routine. Updates simulation clock.
CNFGUP	Configuration update routine. Updates the condition of the aircraft.
CNTRIN	Simulation control data input routine: start time, update times, etc.
CONTND	Finds all possible contenders (passengers wanting to move into) a given node.
EXITIN	Exit information input routines, reads number of exits, locations whether exit is open or closed, and time to open exit, etc.
EXTSIM	Controls cycle between PEM, CEM, and HFM.
INDSPC	Individual Specification. Reads a set of Gaussian deviates and uses them to calculate each passenger's speed through each node type.
INTRAPA	Linearly interpolates between "old and "new" toxicant values from the atmosphere input profile. The interpolation is on time dependent sampling point temperatures and gas concentrations. Spatial approximations are handled by subroutine WGTAVE.
ISTNBL	Is target node blocked? Routine decides whether a passenger's target node (next in exit path) is blocked.

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FIREVAC VERSION 5 SUBROUTINES (Continued)

METRIC	Measures "distance" between two nodes, for use in exit path calculations.
MOVE	Move routine moves the passenger into target node.
NUMXIT	Service function which returns a value of zero if a given node is not an exit, and otherwise returns the exit number.
PASSIN	Passenger input routine reads initial (seat) passengers locations.
PHYSIN	Initialize passenger physical characteristics (at present only sets $F_b = 0$ for all passengers).
PPOSUP	Passenger position update passengers who are able to move at present clock time will be advanced along their exit paths.
PRTYMV	Priority Move. Determines which of the contenders for a given node has priority. Present criterion is longest waiting time.
SNAP	Snapshot routine generates a rough presentation of the columns and rows to give a snapshot of where each passenger is located in the aircraft at a given time.
SPDCHG	Uses human reaction factor to adjust passenger speed through node types for a given passenger.
SPEED	Updates the fractional effective dose, and then calculates a speed factor for that passenger.
SUMRY	Summary routine prints summary of exit output data.
TRCRTE	Traces the path to the nearest exit for a given passenger.
TTOMOV	Time to move? Routine decides whether enough time has elapsed since last passenger move, to allow passenger to move again.
WGTAVE	Uses sample point data of the input atmosphere profile to calculate a weighted average value for a given toxicant and a given node.
XITPATH	Finds optimal paths to open exits for a given passenger.