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SURVIVAL IN EMERGENCY ESCAPE FROM PASSENGER AIRCRAFT

Clyde C. Snow, Ph.D.
John J. Carroll
Mackie A. Allgood, M.S.

Approved by

J. ROBERT DILLE, M.D.
CHIEF, CIVIL AEROMEDICAL INSTITUTE

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AUTHORS: *Clyde C. Snow, Ph.D.
**John J. Carroll
***Mackie A. Allgood, M.S.

Present Address:

*Chief, Physical Anthropology, AC-119
Civil Aeromedical Institute
Federal Aviation Administration
P.O. Box 25082
Oklahoma City, Oklahoma 73125

**Chief, Accident Prevention
National Transportation Safety Board
Bureau of Aviation Safety
Washington, D.C. 25091

***Physical Anthropology, AC-119
Civil Aeromedical Institute
Federal Aviation Administration
P.O. Box 25082
Oklahoma City, Oklahoma 73125

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"Life is short and Art long; the occasion instant, decision difficult, experiment perilous."
—Hippocratic aphorism

I. Introduction.

It is doubtful that Hippocrates, in the 4th Century B.C., envisioned how apt his aphorism might seem to passengers escaping from a flaming aircraft. Within a few seconds, they must make a perilous journey from seat to sanctuary through fire, smoke and a maze of physical and human barriers. Such a passenger needs no philosopher to remind him that the occasion is instant, the decisions difficult and that life may indeed be short.

How short he finds it depends largely upon the number and location of exits, which of these are blocked by flame or impact damage, the human help he receives along the way and the intensity of fire and smoke within the cabin. But in addition to these extrinsic factors, his chance of survival is also influenced by physical and mental attributes of his own that may enable, or prevent, his effective exploitation of the short time he has remaining.

Thus the factors influencing his escape may be grouped as configurational, procedural, environmental and biobehavioral (Table I). The first three may be studied experimentally as, for example, in the laboratory testing of fire suppressant devices or the evaluation of exit configurations and crew procedures in simulated evacuations.

The fourth involves human behavior under conditions of extreme physical and emotional stress not ordinarily reproducible in an experimental setting. To study this "fourth dimension" of survival, the investigator must turn to the careful reconstruction of passenger behavior in actual accidents. An applicable concept is that sometimes employed by social anthropologists, the "natural experiment."[1]

A natural experiment is a situation "where change of a clear and dramatic nature has occurred" and the change itself may be ". . . treated as an independent variable in an experimental setting and its effects observed and recorded."[2]

TABLE 1.—Some factors influencing survival in emergency evacuations.

		Example
Configurational	Standard features of occupant environment controlling access to exits and evacuation flow rates.	Seating density, aisle width, size, number, and location of emergency exits, slides, physical exit cues.
Procedural	Regulatory and training practices of crew and other non-passenger rescue personnel which influence evacuation procedures.	Experience and training of crew.
Environmental	Features of the occupant space and outside A/C which control survivability and evacuation time.	Heat and toxic by-products of combustion, secondary explosion, outside light, and weather.
Biobehavioral	Biological, psychological, and cultural attributes of individual passengers which influence agility and behavior.	Sex, age, physical condition, passenger experience.

In this paper such an approach is used to study several human factors in three aircraft accidents. In all, 261 passengers were involved—105 of whom lost their lives.* The aircraft were jet transports of types still in service and likely to be used for some years to come. In each accident,

* Five crew members also died in one of the accidents (Rome). However, the distinct roles of crew and passengers in evacuation make the former a small, but distinct, risk population and one which should be treated separately in the study of survival. In this paper, all statistics refer only to passengers unless it is specifically noted that crew data are included.

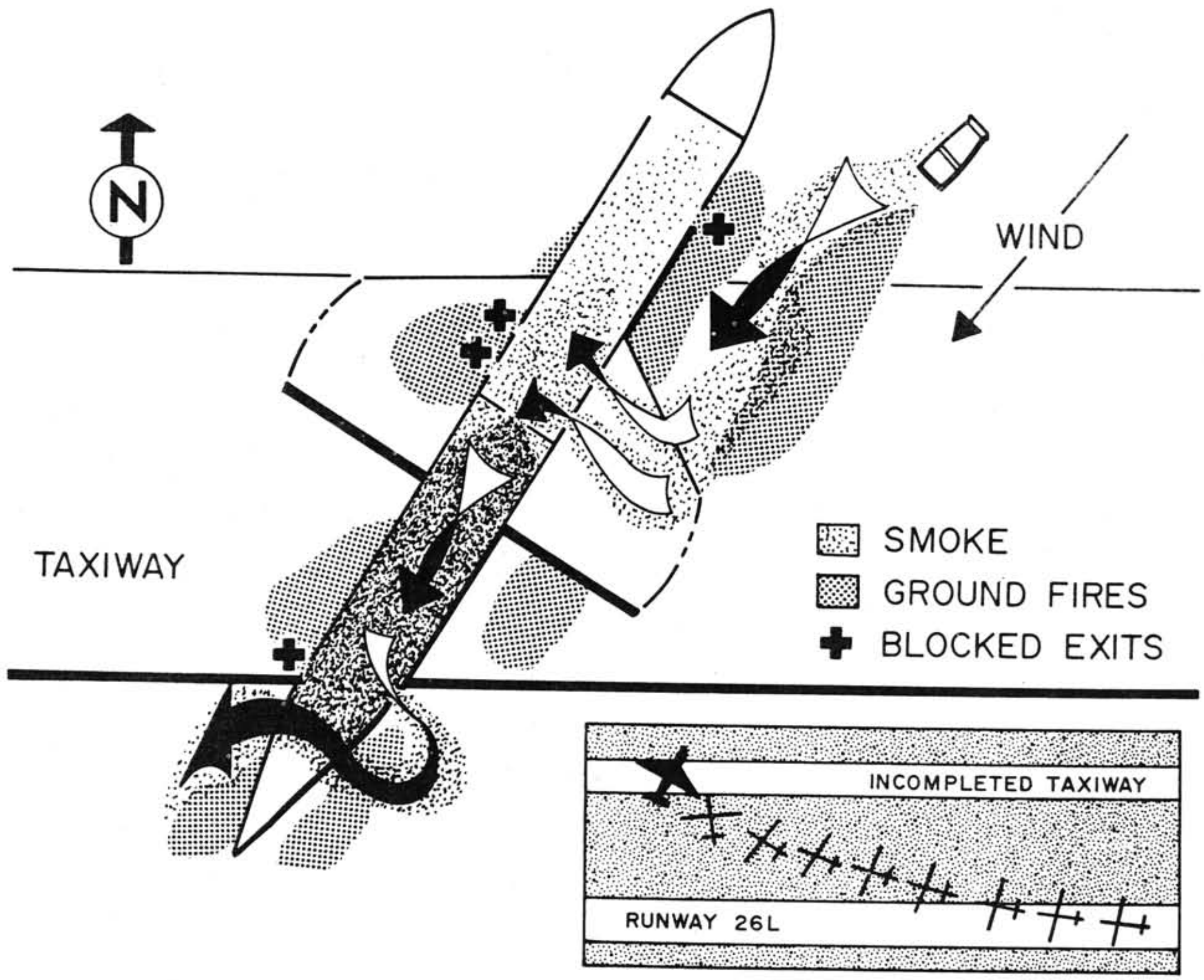


FIGURE 1. Path (inset) and final position of Denver DC–8. Smoke from ground fuel fires forward of right wing entered cabin through opened right window exits. Concentration of smoke was particularly intense in 2nd-class (aft) passenger compartment due to draft produced by open right rear galley exit.

decelerative forces were mild and structural deformation impeding escape was minimal. Fractures and other mechanical trauma, with few exceptions, were minor and sustained during escape rather than at impact; all deaths and major injuries were caused by fire and smoke. Thus, variables introduced by crash forces were insignificant and survival was largely determined by the ability of uninjured passengers to leave their seats and find an exit before succumbing to fire or smoke.

II. The Accidents.

A. Denver.

Shortly before noon on 11 July 1961, a United Airlines DC–8 crashed during a landing at Stapleton Field, Denver. The flight, UAL #859, originated that morning in Philadelphia and made uneventful stops in Chicago and Omaha. A few minutes after leaving Omaha the crew discovered that hydraulic fluid had been lost from the system that controls gear deployment and on-ground steering. The two senior stewardesses were briefed on the situation by the flight captain and told that an emergency landing might be expected. They returned to their stations and alerted the two junior stewardesses; together they reviewed the procedures for emergency evacuation.

About 15 minutes before landing in Denver, the stewardesses were informed that the difficulties had been overcome and that no emergency

FIGURE 2. Denver DC–8. View of the left aft main entry door, rendered unusable for exit route because of impact with truck. The impact deformed the floor area at the door sill, broke the aft lounge bulkhead loose. The occupant of the truck was killed instantly. The door was not opened during evacuation. The soot-free rectangular areas on the lower one-third of the door intterior are the imprints of magazines and other lounge items which were thrown against the door during the violent swerve which occurred when the aircraft struck the taxiway. This pile of debris blocked any attempt by the crew to open the door during evacuation.

was anticipated. A little later the captain announced to the passengers that, despite minor hydraulic problems, a normal landing was probable. Upon landing, they were told, they might see fire trucks by the runway but not to become alarmed since this was a routine precaution. Meanwhile, the stewardesses secured the buffets, opened the door of the divider separating the 1st- and 2nd-class compartments, checked the passengers' seat belts and performed other normal pre-landing duties. The passengers were given no instructions for a possible emergency evacuation.

Approaching from the east, the aircraft made a normal touchdown a few hundred feet beyond the end of runway 26L. During the roll-out, the plane veered suddenly to the right and skidded off the runway, sheering off both main landing gears and sliding on its belly across several hundred feet of open ground. During this time it yawed gradually to the right so that toward the end of its course it was traveling almost sideways (Fig. 1). Directly in its path was a newly-constructed taxiway, the margins of which had not yet been contoured so that they stood as raw concrete abutments rising some 18 inches from the ground. Parked a few feet in front of the taxiway was a panel truck belonging to an airport survey party. The aircraft was brought to a sudden halt when it struck the truck and the edge of the taxiway almost simultaneously. The truck was crushed beneath the fuselage, almost directly under the left aft passenger door (Fig. 2); its driver was killed instantly.

The aircraft came to rest lying across the taxiway at an angle of about 100° to the right of its original course with its final heading slightly to the east of true north (Figs. 1–3). Soon after the aircraft stopped, two major fires broke out. One started from an engine which tore free at impact and tumbled to a point about 60 feet forward of the right wing (Fig. 4). Following

FIGURE 3. View of the aircraft from the right front after fire and removal of fatalities. In foreground are landing gear and one of the 3 engines which were sheared and tumbled forward as the aircraft struck the 18-inch abutment of a new taxiway upon which it came to rest.

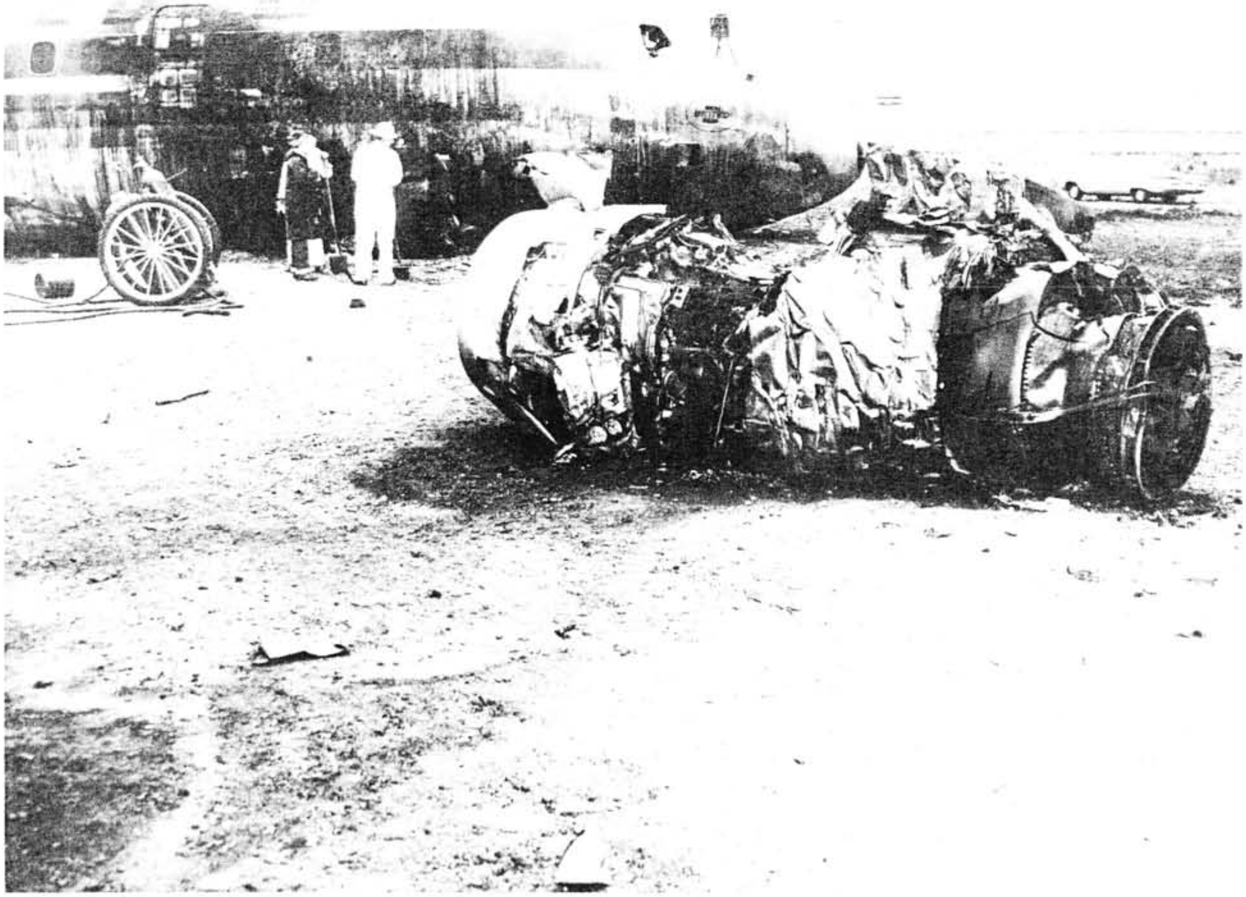


FIGURE 4. Right front view of Denver DC-8 showing detached #4 engine which ignited spilled ground fuel in the right forward area.

a path of spilled fuel, flames spread back from the engine toward the aircraft and soon most of the area along the right side of the fuselage was enveloped by a ground-fuel fire (Fig. 5). This fire produced an acrid black smoke which was blown toward the aircraft by a 7-knot wind from the northeast. When the right window exits were opened this smoke invaded the passenger cabin. Figure 6 is a photograph of the aircraft taken by an airport employee who was one of the first to arrive on the scene. It shows the extent of this outside fire and the spread of smoke.

The second major fire was at the left wing root. It probably originated from the left inboard engine which had been torn loose and lay crushed under the wing. Although sufficient to prevent the use of the left window exits, this fire was of limited extent during the first 5 minutes after the aircraft stopped. Later it flared out of control, penetrated the cabin, and within 15 to 20 minutes destroyed most of the fuselage (Figs. 7, 8).

In the subsequent description of the evacuation, the following points regarding the slide of the aircraft and fire propagation should be kept in mind:

1. All decelerative forces were mild and seat failures did not occur. The ride across the open ground, however, was sufficiently violent to toss articles of clothing, handbags and other objects out of the overhead racks. The most violent event occurred during the last second or so when, after the aircraft struck the taxiway, it made a final, hard swerve to the right.

FIGURE 5. Right front view of Denver DC-8 showing the two overwing exits and right aft galley service door through which a total of 66 passengers escaped. A pool of unburned fuel is shown to the right of the cockpit. Ground fire in this area prevented use of the forward service door and a 7-knot NE wind carried smoke from this fire into the cabin through the open window exits.

2. During evacuation, the principal environmental hazard was smoke. When the aft galley door was opened, a chimney-effect developed, drawing outside smoke into the right window exits, down through the aft section of the cabin and out the open door. For this reason, the concentration of smoke was heaviest in the aft cabin.

3. Although occasional tongues of flame were blown in through the right window exits, destructive invasion of the cabin by fire occurred only after 98 passengers had escaped and 16 others had been incapacitated by smoke.

Configuration. The cabin was divided into 1st- and 2nd-class * compartments by a partition located between the 9th and 10th seat rows (Fig. 9). The 1st-class compartment was in the forward portion of the cabin and contained an 8-seat lounge immediately behind the flight deck. Separating the lounge from the regular seating was a service area consisting of closets, lavatories, and a galley. In the forward cabin were 9 rows of double seats and a 21-inch aisle. Including those in the lounge, there were 44 passenger seats in 1st-class. The 2nd-class cabin was located in the aft section of the aircraft. It consisted of 12 rows of triple seats separated by an 18-inch aisle and, behind these, a 5-seat lounge opposite the galley. With the lounge, there was a total of 77 passenger seats available in 2nd-class.

There were eight potential escape routes in the passenger cabin. Four were door-type exits equipped with ceiling-mounted escape slides. These were located in the extreme forward and aft sections of the cabin. The passenger boarding doors were on the left and the galley service doors on the right. In the 1st-class cabin were four overwing window exits, two on each side, at seat rows 7 and 9. There was no sign or other visual cue in the 2nd-class cabin indicating that the window exits were situated forward, beyond the dividing partition.* However, the stewardesses did call attention to the window exit locations during the standard preflight briefings. During take-offs and landings, the door of the partition separating the cabins was opened

* Throughout this paper "2nd-class" will be used as a substitute for the varied and sometimes confusing euphemisms ("coach," "tourist," "economy," etc.) employed by airlines.

* FAA regulations now require such signs.[3]

FIGURE 6. Right front view of the Denver DC–8 taken by airport employee soon after aircraft came to rest and before arrival of fire-fighting equipment. It shows the extent of outside fire and the direction of smoke dispersion.

and some 2nd-class passengers in the forward rows could see the window exits from their seats.

Although the two compartments were about the same size, the 2nd-class section held about two-thirds of the passengers. The 42 passengers in 1st-class had direct access to six of the eight potential exits; the 72 passengers in 2nd-class, had direct access to only two. Thus, the ratio of passengers to *directly* accessible exits was 7-to-1 in 1st-class and 36-to-1 in 2nd-class.

Crew. The crew of seven consisted of three male flight-deck personnel and four stewardesses. Two of the latter served each compartment. At impact, one of the stewardesses in 1st-class was seated in an aft-facing jump seat near the boarding door, the other was in a lounge seat. In the 2nd-class cabin, one of the stewardesses occupied a seat in the rear lounge and the other sat in a forward-facing jump seat next to the rear boarding door.

Passengers. Of the 114 passengers aboard the aircraft, 38 adults and 4 children* were in 1st-class. One child, aged 5, was traveling with her grandmother;** the other three—a group of two boys of 13- and 14-years and their 4-year-old sister—were accompanied by their parents. Among the adults, there were about twice as many males (26) as females (12). Adult ages ranged between 18 and 73 with a mean of 50.4 years for males and 55.6 years for females. The only invalid in 1st-class was a partially-paralyzed male, aged 65, who was accompanied by his 66-year-old wife.

In 2nd-class there were 72 passengers of whom 11 were children. One of the latter was a 10-year-old boy traveling alone; the other 10 were accompanied by adults. The largest family-unit was a mother with her 1-, 4-, and 8-year-old daughters; another woman was traveling with

* In this paper all passengers under the age of 16 are classified as children.

** The listing of this child under both her own surname and that of her grandmother led to a reported total passenger load of 115 which has been used in all previous official and non-official documents relating to this accident.

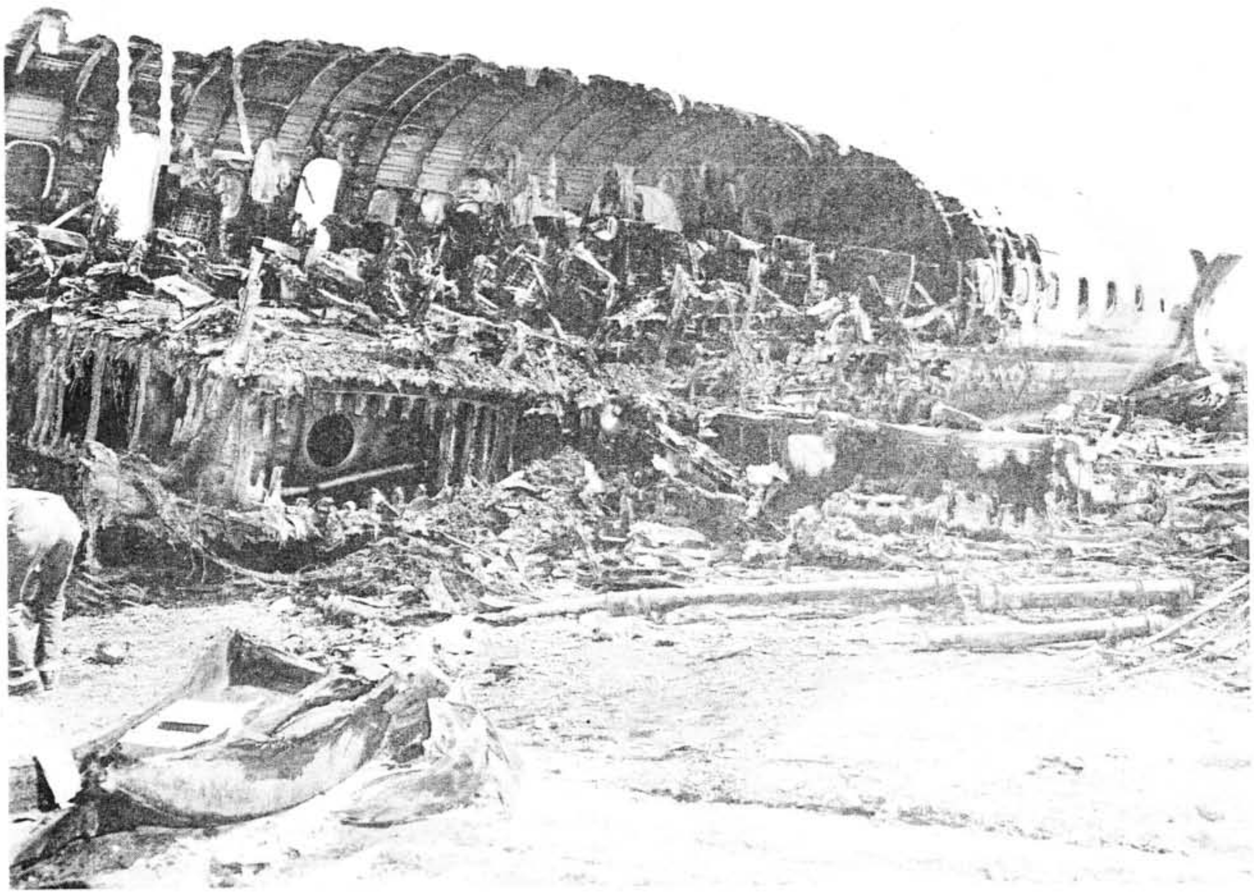


FIGURE 7. Post-fire view of Denver DC-8 from left front. The #1 (left outboard) engine was detached and impacted beneath the left wing root. The resulting fire was initially limited and did not penetrate the cabin until evacuation was complete. It later flared out of control and extensively damaged the aircraft interior.

her infant daughter and 2-year-old son. The other 5 children were not related and each was traveling with a single parent. Four of the 11 children were infants carried by their mothers, the other 7 occupied seats of their own.

Among the 61 adult passengers in 2nd-class there were almost twice as many females (37) as males (24)—the reverse of the situation in 1st-class. In age, they ranged from 18 to 86 years with a mean age of males of 45.7 years and of females, 46.8 years. Two of the 2nd-class passengers were semi-invalids—a 66-year-old male recovering from recent surgery and an extremely obese, elderly female, who was boarded in Omaha with the aid of a fork-lift. The oldest passenger, aged 86, was a female accompanied by her 52-year-old daughter. Table 2 summarizes the age and sex composition of the 1st- and 2nd-class passenger loads.

Later in this paper, age and sex will be studied as variables influencing survival. As shown above, there appears to be a strong difference in the sex ratios and mean ages between the 1st- and 2nd-class adult passengers. For the subsequent treatment of the data, it is necessary to decide whether these observed differences represent sampling fluctuation within a single passenger population or individual samples of two separate populations based on travel-class. To do so, a chi-square test was used to examine the difference in sex ratios between the two classes while their age differences were compared by Student's-*t*

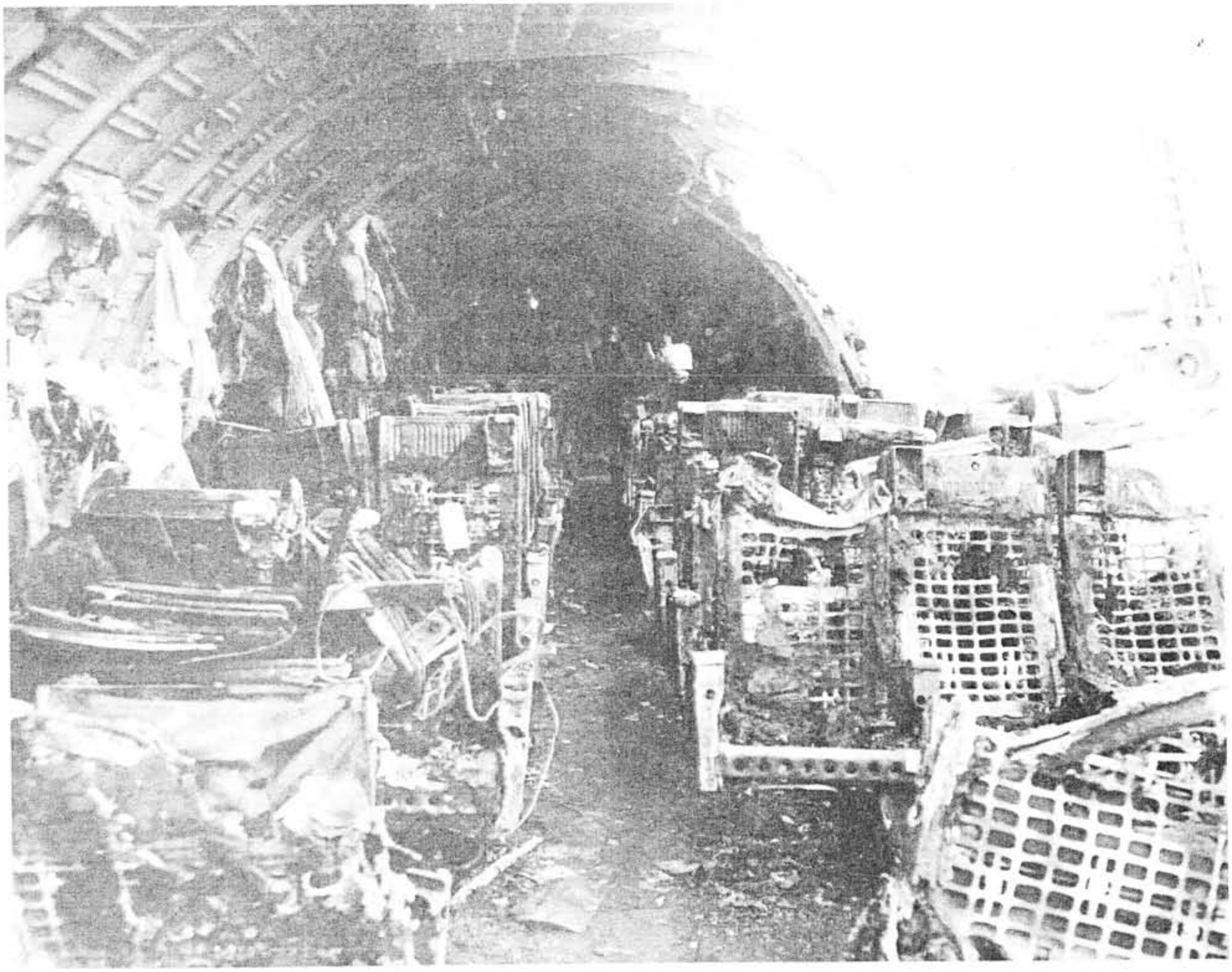


FIGURE 8. Aft-facing view of 2nd-class cabin of Denver DC-8, showing interior destruction and heavy damage to left side by fire originating in left wing-root area.

tests. The results are shown in Table 3. Significant differences were found between the sex ratios ($p < .01$) and the age means ($p < .10$). These disparities are probably related to different travel habits of distinct socio-economic groups. It, therefore, appears preferable to treat the two classes separately in the statistical analyses that follow.

Passenger Seat Location. The original seat locations of 106 of the 114 passengers were determined through survivor interviews (Fig. 9). The eight passengers whose seats could not be precisely identified were adult fatalities seated in the 2nd-class cabin. One of the five females in this group sat in seat 13B—but which of the five is not known for certain. The remaining seven, four females and three males, occupied the six right-hand seats of rows 13 and 14 and the middle seat of row 12 but their exact order of seating is not known. There was one vacant seat in the 1st-class compartment and eight in 2nd-class. Thus, the seating density (seats occupied/seats available) was 97.7% in 1st-class and 89.6% in 2nd-class.*

Evacuation.

Forward Section. Immediately after the aircraft stopped, the 2nd-officer left the cockpit and opened the forward entry door. Working together, he and the senior stewardess quickly deployed the escape slide. By this time, a number of passengers had left their seats and were standing by the door. Since the distance to the ground was only 4½ feet, the 2nd-officer decided not to

* Calculations include lounge seats. Stewardesses occupying lounge or regular cabin seats, but not jump seats, are also counted.

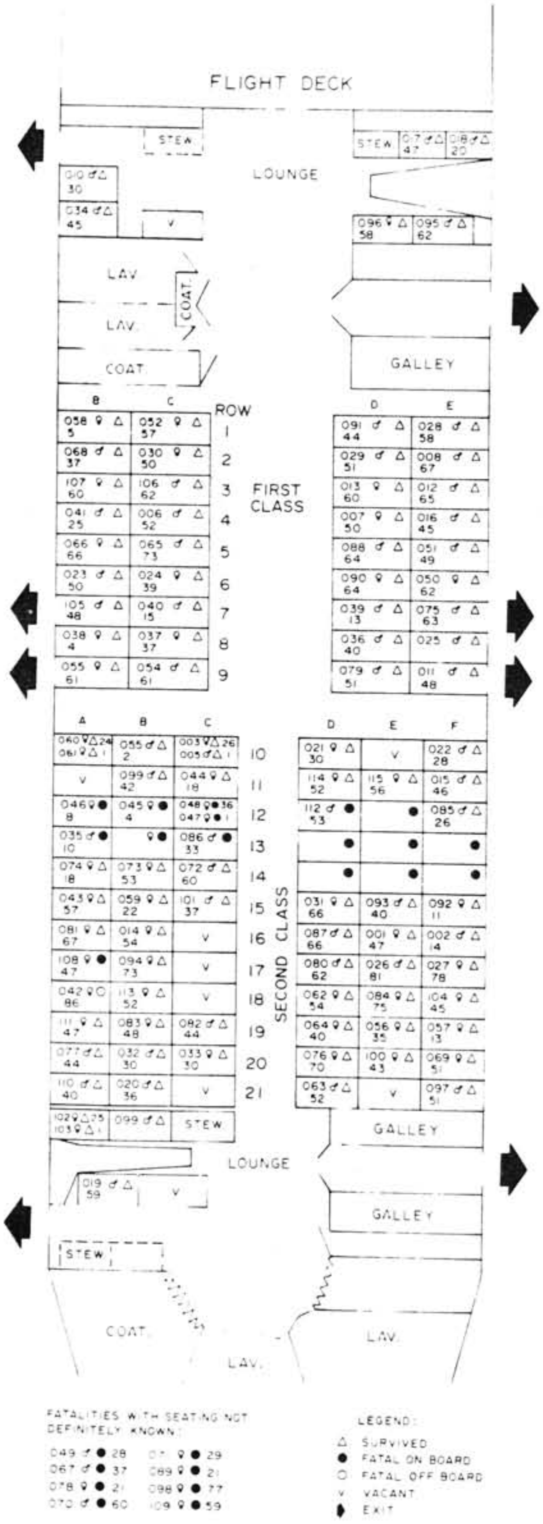


FIGURE 9. Diagram of the seating and distribution of the 114 passengers aboard the DC-8. Sex, casualty status, identification number based on an alphabetical roster of surnames (3 digits) and age (2 digits) of each passenger are indicated.

TABLE 2.—Age and sex of passenger survivors and fatalities of the UAL DC-8 accident at Stapleton Field, Denver, 11 July 1961.

Sex & Age	Fatalities: Inside A/C	Fatalities: Died Later	Fatalities: Total	Survivors	Total Passenger Load
Children					
Male:					
0 – 5	0	0	0	2	2
6 –15	1	0	1	3	4
Female:					
0 – 5	2	0	2	4	6
6 –15	1	0	1	2	3
Total	4	0	4	11	15
Adults (16–55 yrs.)					
Male					
16–25	0	0	0	2	2
26–35	3	0	3	3	6
36–45	0	0	0	11	11
46–55	1	0	1	13	14
Unknown	0	0	0	3	3
Total	4	0	4	32	36
Female:					
16–25	2	0	2	2	4
26–35	1	0	1	6	7
36–45	1	0	1	6	7
46–55	1	0	1	11	12
Total	5	0	5	25	30
(> 55 yrs.)					
Male:					
56–65	1	0	1	7	8
66–75	0	0	0	4	4
76–85	0	0	0	1	1
Total	1	0	1	12	13
Female:					
56–65	1	0	1	9	10
66–75	0	0	0	6	6
76–85	1	0	1	2	3
> 85	0	1	1	0	1
Total	2	1	3	17	20
All passengers	16	1	17	97	114

inflate the slide and evacuation began. Outside the aircraft, the 1st-officer, who had escaped through a cockpit window, and an unidentified man held the bottom of the slide as the passengers disembarked. Meanwhile, the junior stewardess went to the galley door, saw the fire outside and decided not to open it.

When evacuation through the forward boarding door was underway, the senior stewardess went aft and stationed herself near the right window exits. Both of the latter were opened by passengers soon after the aircraft stopped and were already in use when she arrived. By this time, smoke was so dense that she could see no passengers in the 2nd-class cabin but she called for people to come toward her. Several passengers emerged from 2nd-class and she directed them through the right aft window exit. After further calls met with no response, she returned to the forward boarding door and left the aircraft. As noted previously, the left window exits were not opened due to the fire on the wing.

TABLE 3.—Comparison of age and sex ratios of 1st and 2nd-Class adult passengers of the Denver DC-8.

	Males		Females	
1st-class	26		12	
2nd-class	24		37	
Chi-square=6.799		$p<.01$		
1st-class	50.4 yrs.	$t=1.39$	55.6 yrs.	$t=1.52$
2nd-class	45.7 yrs.	$p<.10$	46.8 yrs.	$p<.10$

After evacuation through the forward boarding door slackened, the captain hoisted himself over the threshold and re-entered the aircraft. He and the 2nd-officer went back into the cabin to help lead stragglers back to the door. They described breathing as difficult and, due to smoke irritation, were at times unable to keep their eyes open. Once the forward part of the cabin seemed clear of passengers, the 2nd-officer groped his way back to the partition between the cabins. There he encountered a male passenger, who said

FIGURE 10. Aft galley service door of Denver DC-8 showing deflated escape slide. A total of 40 2nd-class passengers used this exit. The slide burned after approximately 20 passengers had escaped, forcing the remainder to jump.

he was the last person left in that part of the aircraft; together they made their way back to the forward boarding door and escaped.

Although accounts varied, the general reaction among the 1st-class passengers during the evacuation was one of controlled haste with little evidence of irrational behavior or confusion. The vocal and physical assistance by crewmembers was apparently a strong source of reassurance.

2nd-Class. In the 2nd-class cabin evacuation began after some initial delay owing to various loose articles such as magazines, clothing and pillows being ejected from an upper storage locker on the right side of the cabin during the aircraft's final swerve. This debris blocked the rear, main boarding door (Fig. 2). Because of this debris the junior stewardess, who was seated in the adjacent jump seat, did not attempt to open the door. Subsequent investigation revealed that deformation of the floor due to the impact with the truck would have prevented use of the door in any event.

Meanwhile, the senior stewardess opened the aft galley service door on the right side of the rear cabin, tore off the cover of the escape slide, and pulled down the slide package. As it fell, it tumbled over the threshold forcing her to kneel down and lean out the door to retrieve it. After this delay, she inflated the slide; by this time, passengers were crowding into the buffet area

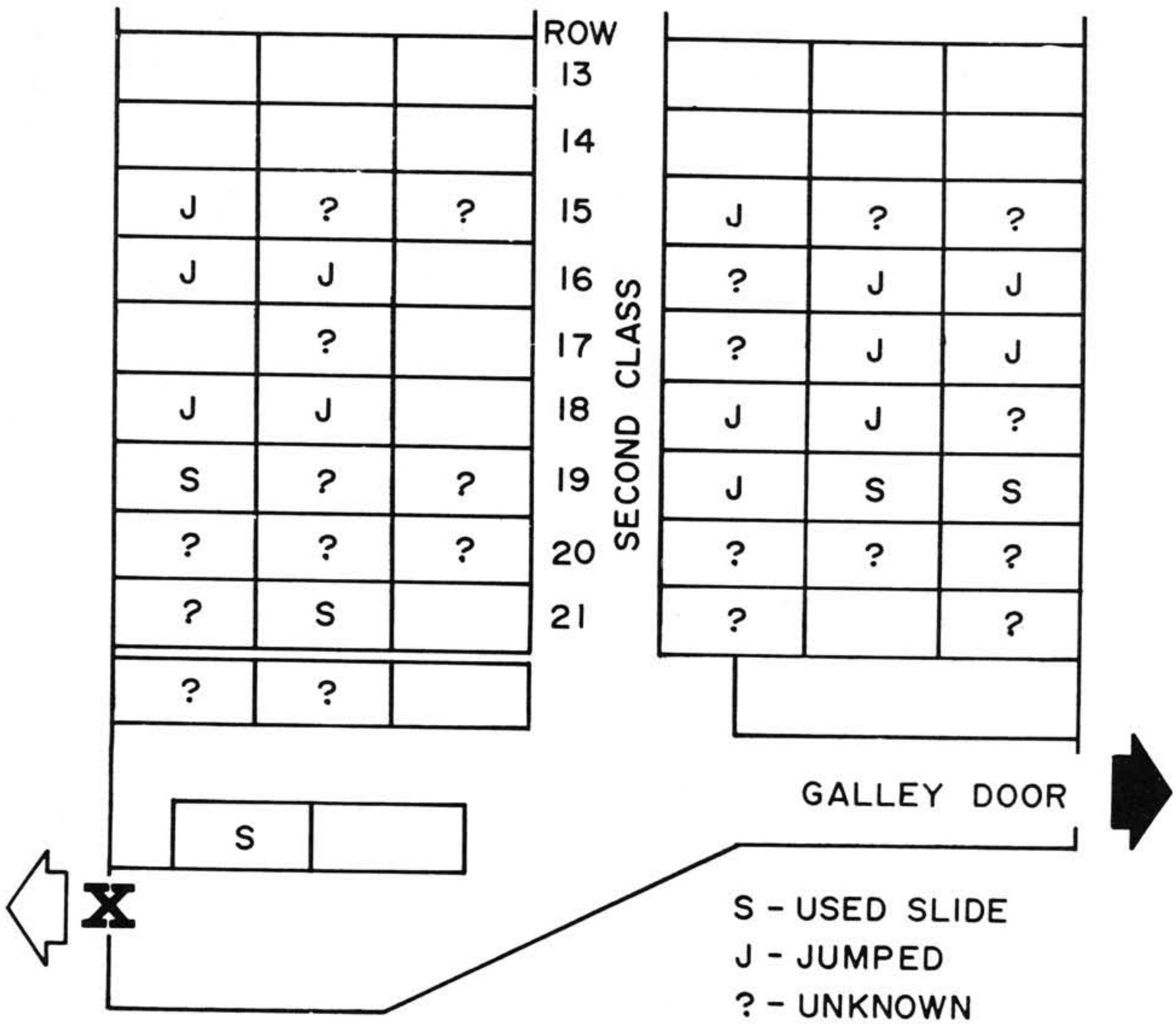


FIGURE 11. Seat locations of 2nd-class passengers of Denver DC-8 whose statements indicated the aft galley door slide was intact when they exited and those who were forced to jump.

behind her. She and a male passenger then jumped to the taxiway and began aiding passengers who by then were descending on the inflated slide. Meanwhile, the junior stewardess (who had been nearly covered with the loose paraphernalia from the storage locker) left her jump seat and took a position near the galley door to assist passengers.

Just prior to the opening of the galley door, the passengers had promptly left their seats and begun to queue up in the aisle. From all accounts, this was done in an orderly and relatively calm manner; little shoving or shouting occurred and many persons took time to collect their personal belongings. As this line was forming, dense, black smoke began filtering into the cabin, making breathing difficult and obscuring vision. Judging from their statements, many passengers—who up to then had reacted calmly—became frightened for the first time. However, even as the smoke increased, displays of overt panic were rare.

Initially, evacuation through the aft galley door proceeded at a rapid rate. After a few moments, however, the ground fire destroyed the slide and forced the remaining evacuees to jump about 6½ feet to the concrete taxiway (Fig. 10). Survivors stated later that the evacuation then slowed due to the hesitation of many passengers to jump into the burning debris of the slide. A review of their statements reveals that of the 18 passengers who mentioned their mode of exiting through the galley door, 5 used the slide and 13 jumped. With one exception, all those who jumped were seated forward of row 19 (Fig. 11). Since it appears that the evacuation line was formed in an orderly manner, it may be assumed that the slide was destroyed about the time the passengers of row 18 were reaching the doorway. Thus, about 20 persons were able to use the slide and the remainder were forced to jump.

Thirteen 2nd-class passengers, seated in the two front rows, went forward and escaped through exits in the 1st-class cabin. Farther aft, a family of three—seated in the left-hand portion of row 14—also used the forward exits. The man, a 60-year-old physician, first led his wife and daughter into the line headed toward the aft door. After several feet, progress slowed and the doctor sensed that they would be overcome by smoke. He then led his family out of the aisle and they knelt down in the space between two seat rows. After a few more passengers filed past, they re-entered the aisle and crawled forward to the right aft window exit.

The junior stewardess continued to assist passengers until a man on the ground yelled for her to jump—that the aircraft was going to explode. She jumped to the ground and ran approximately

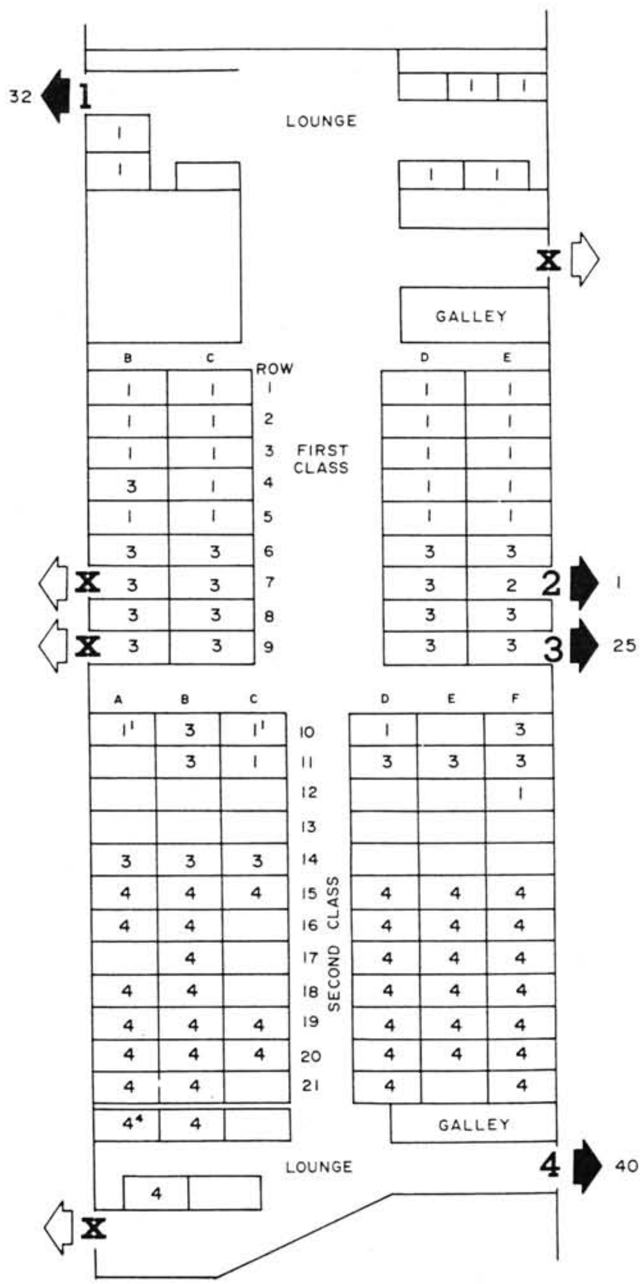


FIGURE 12. Diagram of exit utilization in Denver DC-8 evacuation. Numerals in seats are keyed to exit numbers. Figures adjacent to exits denote total number of passengers using the exit.

50 feet away from the aircraft. She then turned and saw five or six more passengers jump from the exit; after these, no others were seen to escape. At this time, the flight crew, surviving passengers, and ground rescue personnel apparently thought that everyone had safely left the aircraft and only after several minutes was it noted that some passengers were missing. However, by now, the fire in the left wing root had invaded the cabin and rescue workers could not enter the aircraft. Most witnesses estimated that the evacuation was completed within 3- to 5-minutes after the aircraft came to a halt. Of the 98 passengers who escaped, 32 evacuated through the forward boarding door, 26 through the right overwing exits, and 40 through the aft galley service door (Fig. 12).

In a recent study, data relating to FAA and manufacturer test evacuations of DC–8 aircraft equipped with ceiling-mounted escape slides were analyzed.[4] The results show that in such tests the average time required to open door exits (Type I) was 10.0 seconds. The average time required for the deployment of ceiling-mounted escape slides was 34.0 seconds. Once the slide was deployed, the average evacuation rate was 41.0 passengers per minute. Overwing window exits (Type III) averaged 12.6 seconds for opening, followed by an average of 4.7 seconds for the first person to pass through the exit and an evacuation rate thereafter of 32.8 passengers per minute. These figures include instances where unusual delays occurred due to human error or mechanical failures in opening the exits or deploying the slides.

Usually such tests are carried out under optimal lighting conditions, without smoke and with maximal crew assistance; test subjects cannot be considered naive since, to some extent, they must be briefed on test procedures. In contrast, in actual accidents, while environmental factors such as fire and smoke may stimulate greater urgency, overall speed of evacuation may be slowed due to poor visibility, human error and mechanical failure in opening exits or deploying slides. Therefore, it is likely that, for a given aircraft and passenger load, evacuation times are greater in actual accidents than in tests. For this reason, test results can reasonably be used only to provide minimal time estimates of actual accident evacuations.

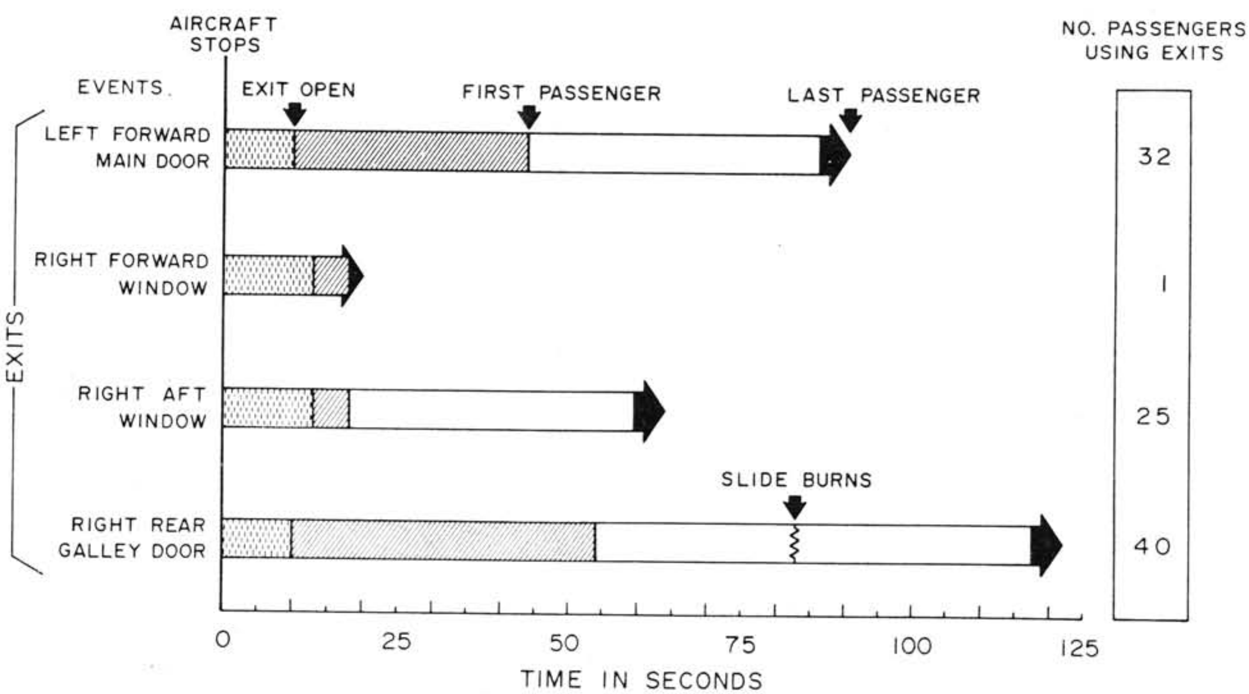


FIGURE 13. Estimated minimal evacuation times for exits used in Denver DC–8 crash. Time estimates are derived from AIA evacuation analysis of DC–8 test evacuation except at aft door where a 10 sec. delay is added for slide deployment and a rate of 2 sec./passenger assumed after the slide burned.

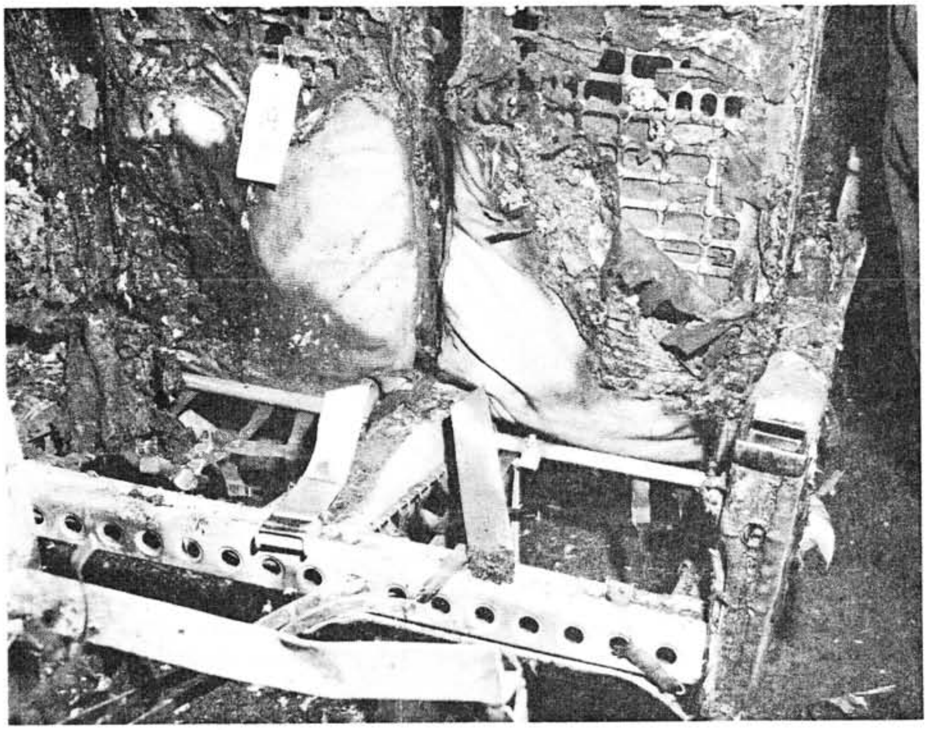
In the analysis shown in Fig. 13, test averages were used to derive a minimal evacuation time for each exit. It was also assumed that the average delay entailed by jumping from the galley service door was 0.5 seconds per passenger and a further delay of 10 seconds occurred due to the previously described difficulty the stewardess had in getting the slide deployed. From these data it appears that evacuation of 58 passengers through the forward exits was completed no less than 1.5 minutes after the aircraft stopped. The escape of the 40 passengers through the aft galley door required *at least* 2.0 minutes.

It was estimated that the first fire equipment arrived between 3 and 5 minutes after the crash and after the evacuation was complete.[5] Several by-standers and airport personnel reached the scene before evacuation was complete and in time to assist deplaned passengers away from the aircraft. However, no attempts were made by firemen or other rescue personnel to enter the aircraft to aid passengers. After escaping, some passengers helped others to get away from the crash. While still aboard, passengers usually did not attempt to help others unless they were members of their own family. It was reported, however, that an Air Force Warrant Officer, seated in 13C, was seen carrying one or more of the children of the mother of three seated in row 12. This whole family and the officer were among the fatalities. Surviving family-units tended to stay together and only in one case did members of the same family use different exits. This was the mother with an infant and a 2-year-old son seated in row 10 on the left. The mother carried the infant to the main forward door while the older child was carried by a male passenger through the right aft window exit.

Survivor Injuries. All of the 1st-class passengers survived. In general, their injuries were not serious and only 7 (16.7%) out of the 42 were hospitalized. The most seriously hurt were two females, aged 62 and 64, who were traveling together and who were seated in row 6 on the right; they received 2nd- and 3rd-degree burns of the head and limbs. Other passengers displayed a wide variety of sprains and contusions most of which occurred outside the aircraft. First-degree burns of the face and hands were also common. In contrast to its frequency among 2nd-class passengers, none of the 1st-class passengers were treated for smoke inhalation. Orthopedic injuries were confined to a dislocated left elbow in the 51-year-old male in 9D and a fracture of the 2nd metatarsal of the right foot in the 37-year-old female in 8C. Both these injuries were sustained when these passengers jumped from the wing after escaping through the aft window exit. Most of the burns were also incurred outside the aircraft. In general, injuries were more serious among passengers who used window exits than those who escaped through the main door.

Injuries among the 2nd-class passengers were both more frequent and more serious than those in 1st-class and 26 (46.4%) of the 56 survivors were hospitalized. Nineteen (33.9%) received treatment for smoke inhalation and 16 (28.6%) for burns. Most of the latter were 1st- and 2nd-degree burns confined to the face and extremities. Six passengers received fractures. One of them, a 79-year-old obese female was thrown from her seat into the aisle during the final swerve of the aircraft and suffered anterior fractures of the left 8th and 9th ribs. Hers were the only injuries attributable to crash impact and there is some question as to whether her seat belt was fastened. The other five passengers with fractures sustained their injuries in jumping from the aft galley door after the slide was destroyed. One, the 86-year-old female in seat 18A, suffered compound tibia-fibula fractures of both limbs and severe burns in the outside ground fire; she died 17 days after the crash. Another passenger, a 57-year-old female, suffered a right tibia-fibula fracture and a broken right wrist. Two passengers broke their ankles and a third had a hairline fracture of the left calcaneus. A 46-year-old male passenger with a previous history of heart disease suffered a coronary attack while helping to carry injured passengers away from the vicinity of the aircraft.

Body Locations and Necropsy Data. Unfortunately, local rescue personnel removed the bodies of 16 onboard fatalities without recording their locations. When questioned later, they recalled that all bodies were found in the 2nd-class compartment and all lay forward of row 19. Subsequent examination of the cabin interior revealed that body locations could be established by the fact that structures beneath a body were relatively undamaged by fire (Fig. 14). Corroborative evidence consisting of fragments of clothing, hair, flesh, and body fluid stains was



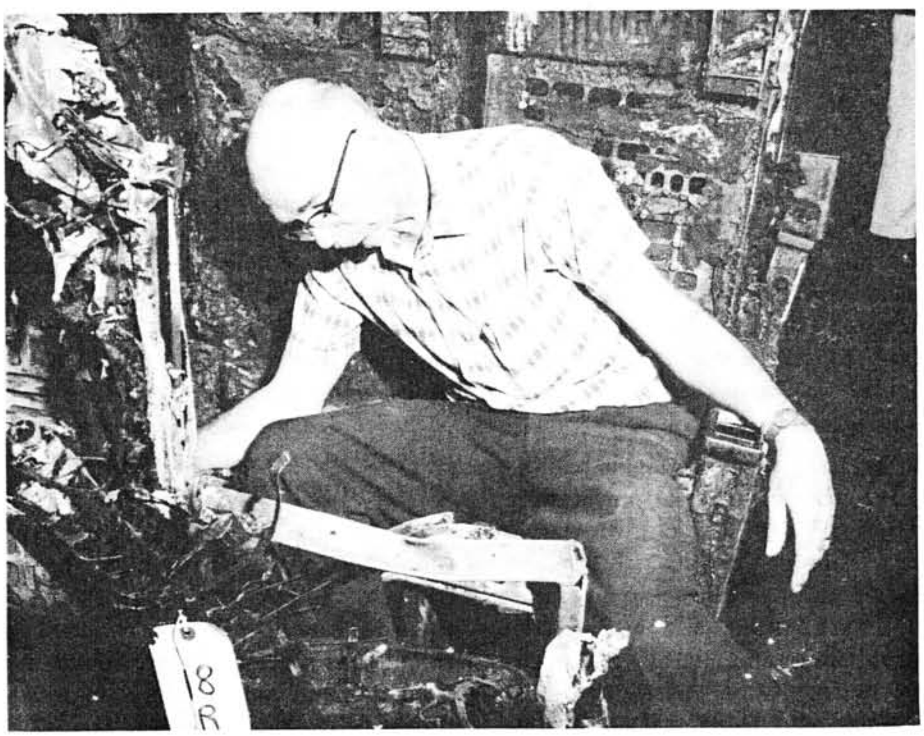


FIGURE 14. This set of photographs shows the evidence on which the investigating team based the location of the casualties found after the fire by the rescue team. The top photograph is how the seat rests, safety belts, and back appeared after the removal of the victims. The lower photograph shows the probable position of the person occupying the seat.

also found at these sites.[6]. In this manner, 16 "body impressions" were located (Fig. 15); all were concentrated between seat rows 13 and 20. Most of the sites were located in or next to the aisle. When their body locations are compared to their original seats, it is apparent that the fatalities had initially joined the line of passengers heading toward the aft doorway. Since no survivor who exited in this direction recalled passing perons who had collapsed, it is inferred that most of the fatalities were at the end of the line proceeding aft.

Complete necropsies were performed on seven of the victims and gross external examinations on the remainder by the Denver City and County Coroner. All bodies displayed extreme 3rd- and 4th-degree burns. No signs of impact trauma were noted and no other significant pathology

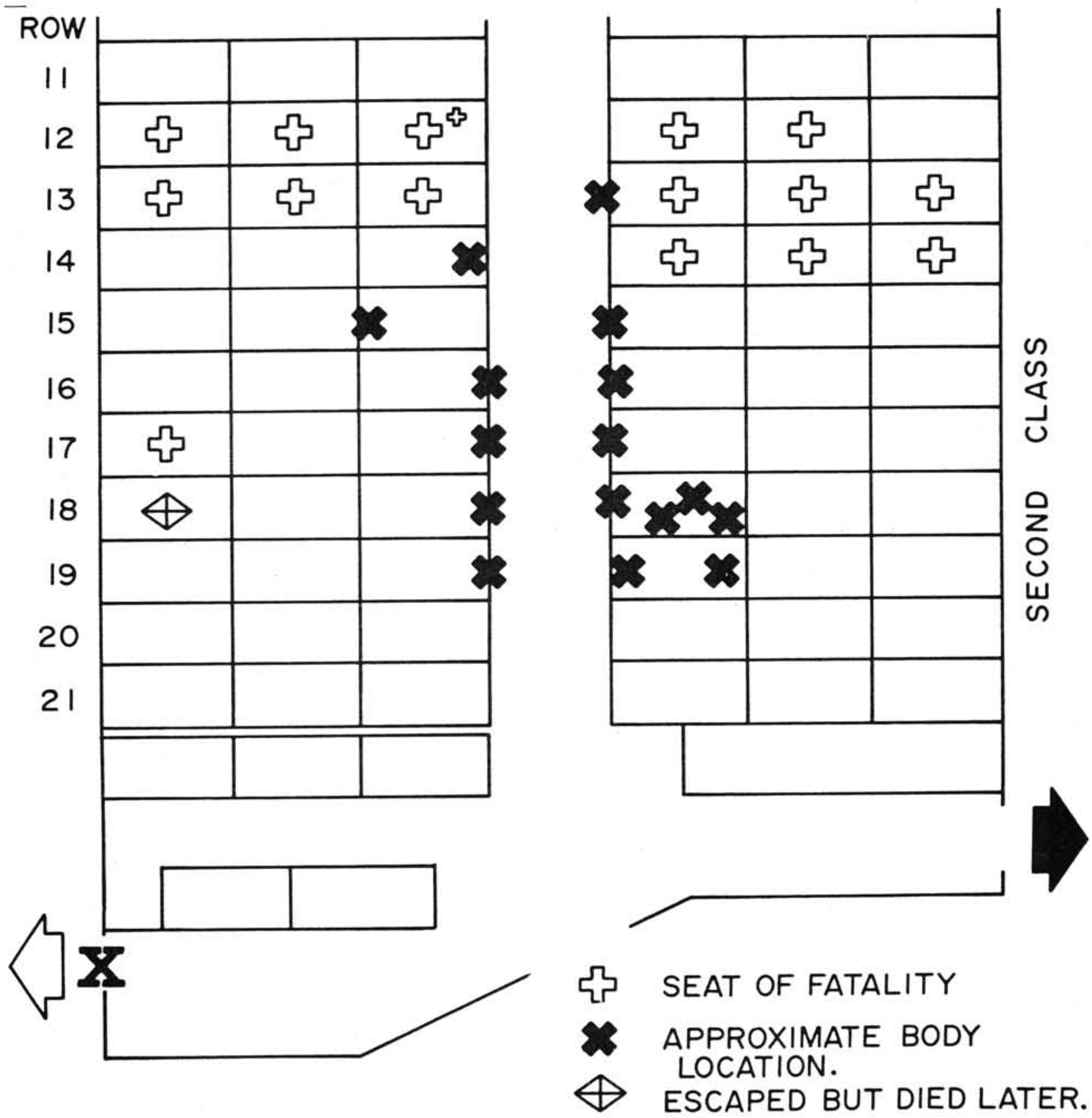


FIGURE 15. Diagram of aft cabin showing approximate body locations of 16 fatalities and their original seat locations.

was observed in the autopsied victims. Blood carboxyhemoglobin (COHgb) concentrations were determined from heart blood samples of all victims and ranged between 30 and 85 percent.

B. Salt Lake City.

Just after dark on 11 November 1965, a United Airlines Boeing 727 crash-landed at Salt Lake City Municipal Airport. The flight was operating between New York and San Francisco with several intermediate stops. Prior to let-down at Salt Lake City, the flight was routine. During the landing approach, however, the aircraft touched down 335 feet short of runway 34L. At impact, the flight recorder noted a vertical deceleration of 4.7g. Both main landing gears sheared and the aft lower fuselage impacted the

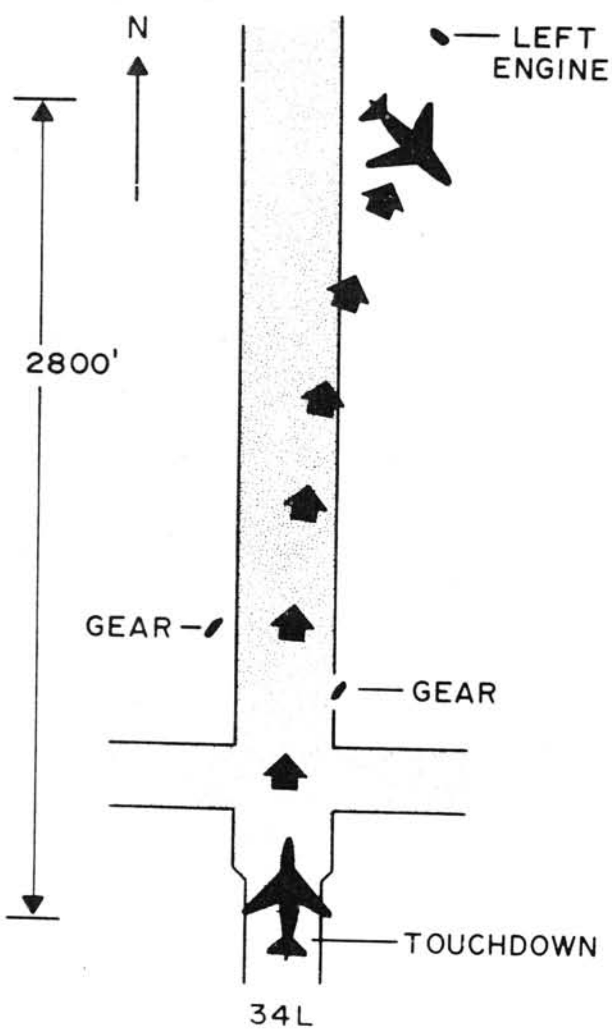


FIGURE 16. Skid path and final location of Salt Lake City 727.

runway with the aircraft in a slightly nose-high attitude. Skidding on its belly with the nose gear still intact and extended, the plane traveled approximately 2,800 feet from the point of impact. During the final 1,100 feet of skid, it veered to the right and came to rest headed 150 degrees to the right of its landing direction and 165 feet east of the runway (Figs. 16, 17). Subsequent investigation revealed "the rate of descent during final approach exceeded 2,000 feet per minute, approximately three times the UAL recommended rate of descent for landing approaches."[7]

A flight recorder indicated an airspeed of 123 knots at touchdown. A straight-line deceleration curve from touchdown to complete stop plotted against the distance between impact and final position gives a skid duration of about 27 seconds, with a mean longitudinal deceleration of approximately 0.25g.

Two ground witnesses, who were near the south end of the airport, observed the landing. They stated that about 3- to 5-seconds after impact there was a muffled explosion and, as the aircraft continued down the runway, a bright orange-yellow flame shot out from beneath the belly. Each said this initial fire occurred near the tail of the aircraft in the vicinity of the engines. It appeared to subside momentarily as the aircraft slowed. During the final swerve, the fire advanced up the fuselage and when the aircraft stopped it was engulfed in flame to an area forward of the wing. Shortly after touchdown, the control tower operators had observed a large burst of flame and immediately notified the Fire Department. According to a 1755 MST airport weather observation, there was a 3-knot northerly wind.

Configuration. The aircraft cabin was arranged for one-class service with 5-abreast seating for 90 passengers. The double seats were on the left and the triple on the right (Fig. 18). The galley was on the right and occupied the area opposite seat rows 7 through 10. At the rear of the aircraft, there was an additional row of right-hand seats (row 21) in the area opposite a coat closet.

Seven potential exits were available on this aircraft. Two of these, the forward passenger boarding door and the galley service door, were equipped with door-mounted escape slides. The boarding door was located on the left, imme-

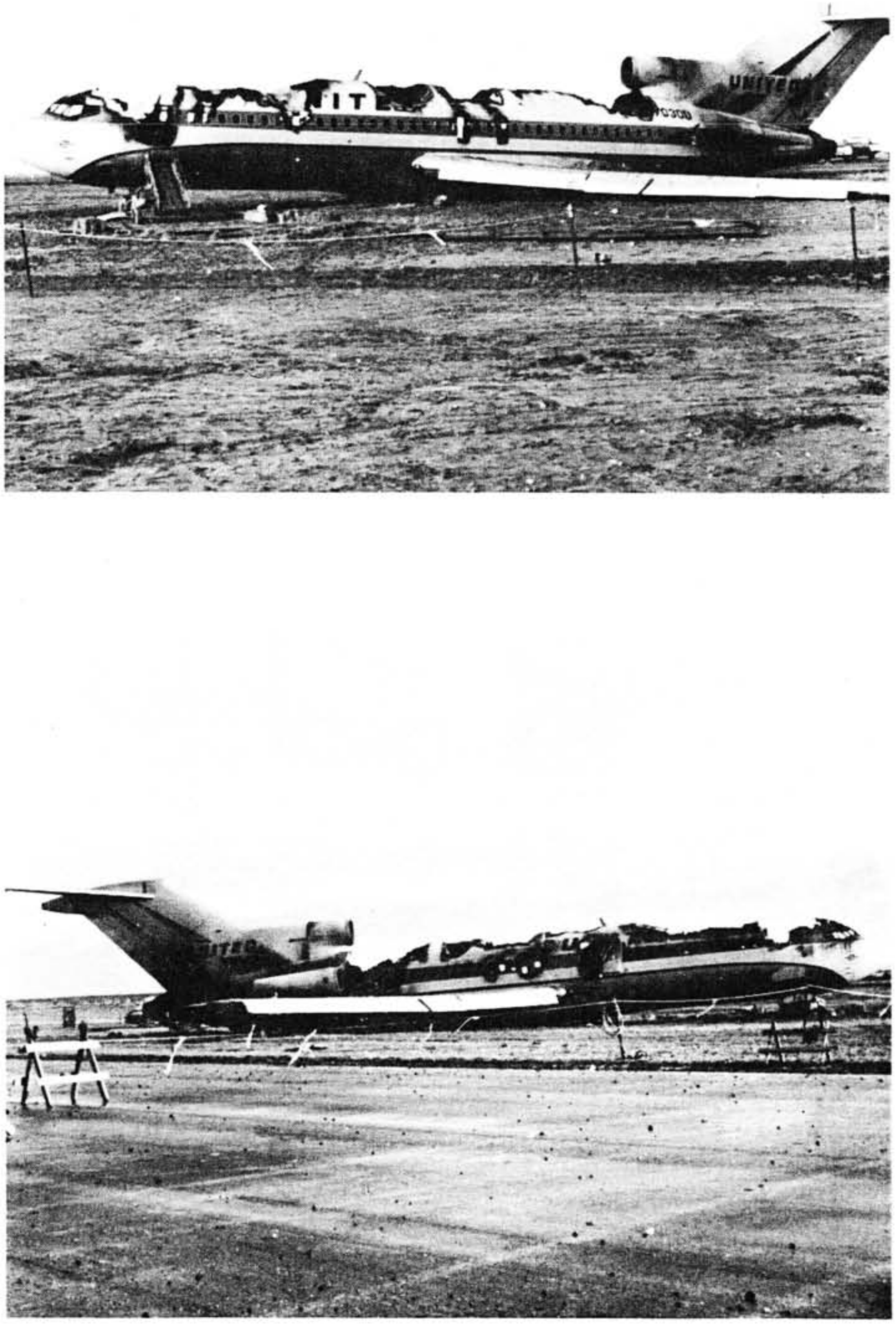


FIGURE 17. Left (above) and right (below) post-crash views of Salt Lake City 727, showing final attitude and exterior fire damage.

diately aft of the flight-deck bulkhead; the galley service door was on the right, opposite seat rows 8 and 9. Four window exits were at rows 12 and 14, two on each side of the cabin. A pressure door, leading to the ventral stairway used for passenger loading at some stations, was located in the aft bulkhead at the extreme rear of the cabin.

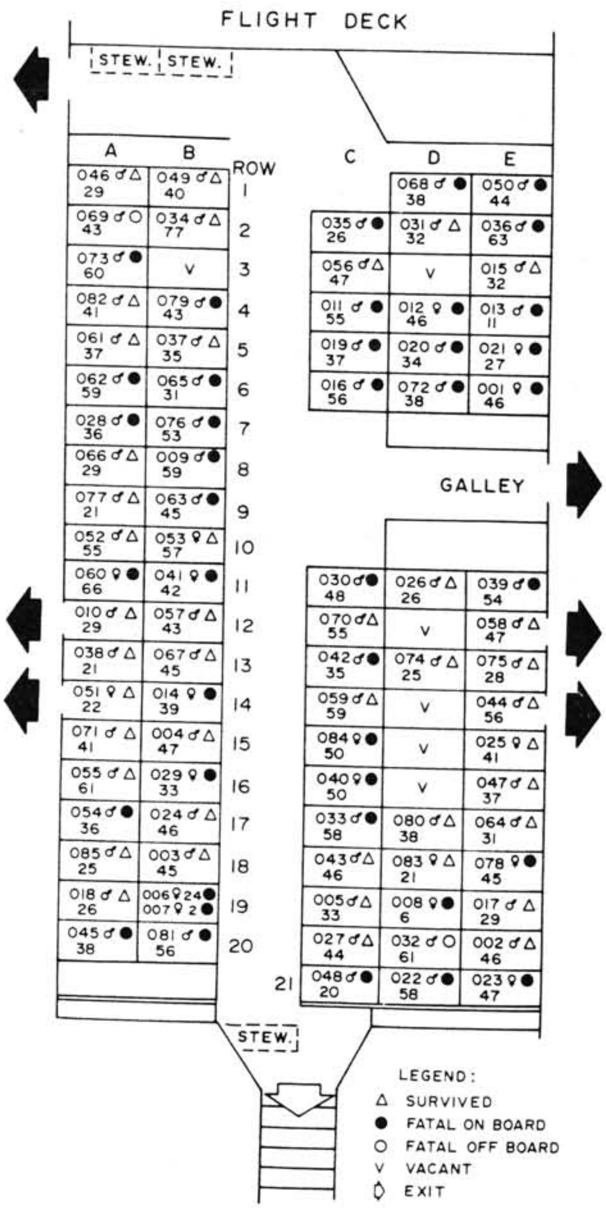


FIGURE 18. Seating diagram (non-scale) of Salt Lake City 727 showing distribution of passengers, their sex, survival status, age (2 digit numeral), and identification number (3 digit numeral) based on alphabetical listing by passenger surname.

Crew. The crew consisted of three male flight-deck personnel and three stewardesses. At the time of impact, two stewardesses were seated in aft-facing jump seats positioned against the flight-deck bulkhead. The third occupied a forward-facing jump seat located at the door leading into the ventral stairway.

TABLE 4.—Age and sex of passenger survivors and fatalities of the UAL 727 accident at Salt Lake City, 11 November 1965.

Sex & Age	Fatalities: Inside A/C	Fatalities: Died Later	Fatalities: Total	Survivors	Total Passenger Load
Children					
Male:					
0 – 5	0	0	0	0	0
6 –15	1	0	1	0	1
Female:					
0 – 5	1	0	1	0	1
6 –15	1	0	1	0	1
Total	3	0	3	0	3
Adults: (16–55 yrs.)					
Male:					
16–25	1	0	1	4	5
26–35	4	0	4	12	16
36–45	9	1	10	10	20
46–55	4	0	4	8	12
Total	18	1	19	34	53
Female:					
16–25	1	0	1	2	3
26–35	2	0	2	0	2
36–45	3	0	3	1	4
46–55	5	0	5	0	5
Total	11	0	11	3	14
(> 55 yrs.)					
Male:					
56–65	8	1	9	3	12
66–75	0	0	0	0	0
76–85	0	0	0	1	1
> 85	0	0	0	0	0
Total	8	1	9	4	13
Female:					
56–65	0	0	0	1	1
66–75	1	0	1	0	1
76–85	0	0	0	0	0
> 85	0	0	0	0	0
Total	1	0	1	1	2
All passengers	41	2	43	42	85

Passengers. There were 85 passengers aboard the aircraft (Table 4). Three were children under the age of 16. One of these was an 11-year-old boy traveling with both parents. The other two, aged 2 and 6, were Indian children from Bolivia who had recently been adopted by an American missionary couple. The older girl's fluency in English is not known. The 2-year-old was held in her foster-mother's lap and the 6-year-old occupied a seat beside her foster-father.

TABLE 5.—Sex and age composition of the SLC 727 passenger load.

Sex	N	% Total Load	Mean Age (Yrs.)	Age Range
Adult Males	66	77.7	42.2	20–77
Adult Females	16	18.8	41.0	21–66
Children	3	3.5		2–11

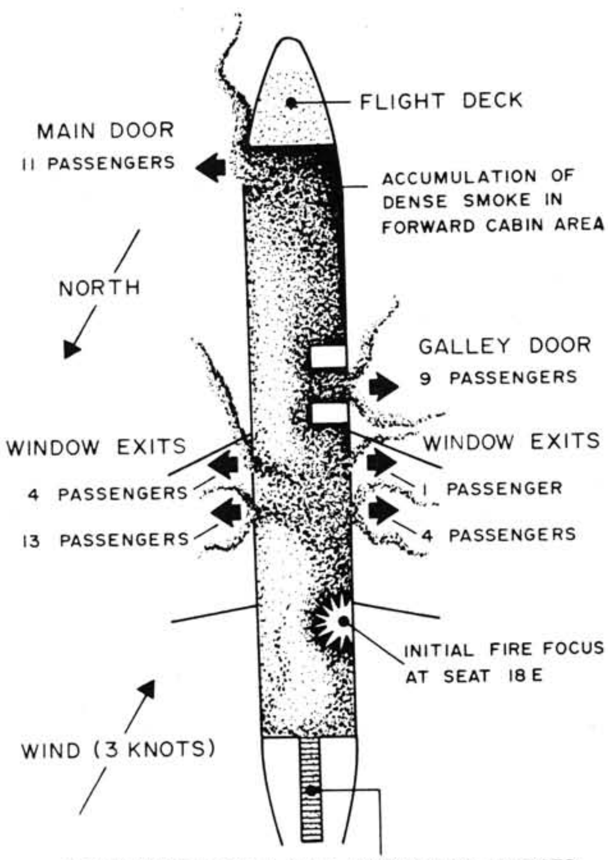


FIGURE 19. Interior diagram of Salt Lake City 727 showing initial fire focus and smoke dispersion in relation to exits.

Among the adult males were three FAA Air Carrier Inspectors, a Salt Lake City fireman, three United States Navy and five United States Air Force personnel. Four of the latter belonged to the crew of a multi-engine aircraft involved in a mid-air collision with a light aircraft a few weeks previously. Among the adult females was a UAL stewardess in uniform, who was traveling "deadhead" to San Francisco. Known invalids and semi-invalids among the passengers included a 63-year-old emphysematous male and a 54-year-old male with severe gouty arthritis. A 66-year-old female with a "heart condition" was boarded in a wheel chair at Denver; she was accompanied by her daughter, aged 42.

The adult passengers ranged between 20 and 77 years of age. The average age of the 66 males was 42.2 years and that of the 16 females was 41.0 years (Table 5). In summary, 3.5% of the passengers were children under 16, 78.8% were adults between 16 and 55 years, and 17.6% were over 55. Among the adults, 19.5% were females.

Passenger Seat Location. The distribution of passengers within the aircraft, as reconstructed from survivor statements, ticket-lift, and location of personal effects is shown in Figure 18. Of the 90 seats available, 84 or 93.3% were occupied. The six vacancies were concentrated among the middle (D) seats on the right side of the cabin.

Evacuation. Upon departing Denver, the stewardess gave the standard briefing on exit locations. The flight to Salt Lake City was uneventful. While some of the survivors felt that the final approach was abnormally steep and others said they heard a short burst of power shortly before touchdown, few sensed the impending emergency until impact.

The touchdown was uniformly described as violent. A few seconds later, as the aircraft skidded down the runway, a fire broke out in the right aft section of the cabin in the vicinity of seat 18E (Fig. 19). The source of this fire was a fuel line supplying the aft-mounted engines from the wing tanks. At impact, this line was ruptured when the right main gear strut was driven up into the fuselage near the trailing edge of the wing. The fuel from this line, still under pressure, was ignited either from broken generator leads or friction sparks. The resulting fire quickly burned through the cabin floor. Passengers, in describing this fire as it penetrated the cabin, repeatedly compared it to a "blowtorch" or "flame-thrower." The deadheading UAL stewardess, seated in 18D, immediately to the left of the initial fire focus, recalled "suddenly there was fire coming out from under the seat of the lady next to me . . . I yelled instructions to remain seated till the plane comes to complete stop, but people were on fire and they kept racing up the aisle. Then the gentleman sitting on the aisle next to me started running up the aisle. My seat was on fire so I took off too." Within seconds, other passengers in the

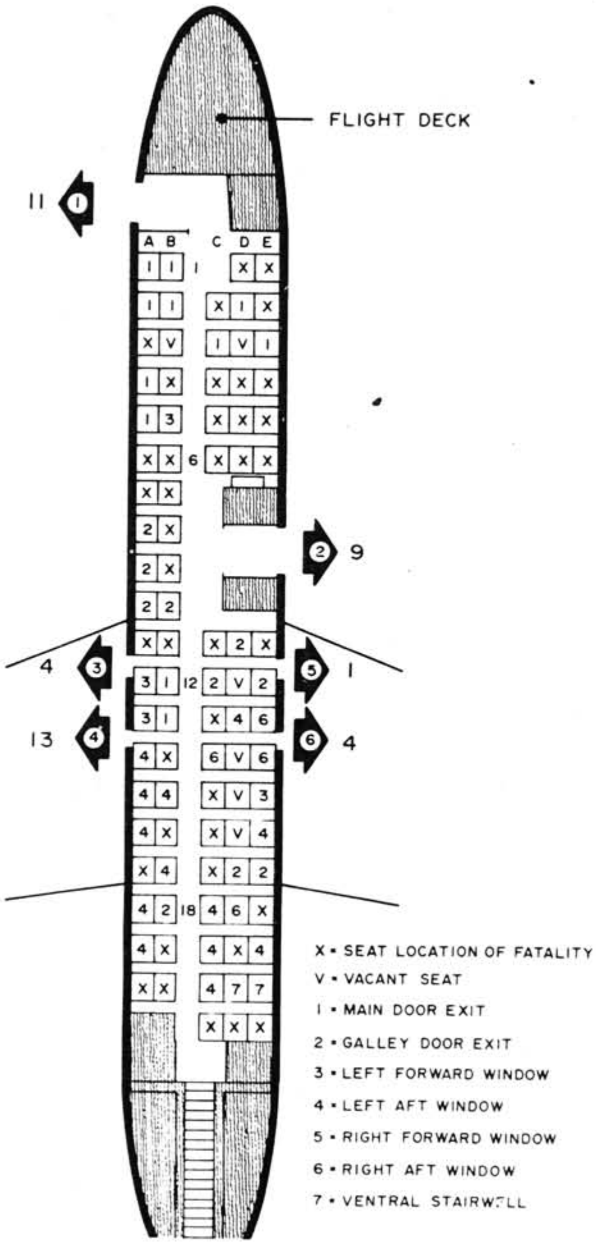


FIGURE 20. Pattern of exit utilization in Salt Lake City 727.

aft section joined this exodus. When the aircraft began its final swerve to the right, several people running up the aisle were thrown off their feet. As the aircraft stopped, the cabin lights went off, smoke accumulated rapidly and the only light available was that provided by the fire in the cabin and that filtering in from outside the aircraft.

Effective evacuation could not begin until the plane came to a halt, approximately 25–30 seconds after impact. All six of the regular exits were used in escape (Fig. 20) in addition, two passengers and the aft stewardess took refuge in the ventral stairwell from which they were rescued some 25 minutes later. In Figure 21, the evacuation sequence is diagramed for each exit. The time estimates are minimal and based on witness interviews and on the average times for exit openings, slide deployment, and test evacuation rates of Boeing 727's of similar configuration.[4] It appears that at least 1.5 minutes elapsed between impact and the escape of the majority of survivors.

The four window exits and the galley service door were opened by passengers. Most of those who used these five exits were seated either along side them or farther aft. Of the 22 passengers who used window exits, none was seated farther forward than row 11. Also, none of the passengers forward of row 6 moved rearward to use the galley service door. The window exits on the left were used by 17 survivors and those on the right by 5. This asymmetry was probably due to the fire which initially advanced up the right side of the cabin and tended to drive passengers to the left. The right aft window exit was opened by the man seated next to it while the aircraft was still in motion. Wind coming through this exit may have intensified the initial fire located a few rows behind it.

Emergency procedures called for the junior stewardess, who occupied the center jump seat in the forward section, to open the galley door. This stewardess saw the fire erupt in the aft section and started to leave her seat and go to the galley before the aircraft had stopped but she was restrained by the senior stewardess. The latter was not aware of the fire because her view of the cabin was blocked by the wind screen. When the aircraft stopped, the junior stewardess again attempted to reach the galley but could not press her way through the crowd of passengers

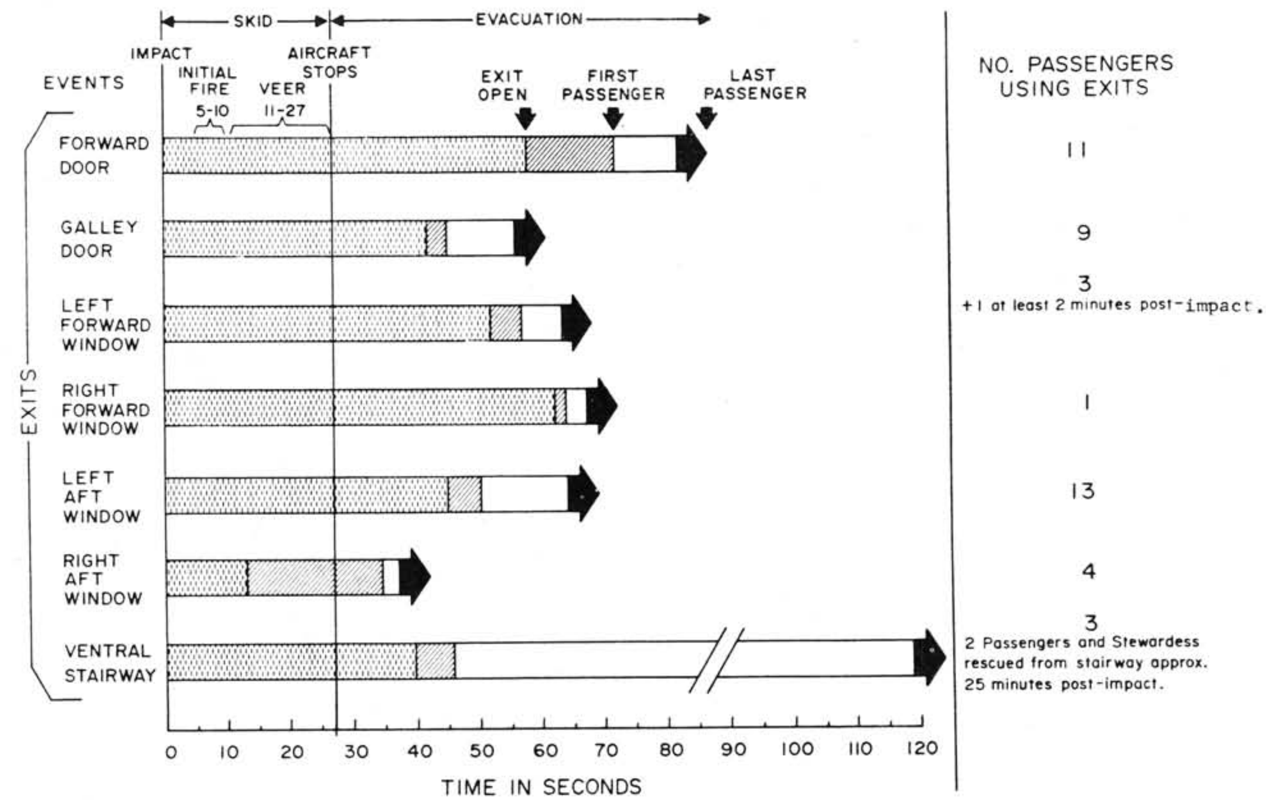


FIGURE 21. Approximate minimal evacuation times for exits used in the Salt Lake City 727 accident. Time estimates are based on number of passengers known to have used each exit and mean evacuation rates for 727 exits under test conditions.[5]

which had rapidly collected around the main boarding door. The galley door was promptly opened, however, by a male passenger seated across from it in row 9. He was followed by 8 other passengers, most of whom were seated opposite the galley. As the escape slide was not deployed at this exit, these 9 passengers were forced to jump to the ground, a distance of about 6½ feet.

After the aircraft stopped, the senior stewardess attempted to reach the forward boarding door but was blocked by passengers already crowded into the area. The 2nd-officer pushed his way into the cabin. After shoving some passengers aside, he managed to open the door and deploy the slide. Evacuation then began and 11 passengers used this exit.

At about the time the forward boarding door was being opened, the aft stewardess opened the rear bulkhead door to see if the stairway exit could be used. As the door opened, she was shoved into the stairwell by two men from row 20, one of whom was already badly burned. Once inside, they found that there was only a 6-inch opening to the outside because the ventral stair was resting on the ground (Fig. 22). They tried but could not completely reclose the pressure bulkhead door. However, the intense fire inside the cabin apparently produced a draft which drew enough fresh air up through the stairwell to provide some oxygen and to keep the temperature in the stairwell within tolerable limits. The events that followed are best described in the stewardess' statement made from her hospital bed on the night of the crash:

"I was sitting in the aft jump seat which is located on the aft pressure door. I knew we had crashed. As soon as we touched the ground fire *immediately* broke out (almost instantaneously) at approximately row 19, seat E, right by the window.

"I started yelling, the 'where, when, and how to evacuate' plus the 'seat belts tight, grab ankles,' till the plane came to a stop. When the plane came to a stop all lights went out. The back of the plane was filled with smoke and fire. I got out of my seat. It took a few extra seconds to get my shoulder straps off. I

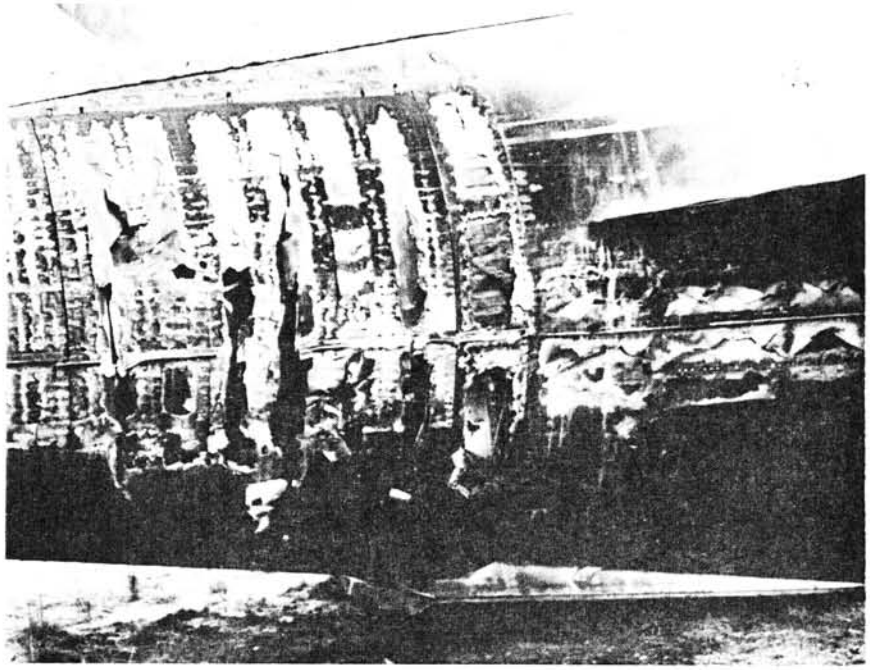


FIGURE 22. *Above.* Left view of Salt Lake City 727 tail section showing ventral stairway resting on ground. The opening was insufficient to allow the escape of the aft stewardess and two male passengers trapped within the stairwell. *Below.* Burned out section of floor and fuselage near initial fire focus in left aft cabin area. Approximately 25 minutes post-impact, firemen entered through this hole to rescue the three persons trapped in the stairwell.

opened the aft pressure door. Immediately two men ran through the door onto the stairs. At this time my hair caught fire. I put it out with my hand and my hat fell off. Then I went to the access door on the other side of the pressure door, to see if I could get the access door open but I couldn't because my hands were so badly burned. So, I went halfway down the stairs to see if it would be possible to get the stairs down. Through a crack between the stairs and the tail of the plane I could see that we were more or less stuck in the dirt and that the stairs had no space to go down. We were flat on the ground—I mean the stairs were flat on the ground.

"Then I knew that the next step for me to do was to immediately go to another exit and help evacuate. I was then at the top of the stairs looking through the cabin. All I could see was smoke and that most of the cabin was on fire. I knew if I tried to get through the cabin to another exit that it would be sure suicide. I knew I couldn't get to another exit without being completely overcome by smoke and fire. I remembered what we were told in training school. 'If there's a solid block of fire in front of you, don't go through it.'

"Therefore, all I could do was wait and pray. I was then on the stairs in the stairwell. The two men were right in front of me at the very end of the stairs lying down. I curled up right behind them into a little ball to get away from most of the smoke and fire and I started breathing through my jacket.

"At this time I couldn't see any possible means of escape for us. We couldn't get out through the cabin and we couldn't get out of the stairs. I thought for sure that I was going to die. I then began to pray and review my life. Meanwhile, it was getting hotter and hotter in the stairwell. The two men weren't talking so I asked one, 'Sir, do you think we're going to get out of here?' His answer was, 'Yes!' It was wonderful to see that he was optimistic. All of a sudden my mind started functioning and I realized that there were so many people; firemen outside and if they only knew that we were in the tail, they possibly could get us out. So, I told the two men to make as much noise as possible; to yell and beat on the side of the plane. I started beating as hard as I could on the side of the plane.

"At this time the fire was getting closer and closer. The aft pressure door was on fire. The heat and fire was pretty close to my legs. I realized if a spark hit my nylons, my whole legs would go up in flames. So I tried as hard as I could to get my nylons off and I finally did. It was a hard struggle since my hands were so burned. I told the other men that it was now or never if we were to get out. I asked them if I could squeeze up where they were to get away from the oncoming fire and they let me. There was fresh air coming through a crack at the end of the stairs. There was an opening of about 2 inches to my left. He, Mr. ——, asked me if I could get my hand through the opening. I stuck it out and started waving. A fireman came over to me (my hand) and said, 'Don't worry we'll get you out.' I told him to hurry because the fire was almost on us. The firemen started foaming the tail from the outside. Mr. —— asked for a fire hose. On his side there was a big enough opening for the hose so he took it and started hosing the stairwell from the inside. Then a fireman came in and took us out through a hole in front of the number 3 engine."

From the time the three were discovered fire-fighters exerted extreme, but unsuccessful, efforts to save them by attempts to chop and cut through the tail with axes and blow torches. Meanwhile, a hole had burned through the fuselage skin near the point of the initial fire focus. After about 25 minutes, the fire was sufficiently under control for firemen to enter this hole and rescue them.

Aside from these three persons, the last passenger off the aircraft was a man in seat 5B. Just after the plane came to rest, he released his seat belt, dropped to the floor on his hands and knees and started crawling forward between the legs of passengers standing in the aisle. He passed the main entry door, which at that time was still unopened, and entered the empty cockpit. He stood up and futilely attempted to kick out a window, then returned to the floor and crawled back into the cabin. The crowd was gone from the main door but due to the dense smoke, he did not see the exit. Continuing aft, he also passed the open galley service door without seeing it. His odyssey finally ended when he reached the left forward window exit which was silhouetted by the outside fire.

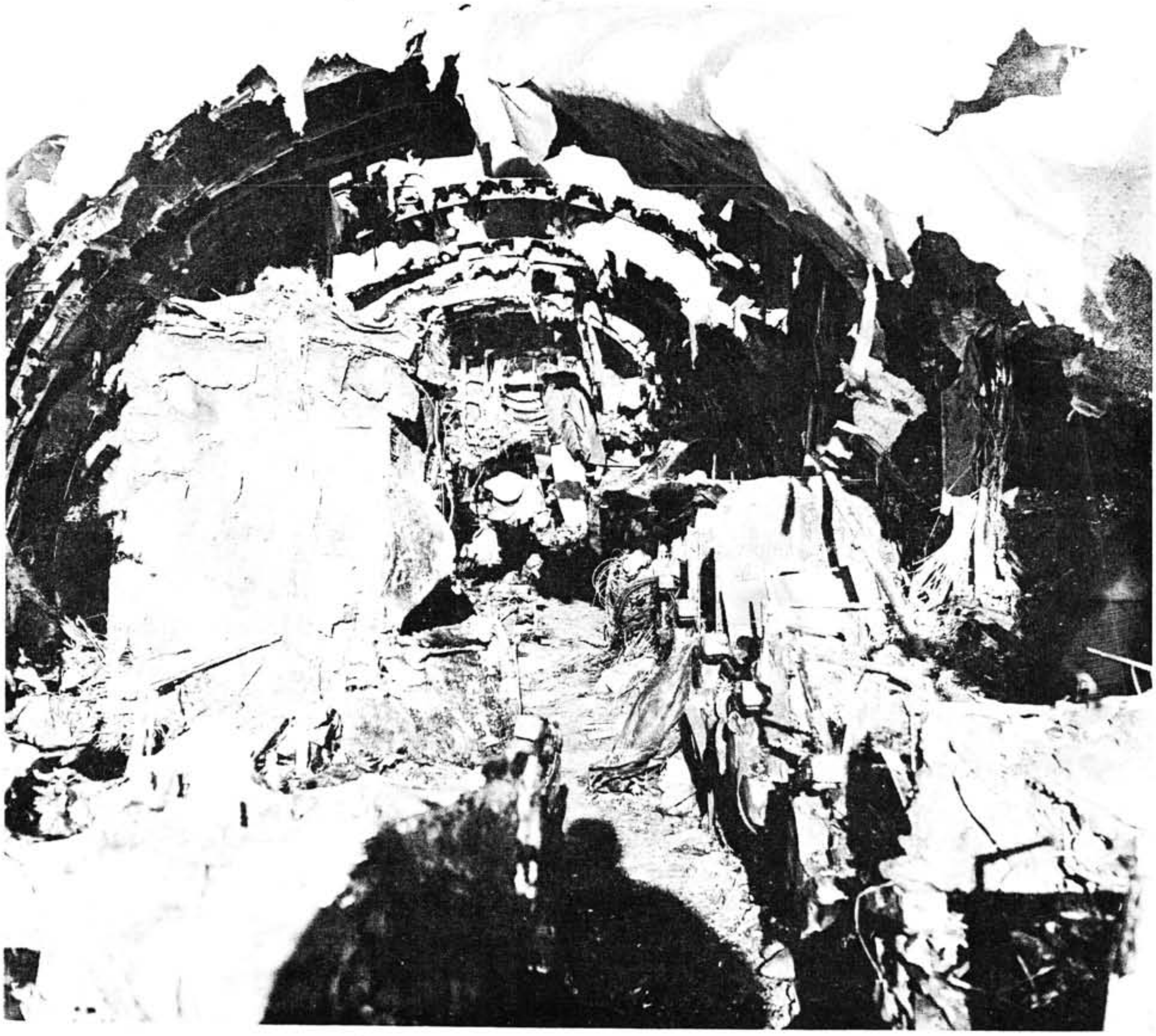


FIGURE 23. Aft view into Salt Lake City 727 passenger cabin showing interior fire damage.

Only one instance is known of a survivor receiving help from someone outside the aircraft. This was the 77-year-old male in seat 2B. When interviewed, he was suffering from severe smoke inhalation and 2nd- to 3rd-degree burns on the hands and face. His impressions were confused and vague, but he recalled that, at impact, he was knocked unconscious by some object from above. When he awoke it was dark and he could hardly breathe. He loosened his seat belt and started crawling forward but collapsed again close to the threshold of the boarding door. He was rescued by an FAA Air Carrier Inspector originally seated in 16B. The inspector, after escaping through the left aft window exit, had gone to the boarding door to assist passengers coming down the slide. After no more passengers appeared, he climbed up the slide and over the threshold. He saw the elderly man lying on the floor and pulled him out of the aircraft and down the slide.

Only seven of the surviving passengers reported hearing any post-impact instructions. A man in the forward cabin heard a stewardess tell them to remain seated until the aircraft stopped. Others, in the aft cabin, heard a woman cry "fire" and a man shouting for them to open the exits and get out. Apparently, one of the early effects of the dense, acrid smoke that rapidly filled the cabin was to cut short any attempts to vocalize and many passengers stated that after a breath or two they could no longer breathe or utter any sound. One man, a registered pharmacist and the only survivor reporting with any medical knowledge, described the sudden effect of smoke upon himself as causing a "massive bronchospasm." Other passengers recalled that after a few initial shouts and cries the cabin suddenly became quiet with only sounds coming from the flames and the muffled efforts of passengers struggling toward the exits. This silence seemed especially eerie, some recalled, because they had always previously imagined such scenes of human panic to be accompanied by screaming.

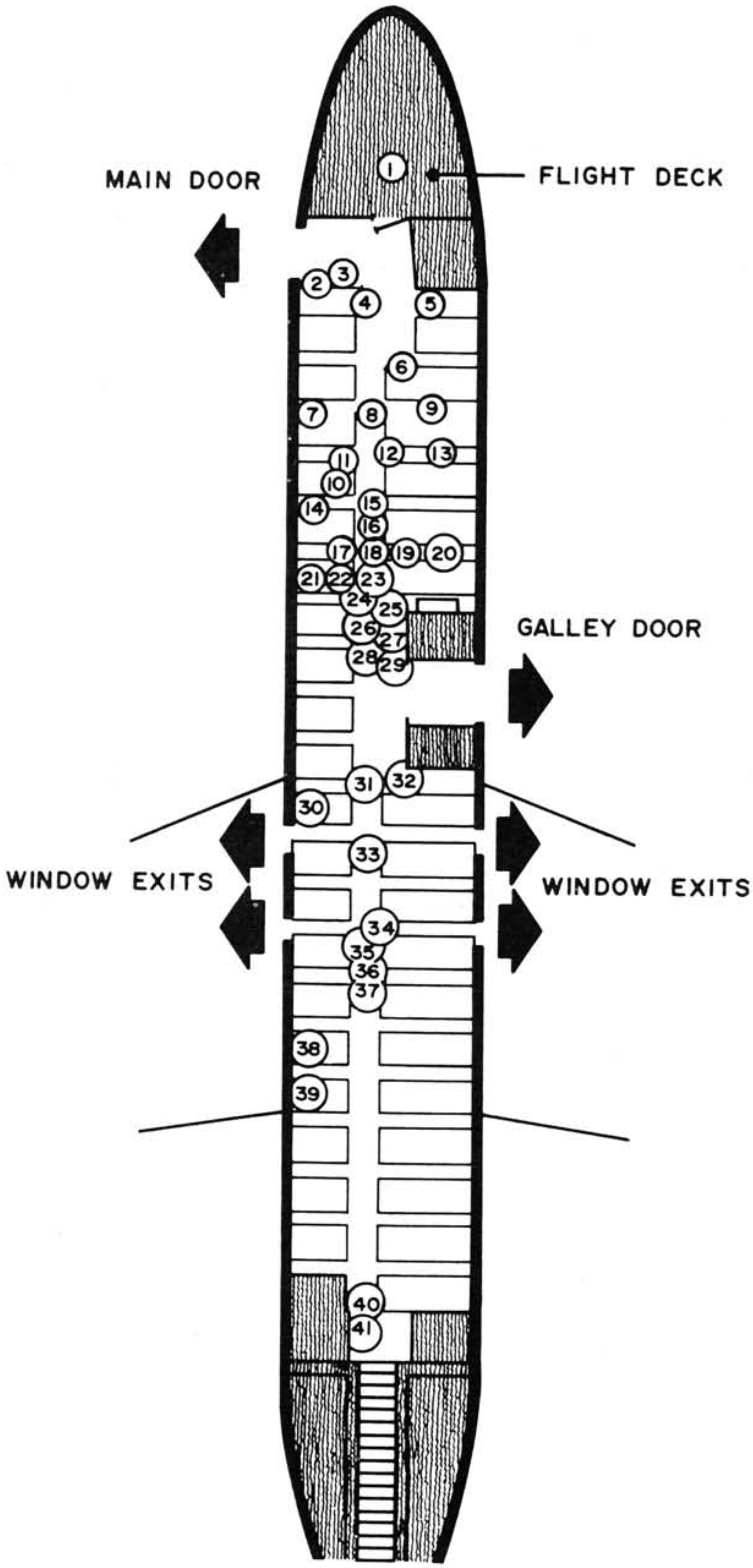
One survivor, who estimated he was the sixth person out of the left aft window exit, timed the propagation of fire after he was outside the aircraft. He estimated that within 90 seconds after impact the entire cabin was engulfed in flame; shortly afterward he heard a small explosion and fire invaded the cockpit. A subsequent analysis of firefighting activities[7] indicated that the first fire truck arrived about 3 minutes after impact. The firemen reported that the fire was free-burning and that flames were coming out of the fuselage from a large hole on the right side at about row 18 and from another place in the vicinity of the right window exits. The cabin interior appeared totally involved, with the fire most intense in the rear section. With the exception of the survivors in the tail, no one was observed to escape after the arrival of the fire equipment. Figure 23 shows the interior fire damage to the aircraft.

Survivor Injuries. Of the 44 passengers who escaped, 11 were uninjured. The remainder displayed a variety of trauma ranging from slight to serious. Seven passengers sustained fractures. Four were vertebral compression fractures, all of which occurred in passengers seated in the first three seat rows of the aircraft. In each case, only a single vertebra was involved. The fractures were located at C–5, L–1, and in two cases, T–12. In addition, both the 1st- and 2nd-officers received compression fractures of T–11 and one of the forward cabin stewardesses received a compression fracture of T–5. Thus, of a total of 17 passengers and crewmen seated forward of row 4, 7 (40%) sustained compression fractures of the spine. Of the 7, all used the slide except the 1st-officer, who crawled through a cockpit window. Therefore, it is postulated that these fractures occurred at impact, indicating that the vertical decelerative forces were more intense in the extreme forward part of the aircraft. It is interesting that none of these fractures reportedly interfered with escape, although one of the male passengers stated that he was aware that his "back was broken" at initial impact.

One male passenger suffered a fracture of the right calcaneus when he jumped from the right wing to the ground. Another sustained a fracture of the right radius when escaping through the forward entry door. Although the slide was inflated, he chose to jump to one side of it and landed with weight on his extended right arm. A female passenger broke her right first metatarsal and left ankle when she jumped from the galley service door.

The only other significant skeletal injury, a dislocation of the left sterno-clavicular joint, occurred in a male passenger seated in 1B. This man reported that as soon as the aircraft stopped he stood up and entered the aisle. The lights were out and the cabin was filling with smoke and there was a crowd of people gathering at the forward entry door. He heard a man, whom he thought was a crewman, say "that if everyone would stand back he could get the door open." Hearing this, he braced himself between the wind-break partition and the cockpit bulkhead and pressed back into the crowd of passengers behind him. Shortly afterwards the door was opened. Apparently his injury occurred during this effort. Other mechanical trauma consisted of a wide variety of abrasions, lacerations, and sprains of a minor nature.

Body Locations and Necropsy Data. When the fire was extinguished 41 bodies were found onboard the aircraft. These were examined *in situ* and their exact locations recorded (Fig. 24). Positive identification was made in all cases by fingerprints, dental records, clothing, jewelry, and other supplementary information. Gross external descriptions were made of all victims and complete necropsies performed on ten. The victims selected for necropsy were recovered from locations throughout the aircraft and included those found in places where they might have



Body #	Sex	Age	Seat
1	♀	27	5E
2	♂	26	2C
3	♂	63	2E
4	♂	59	8B
5	♂	44	1E
6	♂	43	4B
7	♂	38	1D
8	♂	45	9B
9	♂	60	3A
10	♂	38	6D
11	♀	46	4D
12	♂	55	4C
13	♂	11	4E
14	♂	54	11E
15	♂	37	5C
16	♂	53	7B
17	♀	45	18E
18	♂	34	5D
19	♂	59	6A
20	♂	56	6C
21	♀	39	14B
22	♂	35	13C
23	♂	58	17C
24	[illegible]	46	6E
25	♂	36	7A
26	♂	48	11C
27	♀	50	15C
28	♀	33	16B
29	♂	31	6B
30	♂	20	21C
31	♀	42	11B
32	♀	66	11A
33	♂	38	20A
34	♂	36	17A
35	♀	24	19B
36	♀	2	19B
37	♀	6	19D
38	♂	56	20B
39	♀	50	16C
40	♀	47	21E
41	♂	58	21D

FIGURE 24. Distribution of bodies in Salt Lake City 727.

blocked or hindered the escape of other passengers.

Burns involving more than 50% of the body surface were found in all 41 bodies. In the majority (25), 4th degree (charring) burns were predominant. The remaining 16 displayed extensive 1st-, 2nd-, and 3rd-degree burns. No fractures of the skull or extremities were palpable in any victim nor were any other signs of mechanical trauma evident.

The ten necropsied victims displayed no preexisting disease which might have influenced survival. The major viscera were intact, there were no signs of hemorrhage, fracture, or other mechanical trauma. Carbonaceous matter was present in the larynx and trachea of all victims. In eight of the ten necropsies, microscopic examination revealed carbon pigment present in the lumen of the smaller bronchi. Varying degrees of capillary congestion, alveolar hemorrhage and edema were noted in all instances.

Two males escaped but died later of their injuries. The first, aged 61, expired on the seventh post-crash day and was one of the men who took refuge in the ventral stairwell. He was originally seated in 20D, about two rows behind the initial fire focus. According to estimates by the aft stewardess and the other surviving passenger, they entered the stairwell at about 50 seconds post-impact and by this time the subject was badly burned and semi-conscious. The severe 3rd-degree burns of this man's face, arms, and torso (Fig. 25) give some indication of the intensity of the fire in the rear cabin at this time.

The second man, aged 43, died 11 days after the crash. He was seated in 2A, next to the elderly male whose rescue by the FAA Air Carrier Inspector was previously described. His thermal injuries were limited to 2nd-degree burns of the face and head, and death was due to respiratory complications of severe smoke inhalation. Although his escape was possibly impeded by the difficulties of his seat mate, his minor burns but major respiratory injuries, when compared to the severe burns of the other post-crash fatality, reflect a difference in the relative intensity of the thermal and chemotoxic effects between the aft and forward portions of the cabin.

Blood ethanol determinations were made on cardiac blood samples from 35 adult fatalities. Seventeen were negative; another 17 displayed positive values ranging between 0.1 and 1.0 mg./ml. Only one, at 1.5 mg./ml., fell within the range of intoxication where judgment is ordinarily considered impaired. Since blood alcohol production may be associated with postmortem changes, the positive values must be considered with caution and, from the evidence, it appears that alcohol intoxication was not a significant factor in influencing passenger escape.

Carboxyhemoglobin determinations were made on heart blood samples of 35 victims and from blood extracted from the lungs of three. All displayed saturation levels above 10%, which is ordinarily considered the upper limits of normal. Individual values ranged from 13 to 82% with a mean of 36.9 percent.

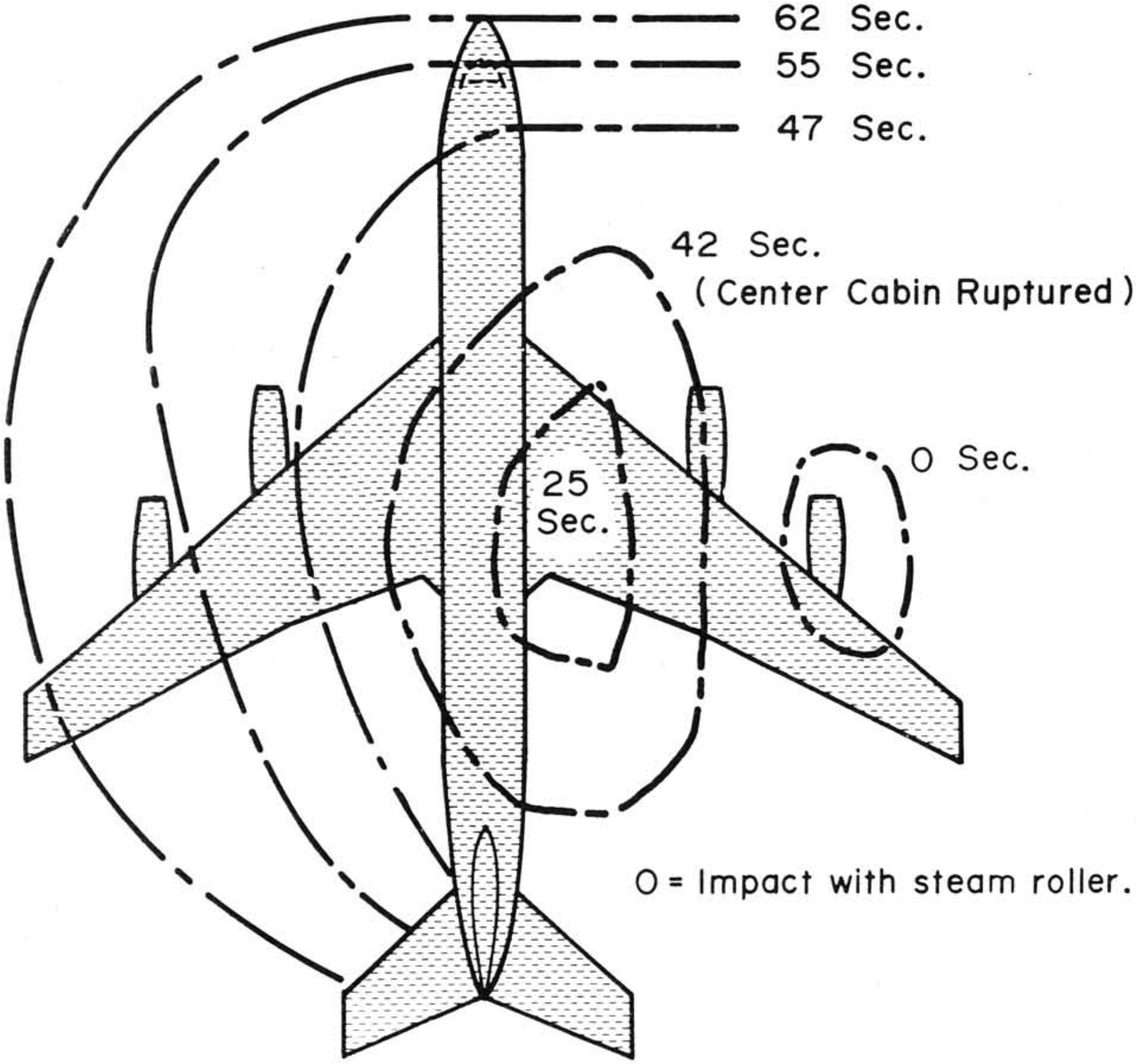


FIGURE 26. Pattern of fire propagation of the Rome 707 accident as reconstructed from survivor reports, ground witnesses, and physical evidence.

C. Rome.

The Rome crash occurred at Fiumicino Airport early in the afternoon of 23 Nov. 1964. The aircraft, a TWA Boeing 707–331 carried 62 passengers and a crew of 11. On departure for Athens, a series of engine malfunction indications occurred and take-off was aborted. The last 1,800 feet of runway was closed for maintenance and as the aircraft entered this area the right outboard engine nacelle struck a steamroller which was moving slowly across the path of the aircraft. At impact, the aircraft's speed was estimated to be 40 knots. Although no jolt was felt by the passengers, a fuel line on the nacelle was torn free and the spewing fuel was ignited. The aircraft continued along the runway some 800 feet beyond the point of impact. Approximately 22 seconds elapsed between impact with the steamroller and the time the aircraft came to a halt. Fuel spilling from the right wing tip surge vent began to burn. After stopping, the captain was notified of the fire on the right wing by another crewman. He immediately cut all engines and activated fire extinguisher controls.

About 20 seconds later the fire spread to a center fuselage tank which exploded, ripping open the floor in the center cabin area. By this time, ground-fire had spread to the left of the aircraft, hampering the escape of passengers from exits on that side. Approximately 20 seconds after the cabin floor explosion, a second—more violent—fuel tank explosion occurred in the area of the right center fuselage. This explosion engulfed the entire aircraft and vicinity in flame, precluding further survival. It is estimated that crash rescue and fire-fighting equipment arrived some 3 minutes and 45 seconds after the accident. The rapid propagation of fire is shown in Figure 26. The combined effects of fire and explosion resulted in the almost total destruction of the passenger cabin.

Configuration. The seating configuration of this aircraft provided accommodations for a total of 140 passengers (Fig. 27). In the forward section was the 1st-class compartment with a 5-seat lounge opposite the galley and five rows of double seats. Behind the fifth row was a partition separating 1st-class from the 120-triple seats of the 2nd-class compartment.

Eight potential exitways were located in the passenger cabin; forward, on the left, the passenger entry door was located immediately behind the flight-deck bulkhead. On the right side, a galley service door was located opposite the lounge. Four overwing window exits—two on each side—were situated between rows 8–9 and 10–11 in the 2nd-class cabin section. In the rear of the aircraft, a galley door was located on the right, and a few feet further aft, a passenger entry door was on the left.

Crew. The crew members consisted of four male flight-deck personnel and in the cabin, a male purser and five stewardesses. In addition to the regular four man flight-deck crew, a TWA Dispatch Coordinator was riding in the cockpit to monitor enroute procedures. The purser and one stewardess occupied the forward jump seats situated on the aft wall of the flight-deck bulkhead. Another stewardess was seated in the forward lounge. In the 2nd-class cabin, two stewardesses were seated in jump seats adjacent to the rear passenger-entry door and a third was in seat 7E.

Passengers. There were 62 passengers aboard the aircraft (Table 6). Six were children under the age of 16. Two, a boy aged 5 and a 7-year-old girl, were accompanied by their mother. Two other boys, aged 9 and 10, were with their 17-year-old sister and their mother. An 8-year-old boy and a 13-year-old girl were traveling with their parents and a 16-year-old sister. Other family groups consisted of two married couples, another couple with their 20-year-old daughter, and a 38-year-old woman and her 65-year-old mother. The wife of the 2nd-officer was traveling in the 2nd-class cabin section. Since this was an international flight, a number of nationalities were represented among the passengers. Persons of U.S. citizenship comprised over one-half (38) of the passenger load and included all of the children. Among the remaining 24 adults, citizens of France (6), Italy (6), and West Germany (4) were most heavily represented. Three Ethiopian Air Force personnel were traveling together, as were two female students from Australia. Canada, the Philippine Republic, and India were each represented by a single passenger. The linguistic abilities of the passengers are not known. The crew included personnel fluent in English, French, Italian, Swedish, and German. None of the survivor accounts mention evacuation difficulties induced by inability to communicate.

Among the passengers was a complete "dead-head" cabin crew consisting of five stewardesses and a male purser. The performance of these personnel during the evacuation is not clear from survivor accounts. There is some indication that at least some of them reverted to their crew roles and aided in evacuation. In the subsequent statistical analysis, however, they will be treated as passengers.

TABLE 6.—Age and sex of passenger survivors and fatalities of the TWA 707 accident at Fiumicino Airport, Rome, 23 November 1964.

Sex & Age	Fatalities: Inside A/C	Fatalities: Died Later	Fatalities: Total	Survivors	Total Passenger Load
Children					
Male:					
0 – 5	1	0	1	0	1
6 –15	1	2	3	0	3
Female:					
0 – 5	0	0	0	0	0
6 –15	2	0	2	0	2
Total	4	2	6	0	6
Adults (16–55 yrs.)					
Male:					
16–25	1	1	2	4	6
26–35	0	2	2	3	5
36–45	1	4	5	4	9
46–55	1	2	3	0	3
Unknown	0	0	0	1	1
Total	3	9	12	12	24
Female:					
16–25	6	2	8	0	8
26–35	2	0	2	1	3
36–45	5	4	9	1	10
46–55	1	0	1	1	2
Total	14	6	20	3	23
(> 55 yrs.)					
Male:					
56–65	2	3	5	2	7
66–75	0	0	0	0	0
Total	2	3	5	2	7
Female:					
56–65	1	1	2	0	2
66–75	0	0	0	0	0
Total	1	1	2	0	2
All passengers	24	21	45	17	62

Among the remaining passengers, there were several others with aviation experience including several TWA personnel on vacation. Two passengers were members of the United States Air Force, three belonged to the Ethiopian Air Force, and two were professional pilots of Saudi Arabia

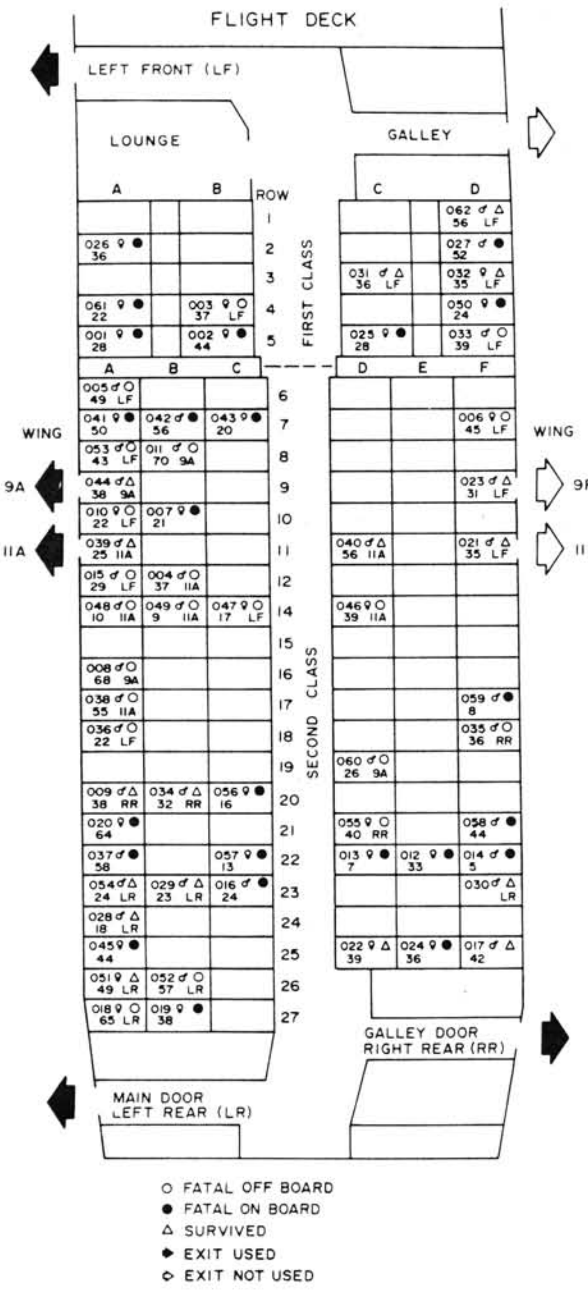


FIGURE 27. Diagram of the cabin interior, exit locations, and passenger distribution of the Rome 707. Sex, age (2 digit number), casualty status, and exit used are shown for each passenger.

Air Lines. The station manager for Lufthansa Air Lines' Rome Office was aboard with his wife. Four male passengers were listed as engineers and a fifth was a director for an export company. In general, the passengers on this flight appear to have been more experienced and knowledgeable of air travel than those involved in the Denver and Salt Lake City accidents.

The 56 adult passengers ranged in age from 16 to 70 years. The mean age of the 31 adult males was 40.6 years, that of the 25 adult females was 35.7 years. In summary, 9.7% of the passengers were children under 16, 75.8% were adults between 16 and 55 years, and 14.5% were over 55 years. Among the adults 44.6% were female.

Passenger Seat Location. The 62 passengers occupied 44.3% of the 140 available cabin seats, a much lower density than observed in the Denver DC–8 (94.2%) or the Salt Lake City 727 (93.3%) crashes where nearly all the passenger seats were occupied. The 1st-class compartment held 12 passengers while the remaining 50 were seated in 2nd-class (Fig. 27).

Evacuation. Survivor statements and a time-motion re-enactment of their experiences and observations permitted a partial reconstruction of the evacuation. The initial take-off roll was normal and among the passengers, the first awareness of a potential emergency came when reverse thrust and braking action were applied. Most survivors sensed the swerving of the aircraft during roll-out but were not aware of impact with the steamroller. These events were well described by the Lufthansa station manager seated in 3D:

"We taxied out for a normal take-off. I knew the runway was limited to 2,000 meters. We 'spooled up' the engines for a rolling take-off. I cannot state exactly, but after 6 or 8 seconds, I noticed that the take-off was going to be interrupted. My wife was looking out the window, I told her to hold onto her seat as braking was to be expected. I had noticed that something was wrong from the change of the tone of the engines and the immediate loss of speed. Unfortunately, the aircraft did not seem to remain on the center line. My wife, looking out the window, said 'My God, a tractor' and immediately afterwards the motor was burning. I looked out from my position (3D), the engine farthest from the fuselage was burning, it was a frightening sight because it seemed the reverse was still O.K. and all the flames were pushed forward of the wings. I told my wife to keep calm. I had noticed before we hit the tractor, the aircraft had made a jump of about half a meter in the air, coming down again the braking was terrible, not smooth at all, like a grass field."

The man seated in 9F saw the fire break out on the right wing after striking the steamroller. While the aircraft was still moving, he left his seat and went forward to tell the pilot about the fire. When he reached the door, the purser and stewardess were still in the jump seats and they told him to sit down until the aircraft stopped. He then yelled, "Fire!" Thus alerted, the purser left his seat and had begun opening the door before the aircraft stopped. As soon as it had stopped, the 2nd-officer left the flight deck and entered the cabin. He noted that at this time the lounge area was already crowded with people. He pulled down the ceiling-mounted slide but having been inadvertently reversed in installation, it fell reversed and he got down on his knees and was turning it around when the first explosion occurred. The stewardess, seated in the lounge, left her seat when the aircraft came to rest and moved forward to the main door. At the time of this first explosion she was thrown out of the cabin over the back of the 2nd-officer and landed spread-eagled on the ground. The 2nd-officer believes that she was blown out by the explosion, but the male passenger who ran forward to warn the crew of fire, stated that he pushed her out and then jumped. This passenger decribed the initial explosion as "small" but that after he was out and had run several steps a "big" explosion occurred.

After the stewardess was thrown from the aircraft, the 2nd-officer saw flames shooting forward from the cabin area. He abandoned his attempt to inflate the slide and dropped to the ground. Thereafter, he was occupied in helping passengers already outside the aircraft—some of whose clothing was afire.

The forward galley service door was found open but no one is known to have used it to escape. According to survivors, the stewardess in the forward jump seat went to this exit after the aircraft stopped. It is assumed that she opened the door and seeing the extent of the fire decided that it could not be used for evacuation. Apparently she remained in the galley area and directed passengers forward until she succumbed to the effects of smoke and fire.

Due to the fire on the right wing the window exits on that side were not opened. The left forward window exit was opened by a man seated adjacent to it as soon as the aircraft stopped moving. He had seen the fire on the right wing while the aircraft was still moving at 20–30 miles per hour. The seat in front of him was reclined, he pushed it forward, removed the exit window, placed it on the seat and shouted to other passengers to get out. He exited and ran to the end of the left wing tip and jumped from the aft edge to the ground shortly before the first explosion. He started running and, within seconds, a second explosion occurred, engulfing the entire aircraft.

The left aft window exit was opened by a 25-year-old USAF officer seated next to it. According to his statement, he opened it with the aid of another male passenger shortly after the aircraft stopped. After passing through the exit, he jumped from the aft inboard section of the wing to the ground. As he touched ground, he heard the first explosion. He then ran approximately 100 feet and stopped. As he looked back the second and major explosion occurred.

In the aft cabin, both the galley service and main boarding door were opened by the stewardesses seated in the jump-seats near the latter. While the aircraft was still in motion, the stewardess in the inboard seat went forward to the galley door. By the time the aircraft stopped, she had opened the door. As she pulled down the ceiling-mounted slide, she saw that smoke and flames were already intense around the exit so she decided not to inflate the slide. Instead, she returned to the aft boarding door which she found open with the slide deployed but not inflated. A female pasenger was standing in the exit, apparently hesitant to make the 10-foot jump to the ground. The stewardess pushed the woman out of the exit and then descended herself with the aid of one of the support straps of the uninflated slide. She ran away from the exit but, hearing a woman screaming behind her, returned and, with the aid of an unidentified man, helped pull the woman away from the aircraft.

The aft entry door had been opened by the other stewardess while her companion was opening the galley exit. She remembered pulling the slide down but before she could inflate it she was either blown (by the first explosion) or pushed from the exit by a passenger. She was briefly stunned by the fall and next remembered trying to get up, then falling down again. Finally, she was helped away from the exit by an unidentified male passenger.

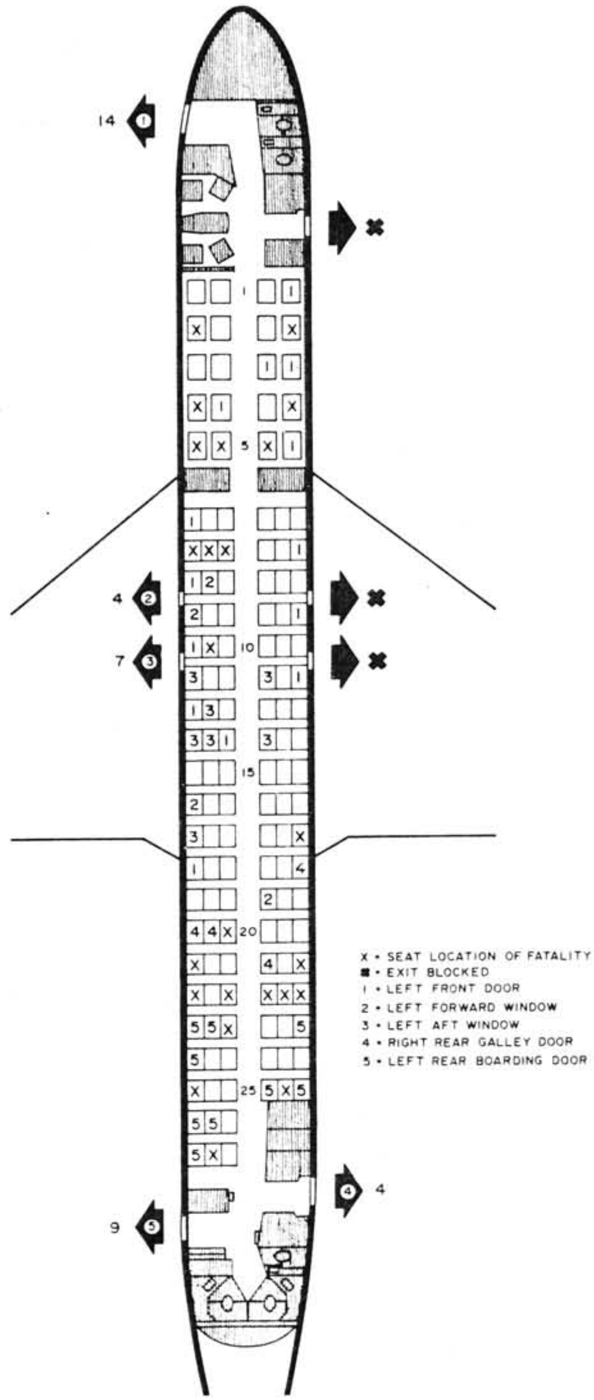


FIGURE 28. Pattern of exit utilization by passengers of the Rome 707.

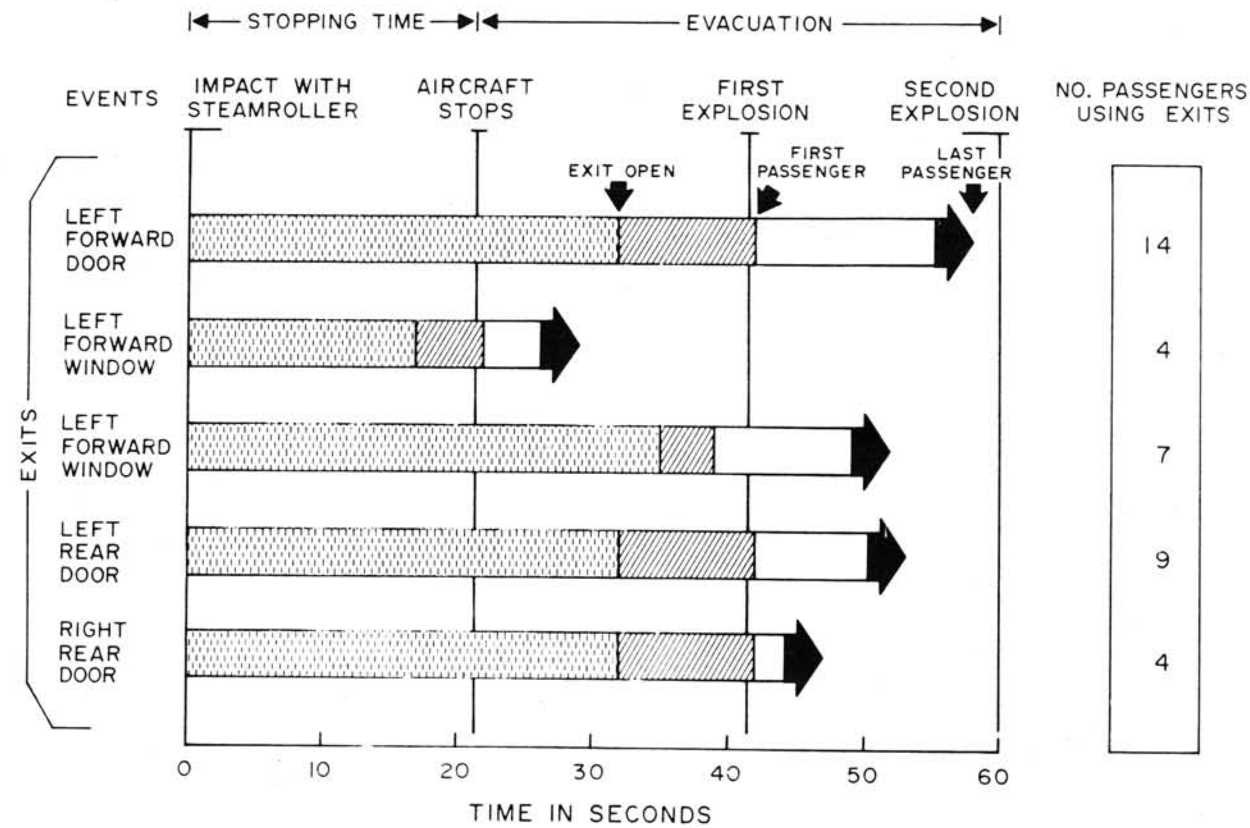


FIGURE 29. Evacuation sequence of Rome 707 showing approximate escape times and number of escapees from each exit.

Figure 28 shows the pattern of escape as reconstructed from survivor statements and physical evidence. According to this reconstruction, 14 passengers used the left forward entry door, 11 the left overwing exits, 4 the aft galley door, and 9 the aft entry door. In the case of some persons whose bodies were found outside the aircraft, the exit used was deduced from the relationship of body location and initial seat location.

Figure 29 shows the minimal estimates for evacuation through each exit in relation to the major events affecting survival. These estimates are based on a time-motion re-enactment of escape activities of certain crew and passengers conducted under controlled conditions in an intact Boeing 707.[8] The entire sequence from impact to final explosion may be divided into three, roughly equal, intervals of approximately 20 seconds each.

During the first interval, from impact with the steamroller to the time the aircraft stopped, some passengers became aware of the fire in the right wing area and alerted the cabin crew. The left forward window exit was opened during this interval but not used until the aircraft had stopped.

The second interval occurred between the time the aircraft stopped and the first explosion. During this time, initial evacuees utilized the left window exits. There was no fire or smoke inside the cabin and passenger behavior was generally described as being calm. Aside from those using the window exits, passengers were leaving their seats and proceeding to the forward or aft doors, all of which were opened by crewmembers promptly after the aircraft stopped.

The third interval was initiated by the first explosion and terminated by the second, more violent, one. The effects of the first explosion were limited to the central fuselage area but were probably of sufficient violence to injure or perhaps totally incapacitate those passengers in the immediate vicinity. It also produced intense heat and smoke within the cabin and triggered more urgent escape attempts among the survivors. By the time it occurred, it is likely that most of the passengers using the overwing exits were already outside the aircraft. This explosion was also sufficiently violent to cause the crewmen to abandon further attempts to deploy the escape slides: evacuation through the main doors began with people jumping to the ground, a distance of 10–12 feet. Meanwhile, outside the aircraft, ground fire had spread and was present in the vicinity of the exitways. Many of the passengers, who jumped from the doorways, were injured at impact with the ground; clothing of others caught fire, hindering escape from the immediate area.

At the time of the final explosion, evacuation was in full progress. Twenty-four passengers were still onboard. Seventeen were outside the aircraft, but died in the enveloping fire. Four others who were also outside the aircraft by this time died later in hospitals. The 17 survivors, some with the aid of other passengers, crew, or ground rescue personnel, had put enough distance between themselves and the aircraft to escape lethal blast or burn injury at the time of the second explosion.

In this accident (as in the other two) the crewmen performed or attempted to perform their assigned evacuation duties in an exemplary manner. The distance between the ground and doorways prevented any attempts by persons outside the aircraft to re-enter for rescue efforts which, in any case, would probably have been futile. Few of the survivors could recall instances of helping or being helped by others while still inside the aircraft. Several, however, when once outside returned to help others away from the burning aircraft.

Survivor Injuries. Of the 17 survivors, 10 were treated for minor injuries and released; the remaining 7 were hospitalized. Four of these were treated solely for burns, two for fractures only, and one sustained burns and fractures. The burns were mostly 2nd- to 3rd-degree involving the face and extremity areas to not more than 25% of the total body surface. All of the fractures were of the lower extremities. Both the burns and fractures were sustained during escape. In contrast to the other two accidents, none of the survivors displayed serious symptoms of smoke inhalation. All of the survivors were adults, 14 were male and 3 were female. The injuries of the four passengers who died later are described in the section below.

Body Locations and Necropsy Data. The body locations of the 24 fatalities who died aboard the aircraft are shown in Figure 30. Most were concentrated in the extreme forward and aft sections of the fuselage. COHgb elevations ranged generally from 13.8 to 49.0% (mean 23.0%) although two were only 3.0 and 10.4%. In general, death was attributed to thermal burns and/or asphyxia. Carbonization was extreme in all cases. Skeletal fractures were generally consistent with the type of fire artifact found in the pathological investigation of U. S. air carrier and military aircraft fire accidents. One iliopelvic fracture was attributed to the collapse and impingement of heavy aircraft structures onto the body at the time of the second explosion.

The locations of the 17 bodies found outside the aircraft are shown in Figure 31. Carbonization of all these bodies was extreme and death was attributed to thermal burns and/or asphyxia. Five of these had fractures of the lower extremities consistent with falling or jumping to the pavement and similar to those observed in the survivors. Many other skeletal fractures, particularly of the skull and upper extremities were of the type generally observed in badly burned bodies and classified as fire artifacts. The carboxyhemoglobin values in these fatalities were below 10.0% in most cases. Three, however, exceeded this level with values of 24.6%, 26.0%, and 35.8%. Two victims died within 24 hours of the crash of severe 2nd- and 3rd-degree burns involving 80% of the body surface. A third postcrash victim, a 54-year-old male, died approximately one week after the accident. His initially reported injuries were relatively minor: 1st and 2nd-degree burns of the face, hands, and right leg with a simple fracture of the right calcaneus. The exact cause of his death was not reported. The last fatality was a 40-year-old female who died approximately one month after the accident. She sustained 2nd- to 3rd-degree burns of the legs, arms, and face involving 50–60% of the total body surface, an anterior fracture of the 4th rib and a left Colles fracture. Her husband and three children died aboard the aircraft. The exact cause of her death was not reported; it brought the passenger death toll to 45, or 72.6% of the total passenger load.

III. Analysis of Data.

Carbon Monoxide. Carboxyhemoglobin determinations were performed on 83 victims of the three accidents. The values display a gradient

PASSENGER NO.	SEX	AGE	SEAT	NATIONALITY
1	♀	28	5A	Philippines
2	♀	44	5C	France
7	♀	21	10B	Australia
12	♀	33	22E	U.S.A.
13	[illegible]	7	22D	U.S.A.
14	♂	5	22F	U.S.A.
16	♂	24	23C	Ethiopia
19	♀	38	27B	U.S.A.
20	♀	64	21A	U.S.A.
24	♀	36	25E	U.S.A.
25	♀	28	5D	France
26	♀	36	2A	U.S.A.
27	♂	52	2F	U.S.A.
37	♂	58	22A	India
41	♀	50	7A	Italy
42	♂	56	7B	Italy
43	♀	20	7C	Italy
45	♀	44	25A	U.S.A.
50	♀	24	4F	West Germany
56	♀	16	20C	U.S.A.
57	♀	13	22C	U.S.A.
58	♂	44	21F	U.S.A.
59	♂	8	17F	U.S.A.
61	♀	22	4A	Germany

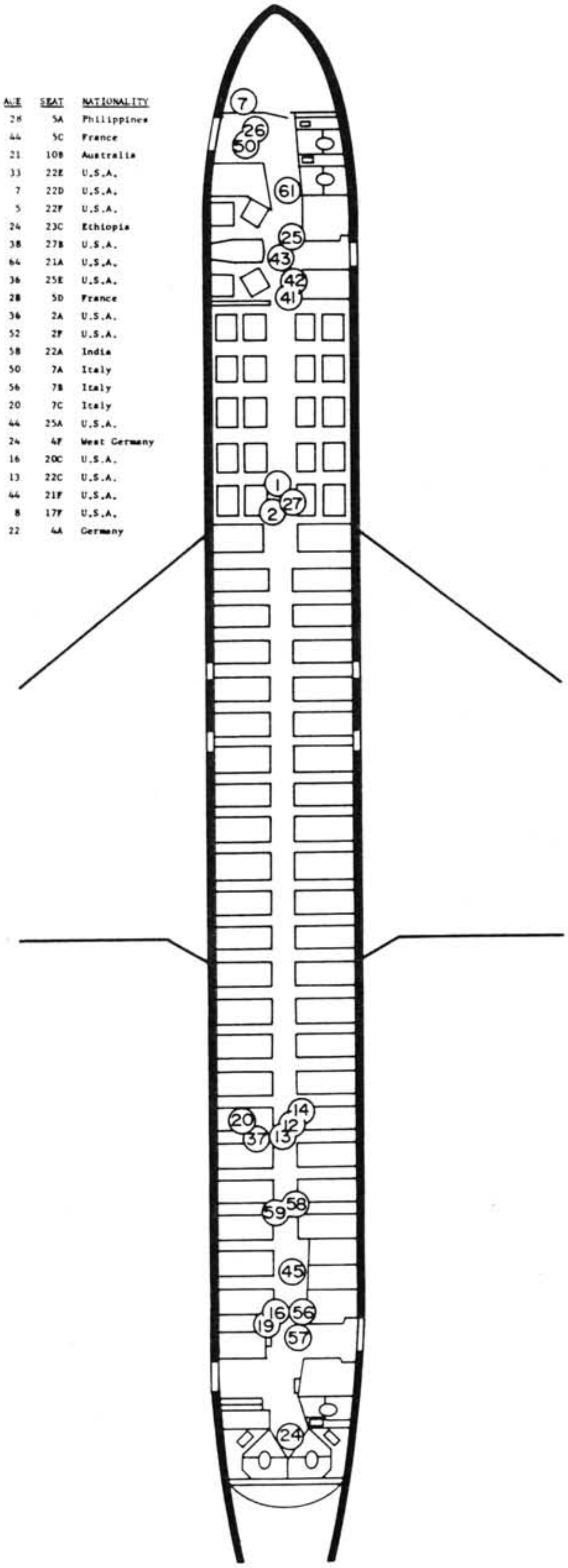
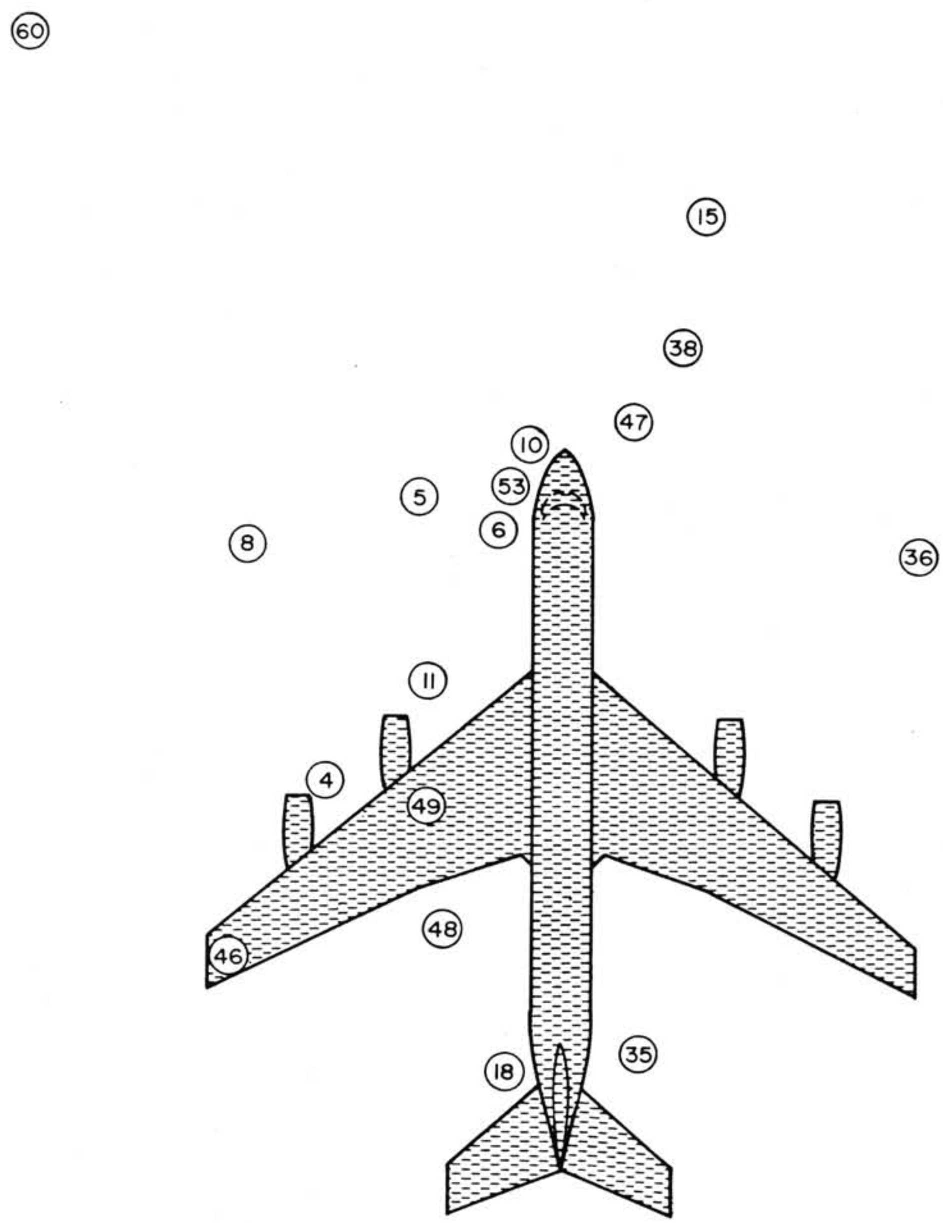


FIGURE 30. Distribution of bodies found within the Rome 707.



PASSENGER NO.	SEX	AGE	SEAT	NATIONALITY
4	♂	36	12B	U.S.A.
5	♂	49	6A	U.S.A.
6	♀	45	7F	U.S.A.
8	♂	68	16A	U.S.A.
10	♀	22	10A	Australia
11	♂	70	8B	U.S.A.
15	♂	29	12A	U.S.A.
18	♀	65	27A	U.S.A.
35	♂	36	18F	U.S.A.
36	♂	22	18A	U.S.A.
38	♂	55	17A	U.S.A.
46	♀	39	14D	U.S.A.
47	♀	17	14C	U.S.A.
48	♂	10	14A	U.S.A.
49	♂	9	14B	U.S.A.
53	♂	43	8A	U.S.A.
60	♂	26	19D	Canada

FIGURE 31. Distribution of bodies found outside the Rome 707.

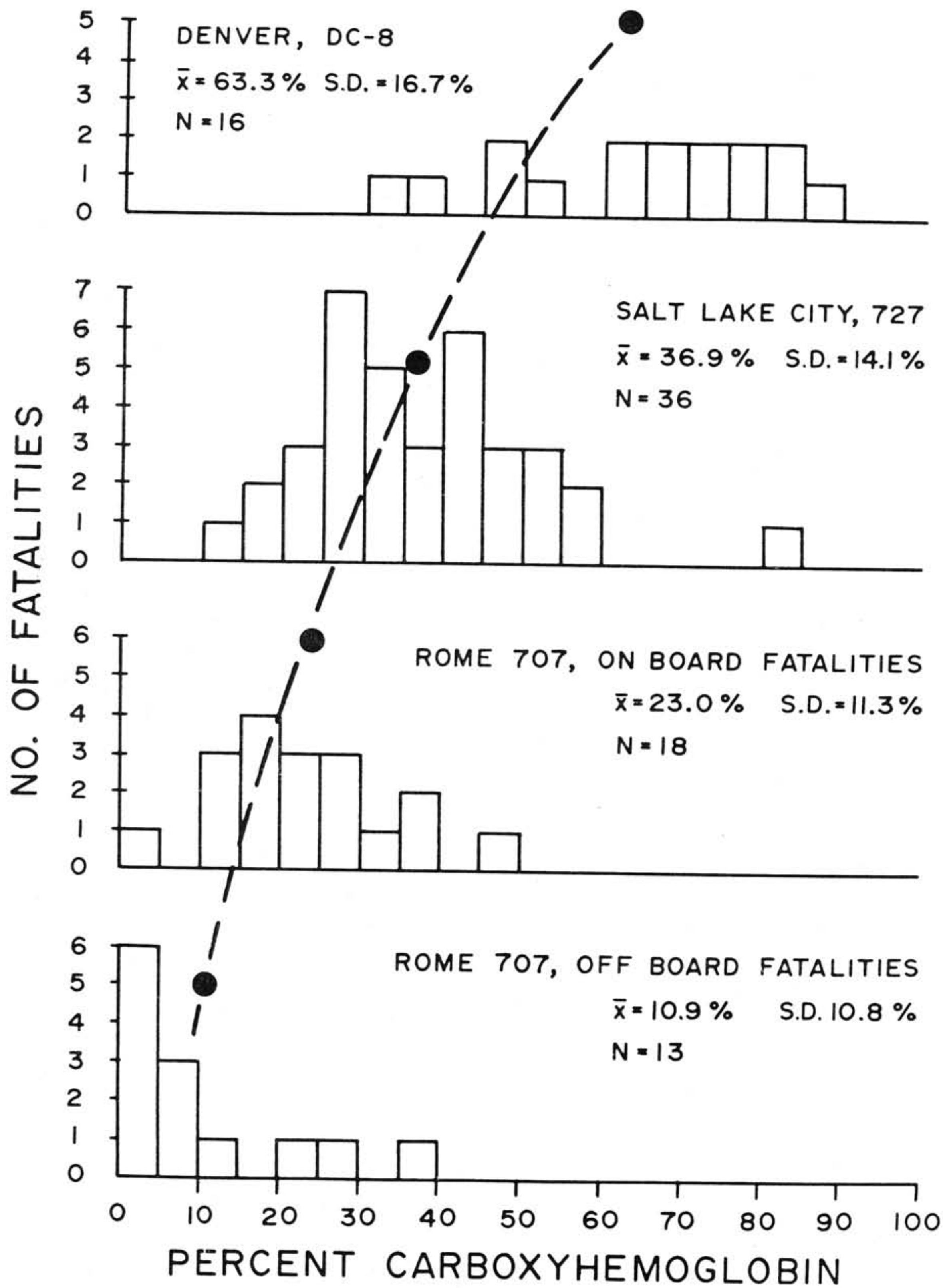


FIGURE 32. Distribution, means, and standard deviations of carboxyhemoglobin levels in 83 Denver, Salt Lake City, and Rome accident victims.

with those of Denver the highest, Salt Lake City intermediate, and Rome lowest (Fig. 32). Among the Rome victims, the COHgb values of onboard fatalities were higher than those who died outside the aircraft. The differences between the means of the groups are statistically significant.

At Denver, the values were all above 30%, the level at which definite symptoms of CO poisoning such as vertigo, shortness of breath, and impairment of judgment normally appear.[9] About three-fourths of the Denver concentrations exceeded 50%, the threshold of collapse and unconsciousness. In three victims, the levels were greater than 80% indicating that they may have died of CO poisoning before fire reached them. Among the Salt Lake City victims, the carboxyhemoglobin concentrations cluster between 40- and 60%, the range in which symptoms normally vary from confusion to complete collapse. The highest value, 85%, was found in the 11-year-old boy, and is the only one high enough to suggest death by carbon monoxide; his body was found beneath those of his parents and, protected from fire, he may have lived longer than the average fatality.

Since altitude hypoxia and carbon monoxide act synergistically,[10] both the Denver and Salt Lake City passengers may have been more than normally susceptible to carbon monoxide poisoning. Both flights originated near sea level, in-flight cabin pressures were in the neighborhood of 5,000 feet, and the crashes occurred at high altitudes (Salt Lake City—4,300 ft., Denver—5,280 ft). In unacclimatized subjects, tolerance to carbon monoxide is reduced by approximately one percent for each 330 feet of increase in altitude.[11] Thus, those victims who normally resided at low altitudes may have become disoriented or lost consciousness at carboxyhemoglobin levels 10–15% less than usually observed.

The carboxyhemoglobin concentrations of the Rome crash victims were the lowest observed in the three accidents. Those of the onboard fatalities averaged 23.0% and most fell below the values where symptoms are ordinarily observed. Most of the off-board fatalities had concentrations of less than 10%, indicating no significant exposure.

The highest concentrations, indicating relatively long exposure times, occurred at Denver where fire was not present within the cabin. At Salt Lake City, there was fire onboard throughout the evacuation and the intermediate COHgb values suggest significant exposure prior to death by fire. At Rome, where the thermal element predominated, they were lowest, indicating extremely short exposure time with fire and blast as the principal lethal agents. When the mean carboxyhemoglobin concentrations of the victims are plotted against fatality percentages, an inverse relationship is noted. (Fig. 33). This suggests that, within limits, the carboxyhemoglobin means may serve as an index of the overall lethality of the thermal, as opposed to gaseous, elements of the accident environment.

Passenger Response. In reviewing the collected statements of the survivors, one is struck by the difference in their overall assesments of passenger behavior in the three accidents. The behavior of Denver passengers was generally described as more calm and orderly than that reported at Salt Lake City or Rome. A rough indication of the passenger reaction might be provided by the use of the word "panic" in the spontaneous written statements of the survivors. While the rubric "panic" includes many varied and distinct kinds of behavior,[12] as used by laymen, it generally refers to the overall frequency of disorderly, self-serving, irrational reactions motivated by fear. Unfortunately, the statements of the Rome passengers were available only as translated summaries and the analysis below is limited to the Denver and Salt Lake City accidents. In these latter, the written statements were reviewed and each occurrence of the word panic noted. Of course, it could be used in both a positive and negative sense—the first to indicate that panic was evident, the latter that it was not. The results are shown in Table 7.

At Denver, of 47 statements available, no passenger mentioned panic as occurring but 5 (10.6%) stated that panic *was not* present. In contrast, among 29 Salt Lake City survivors 11 (37.9%) described panic, and only 2 (6.9%) stated that it did not occur. Thus, the use of the word correlates well with other, more objective, assessments of the intensity of the thermotoxic environment.

TABLE 7.—Frequence of the use of the word "panic" to describe evacuation behavior in written statements of Denver and Salt Lake City survivors

	"Not Mentioned"	"Panic'	"No Panic"
Denver 1st-class	19	0	2
2nd-class	28	0	3
Salt Lake City	16	11	2

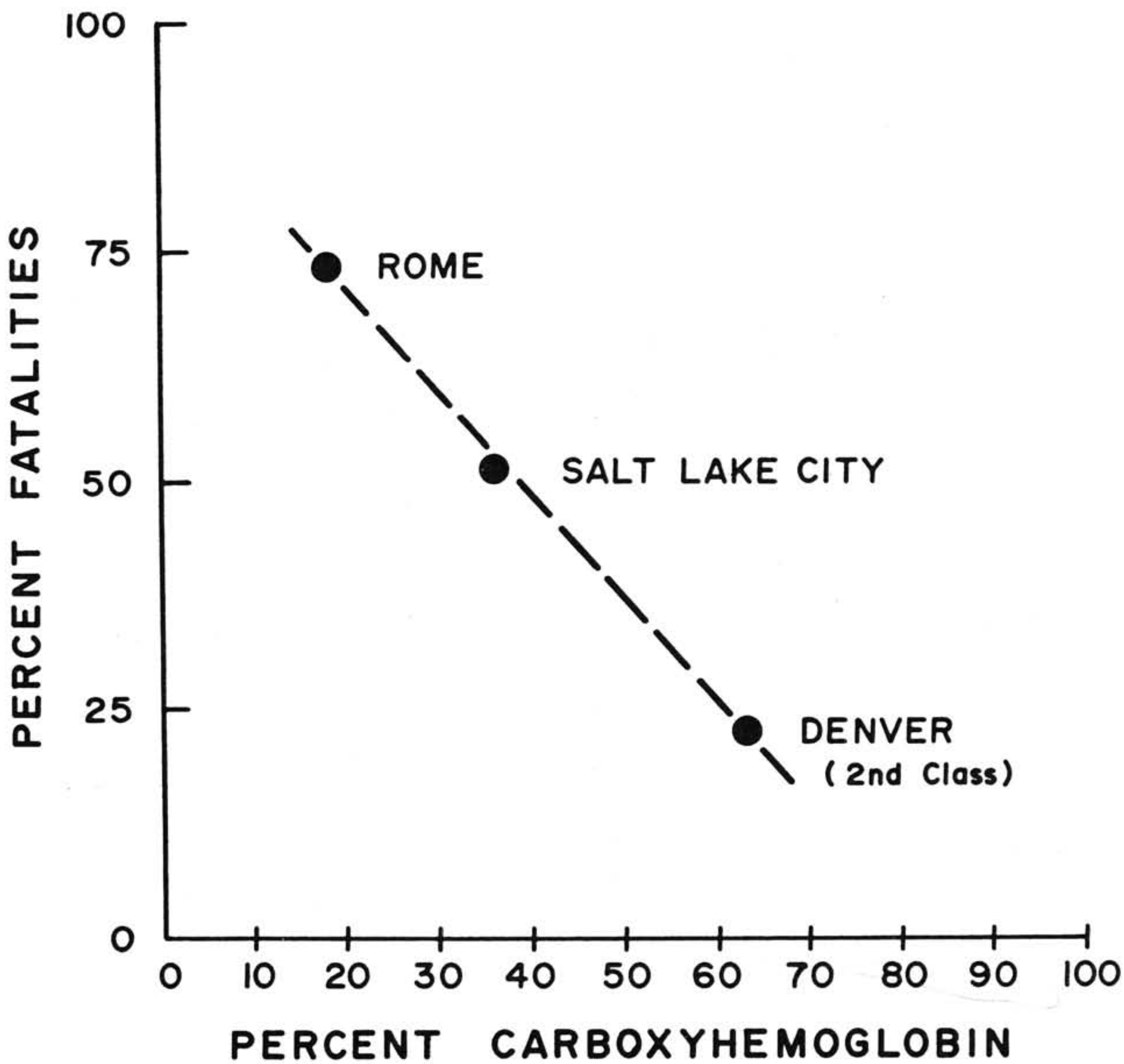


FIGURE 33. Relationship between mean carboxyhemoglobin concentrations of victims and fatality percentages in the three accidents.

Seat-to-Exit Distance. Present FAA certification regulations require the manufacturer to demonstrate that his fully-loaded aircraft can be evacuated in 90 seconds or less when half of the available exits are used.[13] Within these limitations, the size, number, and location of exits in a given aircraft are largely determined by design considerations, economic factors, and the results observed in experimental evacuations: While actual exit configurations vary from one type of aircraft to another, there is always some asymmetry of exit distribution in relation to passenger seating so that some passengers must travel farther than others to reach a potential exit. In the actual accident, the primary exit configuration may also be drastically altered by factors such as fire or structural deformation which may block certain exits and force nearby passengers to pass to more distant ones. To some extent, the time that a given passenger is exposed to the lethal cabin environment will be a function of the distance he must travel to reach an exit. The hypothesis that probability of survival might be influenced by seat-to-exit distances, therefore appears a reasonable one.

The testing of this hypothesis is complicated by several factors. In most instances, only the exits used by survivors are known for certain. Unless they were interviewed before they expired or were observed by other survivors, the exits used by off-board fatalities must be inferred. Likewise, there is no way to determine exactly which exits the onboard fatalities were attempting to reach before they died. The problem is further complicated by the fact that passengers do not always make for the nearest exit. The reasons for such seemingly illogical choices vary. For example, some passengers state that they bypassed potential exitways because they "joined the crowd" headed for a more distant one; others, unfamiliar with the particular aircraft's configuration and despite the standard pre-flight briefing on exit locations, were simply unaware of nearby exits. Many of this latter group, particularly at Denver, stated that they more or less automatically headed back in the direction from which they boarded the aircraft. Sometimes such choices are more logical—a given exit may be blocked or appear to be blocked by fire, its location may be hidden by smoke or, although later used, it might have been unopened at the time the passenger passed it. In the Salt Lake City accident, some survivors, noting a crowd around the window exits, chose to ignore them and went to the more distant galley door.

In reviewing survivor statements, one is impressed by the rarity of instances in which a passenger, once impelled toward a given exit, changes his mind and chooses another. Mute testimony of this is also found in the Salt Lake City accident where a large pile of bodies was found a few feet forward of the galley door (see Fig. 24). This door was opened early in the evacuation and successfuly used by several passengers. Many of those whose bodies were found close to it were originally seated aft of the door and must have passed it on their way forward. Some of these passengers were probably overcome by smoke while waiting for the forward entry door to be opened. None appeared to have reversed his direction in an attempt to reach the open galley door a few feet behind him.

In the three accidents considered here, two measurements were devised to study the seat-to-exit distance as a function of survival. The measurements chosen were relative, rather than absolute distances, since a relative distance is easier to compute and also because it minimizes the difficulties in comparing data from differently-sized aircraft.

The basic unit of measurement is the "*seat-row unit*." Two ratings for each passenger were computed:

a. *Seat-to-Exit Distance* (SED)—The number of seat rows *including his own*, separating a survivor from the exit he used or, in the case of a fatality, the exit he was attempting to use as inferred from physical or witness evidence.

b. *Seat-to-Usable-Exit Distance* (SUD)—For both survivors and fatalities, the number of seat

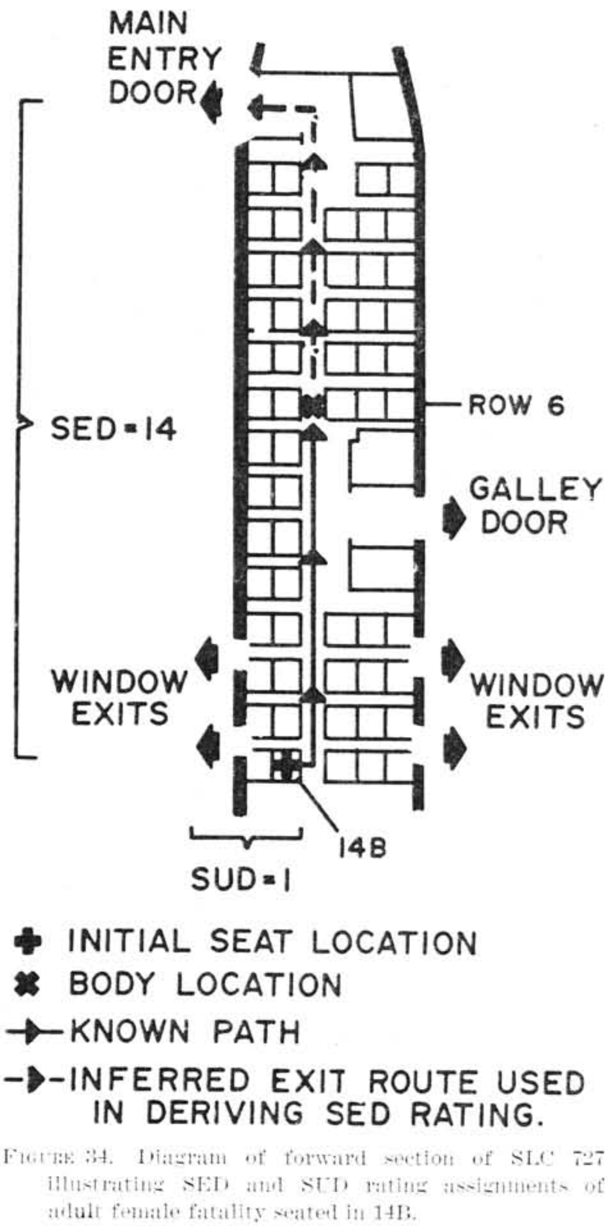


FIGURE 34. Diagram of forward section of SLC 727 illustrating SED and SUD rating assignments of adult female fatality seated in 14B.

rows, *including his own*, separating a passenger from the nearest usable exit. A "usable exit" is defined as one successfully used by at least one survivor.

Both these measurements ignore distances incurred by the necessity to pass non-occupant spaces such as galleys, closets, lavatories, and lounge areas. Thus, 1st-row passengers, who used the front main entry doors in the Salt Lake City and Denver accidents, were given SED ratings of 1.0 although the Denver evacuees, in passing the galley and lounge areas, traveled several feet farther to reach the exit. Another problem was posed by the lounge seating areas. On the Denver DC–8 both lounges were occupied by passengers at the time of the crash; no lounges were available on the Salt Lake City 727 and, although a forward lounge was available on the Rome 707, it was not occupied by any passengers at the time of the crash. This difficulty was resolved by assigning ratings of "O" to the lounge-seated passengers of the Denver DC–8.

In the case of fatalities, computation of the SUD rating offered no problems since the only information required was the original seat location and the nearest usable exit. The SED ratings for onboard fatalities were inferred after a review of the body location in relation to the fatality's original seat. The assumption was made that the passenger traveled directly from his seat to his final location and died attempting to reach the nearest usable exit beyond his line of travel. A specific example of the computation of these ratings is shown in Figure 34. It diagrams the body location, initial seat, and relevant exits of the female fatality seated in 14B of the Salt Lake City 727. This woman's seat location was determined through interview with her companion seated in 14A. According to the latter, the victim left her seat and ran forward shortly after the aircraft stopped. Her body was found in the aisle near the sixth row. She was assigned an SUD rating of 1.0 since she was seated in a row in which a window exit was located (note that the SED, SUD definitions offered above require the passenger's own seat row to be counted in computing the rating). The closest usable exit to her body was the galley service door. She had already passed this door, however, and an SED "14" was given based on the assumption that she was attempting to reach the forward entry door. Table 8 gives the mean SED and SUD ratings for survivors and fatalities of the three accidents. The means were compared by Student's-t tests and the resulting probability values are also shown in the table.

TABLE 8.—Means of SED and SUD ratings of survivors and fatalities of the Denver, Salt Lake City, and Rome accidents. The probability (p) values between means are based on student's-t tests.

		N	$\bar{x}$		p
Denver (2nd-class)					
SED	Survivors	55	4.62		<.001
	Fatalities	17	7.81		
SUD	Survivors	55	3.46		<.05
	Fatalities	17	4.76		
Salt Lake City					
SED	Survivors	42	3.67		<.001
	Fatalities	43	6.83		
SUD	Survivors	42	3.07		n.s.
	Fatalities	43	3.56		
Rome:					
SED	Survivors	17	4.06		
	Fatalities:				
	Onboard	24	4.62	n.s.	n.s.
	Offboard	21	4.47		
	All	45	4.55		
SUD	Survivors	17	2.29		
	Fatalities:				
	Onboard	24	3.71	n.s.	<.02
	Offboard	21	3.56		
	All	45	3.64		

The distribution and means of the SED ratings of survivors and fatalities are shown in Figure 35. At Denver, no 1st-class passenger traveled more than six seat-row units to gain an exit and the average passenger in this compartment passed 2.5 rows. The 2nd-class survivors had, on the average, farther to go (mean SED = 4.6) and with several traveling as far as 10–12 seat-row units. Most of the latter were those seated in the extreme forward portion of the 2nd-class cabin who escaped through the front main entry door. The mean SED ratings of the fatalities was 7.8, about twice that of the survivors. The range of the ratings was more limited among the fatalities, with most seated between 7 and 9 seat–row units from the exit they attempted to use, the right aft entry door.

As at Denver, the mean SED distance of Salt Lake City survivors was 3.7 seat-row units, or about half that of the fatalities (mean = 6.8 seat-row units). At Rome, the differences were the least observed in the three accidents with a mean for survivors of 4.06 compared to 4.62 for onboard fatalities and 4.47 for those who died outside the aircraft. The differences in SED means of survivors and fatalities were statistically significant ($p < .001$) in the Denver and Salt Lake City accidents, but not in the Rome crash. The small difference observed at Rome may be due in part to an underestimate of the SED means of fatalities. Several of the offboard fatalities, who had been seated close to window exits, were found near the left main entry door and may have actually used this door in making their escape. In the absence of contrary evidence, however, it was necessary to assume that they used the window exits nearest them in computing their SED ratings. In all three accidents, however, it is clear that fatalities were more apt to attempt more distant exits than survivors.

When the SED and SUD means are compared further differences of interest are revealed. In all three accidents, the SUD means are smaller than the corresponding SED means. The larger SED values are a reflection of the previously discussed fact that many passengers, through choice or necessity, traveled to more distant exits. Also, as in the case of the SED ratings, survivors display smaller SUD mean values than fatalities although the magnitude of the SUD differences are not as great as those observed in the SED ratings. This finding indicates that initial seat location gave the survivors some slight advantage in escape but that their advantage was magnified greatly by less efficient exit exploitation by the fatalities during evacuation.

To summarize, the effect of distances on survival, as measured by the SED and SUD ratings appears as follows:

a. In all three accidents, survivors, on the average, sat closer to potentially usable exits than fatalities.

b. Among both groups, survivors and fatalities, many passengers tended to sacrifice some of their initial locational advantage by ignoring nearby exits in favor of more distant ones.

c. These tendencies toward less effective exit utilization were more pronounced among fatalities than survivors.

Travel Class and Survival. In two of the three accidents, Denver and Rome, the aircraft cabin was divided into 1st- and 2nd-class compartments: in the third, Salt Lake City, passenger service was single class. It has already been pointed out that significant differences in age and sex composition occurred between the 1st- and 2nd-class passenger loads at Denver and, for this reason, they have been considered separately. On the Rome 707, no significant differences in sex ratios or mean ages were found between the two compartments and the two classes were combined for analysis. In Table 9 below, the fatality rates of the travel classes are compared for these two accidents. All of the 17 Denver fatalities occurred among 2nd-class passengers. However, at Rome, fatalities were uniformly distributed with about two-thirds killed in each class. Chi-square analyses indicate that the Denver disparities are statistically significant.

TABLE 9.—Distribution of fatalities and survivors according to travel class in the Denver and Rome accidents.

	1st-class	2nd-class
Denver:		
Survivors	42	55
Fatalities	0	17
Chi-square=9.868	$p < .005$	
Rome:		
Survivors	3	14
Fatalities	9	30
Chi-square=0.0102	Not significant	

The question arises as to whether the differences in travel class fatalities at Denver may be related to the difference in age and sex ratios of the two classes. As will be shown below, age and sex did not demonstrably affect survival *within* the 2nd-class compartment at Denver, it is therefore doubtful that it would affect inter-class survival. In this accident, the primary factors controlling survival would appear to be environmental, procedural and configurational since, as pointed out previously, the infiltration of smoke seems to have been heaviest in the 2nd-class cabin while crew assistance and direction was more effective in 1st-class. Ratio of passengers to potential exit was also more favorable in the 1st-class compartment and the lack of cues indicating that the window exits were located in 1st-class further lessened the probability of survival in 2nd-class. Many 1st-class passengers at Denver were aware of the fire hazard since it was initially concentrated in the forward area outside the aircraft. In contrast, at Rome, the fire and explosions were focused in the center of the aircraft and probably had a uniform effect on both forward and aft sections of the aircraft. Also, in this accident, crew assistance, while heroic was probably

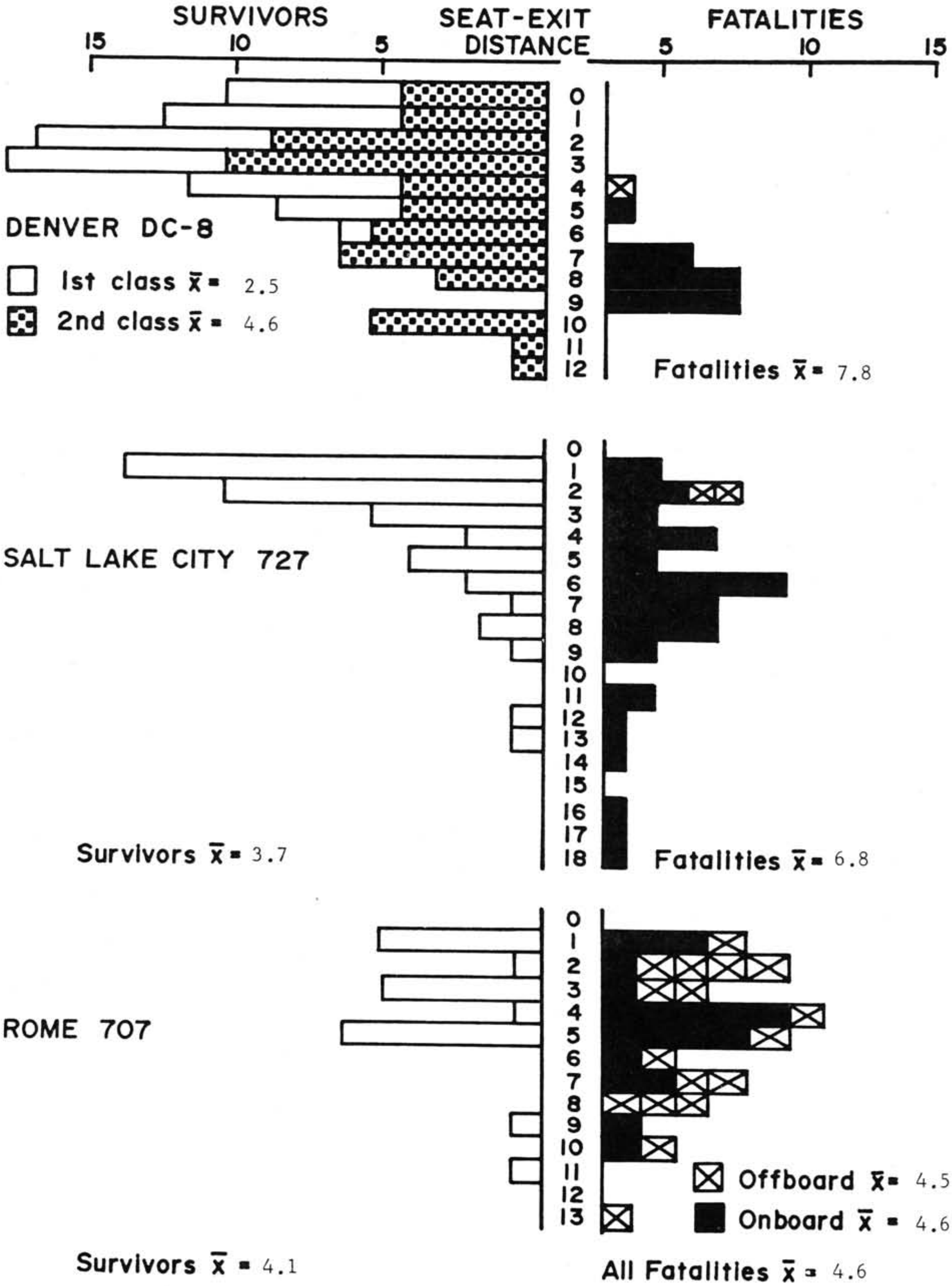


FIGURE 35. Distribution and means of SED ratings of survivors and fatalities of the three accidents.

less effective due to the shorter time available and the intensely lethal environment.

Influence of Sex on Survival. Among the 261 passengers of the three accidents, there were 90 adult females, 147 adult males, and 24 children under 16 years of age. The fatality rates, expressed as percentages of these three groups were 34.0% for males, 46.7% for females, and 66.0% for children. Considering adult passengers alone, the disparity in males and females is of borderline significance (Table 10).

TABLE 10.—Chi-Square analysis of relationship between sex and survival in adults. (Combined data from all three accidents.).

	Survivors	*Fatalities*
Males	97	50
Females	48	42

Chi-Square=3.7630, $p < .10$, 1 d_f

In the previous sections, it was pointed out that the three accidents differed strongly both in environmental factors and in passenger reaction. With these differences in mind, it is of interest to further analyze the relationship between sex and survival by considering the individual accidents in detail. In Table 11, these data are presented for all passengers except for those in 1st-class at Denver among whom there were no fatalities of either sex.

The results show that at Denver the sexes fared about equally well, although the overall sample was small. In contrast, at both Salt Lake City and Rome, female mortality was much higher. In the former accident 4 of 12 females survived, in the Rome accident, 3 of 22. Stated in percentages, only 17.9% of the adult females of these two accidents survived compared to 53.6% of the males. Chi-square analyses performed on the individual accident data indicate that sex was not a statistically significant factor in survival at Denver whereas at Rome and Salt Lake City, the sex-influenced differences in fatality rates were statistically significant.

Parental Status. In view of the high mortality (66%) among children aboard, it may be asked whether part of the greater female mortality was a contribution of mothers who died while attempting to help their children escape. Excluding the Denver 1st-class passengers, there were 11 females accompanied by children in the three accidents (Table 12); 6 of these, or 54%, were fatalities—only slightly higher than the overall female fatality rate. This is further offset by the mortality of fathers, 2 out of 4 of whom died. Referring back to Table 11, the figures in parentheses are the mortality statistics for the various groups with parents of both sexes eliminated. When the Chi-square analyses are repeated, using the "non-parent" statistics, slightly smaller values are obtained. The results are still statistically significant in the Rome accident and of borderline significance (p. <.10) for Salt Lake City. To some extent, this reduction in significance is probably a function of smaller sample size. In summary, it appears that mortality among females with children had only a small effect on the higher overall rate and other factors must account for the proportionately greater number of deaths among adult females.

TABLE 11.—Chi-Square analysis of relationship between sex and survivability. (Figures in parentheses are survivors not accompanied by children.).

	Survivors	*Fatalities*
Denver: (2nd-class only)		
Male	19(18)	5(5)
Female	29(24)	8(7)
Chi-Square	All adults=0.060; Non-Parents=0.066	
Salt Lake City:		
Male	38(37)	28(27)
Female	4(4)	12(10)
Chi-Square	All adults=4.243**; Non-Parents=2.853*	
Rome:		
Male	14(14)	17(16)
Female	3(3)	22(19)
Chi-Square	All adults=5.715***; Non-Parents=4.881**	

*$p < .10$
**$p < .05$
***$p < .02$

TABLE 12.—Distribution of fatalities and survivors among parents accompanied by children in the three accidents.

		Survivors	*Fatalities*
Denver	Fathers	1	0
	Mothers	5	1
Salt Lake City	Fathers	1	1
	Mothers	0	2
Rome	Fathers	0	1
	Mothers	0	3
Sub Total	Fathers	2	2
	Mothers	5	6
Total		7	8

According to recent anthropometric surveys, adult American females have an average body weight of about 142 pounds compared to a 168-pound average for males.[14] Such a size disadvantage, along with its correlates in both absolute and relative strength, would be expected to operate strongly against females in evacuation in which active competition for exits occur. In addition to their size disadvange, females may have other, less obvious ones. Typically, for example, they are less experienced and less frequent air travelers than males. Also, their clothing is probably more restrictive and more flammable than that of males. Mothers traveling with young children might naturally be expected to preoccupy themselves with efforts to save their children and thereby increase their own peril. Although less evidence is available, it would not be unexpected to find that even deeper-seated physiological, psychological, and cultural factors might also condition female response to disaster. Thus, many factors could operate together to lessen female probability of survival.

Influence of Age on Survival. In general, as age increases, agility and strength diminish, reflexes slow, and quite often decisions are made with more hesitation. All these factors, acting together, might be expected to put older passengers at a disadvantage during an emergency evacuation. It is also probable that elderly people travel less frequently than younger so that, as a group, they are less experienced air passengers. Children, quite naturally, may also be considered more vulnerable because of their physical and emotional immaturity as well as their lack of air travel experience. For these reasons, it seems worthwhile to examine the influence of age on survival.

The ages of all but 3 of the 261 passengers were obtained from interviews, hospital records, or death certificates. The data used were, with few exceptions, based on stated age rather than calculations to the nearest birthday. Means based on stated age may be slightly lower than nearest birthday, or chronological age, since persons nearing their next birthday commonly give an age based on their last birthday; e.g., a person 1-day away from his 35th may state his age at 34. Such errors, however, would tend to offset all the means uniformly and may be considered negligible when comparing one passenger group with another.

The 261 passengers were first divided into three groups based on stated age. Those of 15 years or less were classified as children. The adults were subdivided into a "young" group with ages from 16–55 years and an "old" group, aged 56 years or older. The distribution of survivors and fatalities within the three age groups is shown in Table 13.

TABLE 13.—Distribution of survivors and fatalities among children, young adults, and old adults in 261 passengers

	Children (1–15 yrs.)	Young Adults (16–55 yrs.)	Old Adults (> 55 yrs.)
Survivors	11	109	38
Fatalities	13	70	20
Chi-Square=2.784	not significant (2 d_f)		

The overall incidence of fatalities was 54.2% among children, 39.1% in young adults, and 34.5% in old adults. The Chi-square analysis indicates that these differences are not statistically significant. Again, however, as in the case of sex, significant trends in the age data may be obscured by lumping the statistics from all three accidents.

Reserving the children for later study, we will first examine age as a factor in adult survival. Table 14 gives the means, standard deviations, and observed ranges of age among adult females of the three accidents (the Denver data includes only 2nd-class passengers).

TABLE 14.—Relationships between age and survival of adult females in the Denver, Salt Lake City, and Rome accidents.

Females	N	$\bar{x}$	S.D.	OR	t	p
Denver (2nd-class)						
Survivors	29	46.75	17.56	18–78	−0.02	>.05
Fatalities	8	47.00	24.96	21–86		
Salt Lake City:						
Survivors	4	35.25	17.17	21–58	−0.83	>.05
Fatalities	12	42.91	11.27	24.66		
Rome:						
Survivors	3	41.00	7.21	35–49	+1.19	>.05
Fatalities	22	34.95	13.71	16–65		

In all instances the means fall in the mid-decades of life, with Denver fatalities averaging 47 years and Rome fatalities at about 35 years. The mean ages of survivors and fatalities at Denver are almost identical, at 46.75 and 47.00

years, respectively. At Salt Lake City, the female fatalities averaged about 8 years older than female survivors while at Rome the trend was reversed with survivors older by about 6 years. Student's-t test failed to demonstrate significant differences in the age means of survivors and fatalities in any of the three accidents. Sample sizes, however, are small—especially in the case of Rome and Salt Lake City survivors, and it might be argued that lack of sufficient numbers in these groups obscured otherwise significant differences. Such an argument is partially countered with the observation that the differences observed are divergent: female survivors were older at Rome, younger at Salt Lake City, and about equal to fatalities in age at Denver. If age were a factor a consistent trend in one direction or another would be expected, despite small sample sizes. In summary, it appears that age plays no significant role in determining survival among female adults.

The age means of adult male survivors and fatalities are given in Table 15. As in the case of females, the means are concentrated in the mid-decades. At Denver, survivors averaged about 6 years older than fatalities but the difference was not found to be statistically significant. This trend was reversed at Salt Lake City and Rome where survivors were significantly younger than fatalities—the difference amounting to almost 12 years at Rome. In these two accidents, it appears that younger males were definitely favored.

Thus far, two groups, adult females and old males (Table 16), have been identified as having statistically poorer chances of survival in the two accidents, Rome and Salt Lake City, where speed, strength, and agility would be expected to play a dominant role in reaching an exit.

It might be asked which of these two groups fared better. Thirteen out of 20 (65%) of the old males died compared to 34 of 41 (82%) of the adult females. These differences are not, however, statistically significant (Table 16).

Of the 24 children involved in the three accidents, 4 were in the 1st-class cabin at Denver and, along with the other 1st-class occupants, all escaped. In the 2nd-class at Denver, there were 11 children, 4 of whom died aboard, thus comprising about one-quarter of the 17 fatalities. When compared to adult survival (Table 17), however, the incidence of fatalities does not appear excessive, especially in light of the fact that 3 of the 4 child-victims belonged to a single family.

TABLE 15.—Relationships between age and survival of adult males in the Denver, Salt Lake City, and Rome accidents.

	Males					
	N	$\overline{x}$	S.D.	OR	t	p
Denver (2nd-class)						
Survivors	19	46.88	14.45	26–81	0.74	>.05
Fatalities	5	41.60	14.01	28–60		
Salt Lake City:						
Survivors	38	39.57	12.41	21–77	−2.08	<.05*
Fatalities	28	45.85	11.85	20–63		
Rome:						
Survivors	14	33.76	10.01	18–56	−2.68	<.02*
Fatalities	17	45.61	14.63	22–70		

*Statistically significant

TABLE 16.—Distribution of fatalities and survivors among adult females and old males in the Rome and Salt Lake City accidents.

	Old Males	Adult Females
Survivors	7	7
Fatalities	13	34

Chi-Square=1.534 Not significant (1 d_f)

At Salt Lake City and Rome, in contrast, there were nine children aboard, all of whom were fatalities. Table 18 compares the mortality data of children with the combined totals for old males and adult females for these two accidents. Among the latter, the incidence of fatalities was 77% compared to 100% among children. Chi-square analysis of this difference is not significant (Table 18). When compared with the statistically best survivors, young males, the differences are highly significant (Table 19). Thus, children can be identified as being statistically high fatality risks along with old males and females.

TABLE 17.—Distribution of survivors and fatalities among children and adult passengers in the Denver 2nd-class cabin.

	Children	Adults
Survivors	4	13
Fatalities	7	48

Chi-square=0.485 Not significant (1 d_f)

In summary, sex and age appear to have played a role in determining survival at Rome and Salt Lake City, but not at Denver. In the former two accidents, adult males under 55 years of age fared better than children, elderly males, and females

TABLE 18.—Distribution of fatalities and survivors among children and old males and adult females in the Salt Lake City and Rome accidents.

	Children	*Old Males Adult Females*
Survivors	0	12
Fatalities	9	49
Chi-square=0.976	Not significant (1 d_f)	

TABLE 19.—Distribution of fatalities and survivors among children and young adult males in the Salt Lake City and Rome accidents.

	Children	Young Adult Males
Survivors	0	47
Fatalities	9	30
Chi-square=9.776	$p<.005$ (1 d_f)	

to a statistically significant degree. Among the latter three groups, elderly males have the best survival record, followed by the females who, in turn, fared better than the children. The differences within the three latter groups are not statistically significant but small sample sizes might to some extent obscure stronger trends. The results are summarized in Table 20.

TABLE 20.—Percentage of fatalities in age and sex groups in the Denver, Salt Lake City, and Rome accidents.

	Young Adult Males	Old Adult Males	Females	Children
	Percent	Percent	Percent	Percent
Denver (2nd-class)	22.2	20.0	21.6	36.6
Salt Lake City	33.4	61.5	75.0	100.0
Rome	50.0	71.4	88.0	100.0

Injury Severity Among Survivors. Survivor injuries have been described in detail in the sections dealing with the individual accidents. In the following analysis an attempt is made to quantitate overall injury severity as it relates to the accident environment and the age and sex of survivors. To do so, the hospital records of the 145 adult survivors were reviewed and, comparing these with survivor statements, specific injuries that appeared to have been caused by initial impact were eliminated. Five such injuries were identified: the vertebral compression fractures sustained by four Salt Lake City passengers and the rib fractures of the elderly female in the Denver 2nd-class cabin who was thrown from her seat during the final swerve of the aircraft. The remaining injuries reported in survivors are those which occurred during escape—either within or outside the aircraft. A severity rating was then assigned for each survivor using the 10-point AVCIR injury severity scale[15] modified to include burns and smoke inhalation. Since those passengers who escaped but died later have been included among the fatalities, the actual ratings varied between 1- and 5-degrees of severity. The distribution of these ratings is shown in Table 21 below.

TABLE 21.—Modified AVCIR injury severity ratings of 145 adult survivors of the Denver, Salt Lake City, and Rome accidents.

	N	Percent
1. Trivial or none	73	50.3
2. Minor	27	18.6
3. Moderate	29	20.0
4. Severe	11	7.6
5. Serious	5	3.5
6. Critical	0	0.0
	145	100.0

About half of the passengers escaped without significant injury, the remainder were treated for injuries varying from minor (18.6%) to serious (3.5%). As might be expected, however, some interesting variations in severity are noted when the individual accidents are considered in detail. For example, Figure 36 shows

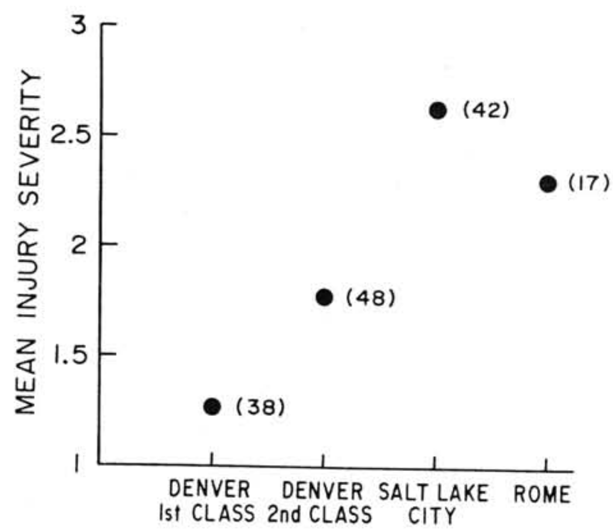


FIGURE 36. Mean injury severity rating of 145 adult survivors of the three accidents. (Numbers in parentheses=N.).

the mean injury severity rating for survivors of each of the accidents; the 1st- and 2nd-class Denver passengers are considered separately. In the first three groups, Denver 1st-class, Denver 2nd-class, and Salt Lake City there is a near linear rise in mean injury severity which generally parallels the total fatality rates and the overall intensity of the thermotoxic environment. The means for Rome drop below expectation, possibly because of small sample size, but more probably because these 17 survivors were the least injured of those who managed to escape the aircraft, the more seriously hurt being those caught outside by the second explosion.

Since the number of individuals in the various injury categories is small, the passengers were grouped as "injured" and "uninjured" in order to perform Chi-square analyses comparing adult males and females (Table 22). At Denver, the differences in injury incidence are significantly higher among females in the 1st-class cabin and not significant in 2nd-class. At Salt Lake City and Rome, the results were not statistically significant as would probably be expected since the number of female survivors is small. It will be recalled that sex was not a significant factor in survival at Denver, but was significant at Rome and Salt Lake City, yet the findings are reversed in regard to injury. A possible explanation is found, perhaps, in the very low incidence of survival among adult females in the latter two accidents. In them, the lethal agents—smoke, fire, and blast—were intense within the cabin throughout most of the evacuation. The factors selecting against females thus operated throughout the accident and produced fatalities rather than injured survivors. At Denver, in contrast, intracabin environment was comparatively mild and nearly all of the survivors received their injuries when forced to jump and run the gauntlet of flame outside the aircraft. The outside fire environment at Denver, while intense enough to produce some injury, was not sufficient to cause death (except in the 86-year-old woman who died later).

TABLE 22.—Comparison of injury severity in male and female passengers of the three accidents.

	Male	Female
	Denver (1st-class)	
Uninjured	24	7
Injured	2	5
Chi-square=4.248	$p<.05$ *	
	Denver (2nd-class)	
Uninjured	13	12
Injured	6	17
Chi-square=2.367	$p>.05$	
	Salt Lake City:	
Uninjured	9	1
Injured	29	3
Chi-square=0.312	$p>.05$	
	Rome:	
Uninjured	7	0
Injured	7	3
Chi-square=0.903	(1 d_f)	

* Statistically significant

Table 23 compares the age means of injured and uninjured survivors of the three accidents. At Denver, the age means are nearly identical for both male and female survivors in the 1st-class cabin and for males in the 2nd-class cabin. There is a strong and statistically significant difference among the females in 2nd-class, with the injured women averaging about 17 years older than those uninjured. Again, the sample sizes for females are too small for any meaningful comparison at Salt Lake City and Rome. Salt Lake City males, however, do display a significant difference with the uninjured averaging about 10 years younger than the injured. At Rome, uninjured males were also slightly younger but the results are not significant. As previously mentioned, it is probable that the second explosion at Rome killed the more seriously injured of those already outside the aircraft, thus obscuring some otherwise strong age

TABLE 23.—Age comparisons of injured and uninjured survivors of Denver, Salt Lake City, and Rome accidents.

	Males		Females	
	N	Mean Age (yrs.)	N	Mean Age (yrs.)
	Denver (1st-class)			
Uninjured	24	50.4	7	55.1
Injured	2	50.5	5	56.8
	Denver (2nd-class)			
Uninjured	13	47.4	12	37.2 *
Injured	6	45.8	17	54.5
	Salt Lake City			
Uninjured	9	31.9 **	1	47.0
Injured	29	41.9	3	35.0
	Rome			
Uninjured	7	34.0	0	
Injured	7	36.7	3	43.7

*Student's-t=3.136 $p<.01$ (27 d_f)
**Student's-t=2.77 $p<.01$ (36 d_f)

differences in the males. The significant age difference in Salt Lake City males is not unexpected since age was also a factor in determining male survival. The Denver results are more difficult to explain since it is hard to see why age would affect 2nd-class female injuries, but not those of 2nd-class males or 1st-class passengers of either sex.

In the analysis of mortality statistics it was shown that, as a group, old males, adult females, and children were poorer survival risks than young adult males. In Figure 37, the mean injury severity ratings of the two groups are compared. Both groups show the same pattern of linear rise observed in the overall severity ratings (Fig. 36), but the combined mean of children, females, and old males is consistently higher than those of young males, indicating that this group is liable to suffer more frequent and more severe injuries than the young males as well as contributing a significantly larger share of fatalities.

Effects of Nationality. In the Salt Lake City and Denver crashes only a few of the passengers aboard were non-U.S. Nationals. In Rome, 9 nationalities were represented with U.S.A. furnishing 32 (51.6%) of the total adult passenger load (Table 24). Other nationalities represented among adults were French (6), Italian (6), German (4), Ethiopian (3), Australian (2), Canadian (1), Filipino (1), and Indian (1). These categories are too small for statistical analysis but, to see if linguistic or cultural differences may have had some detectable influence, the English-speaking nationalities (U.S.A., Canada, and Australia) were lumped and compared with those passengers from non-English-speaking nations. Only 22% (8 out of 36) of the "English" survived compared to 45% (9 of 20) of "non-English" group. However, these differences are not statistically significant. No differences are apparent in the differential survival of the sexes within the various national groups.

TABLE 24.—Survivors and fatalities of Rome Crash grouped by nationality and sex.

Nationality	Survivors		Fatalities	
	Male	Female	Male	Female
U.S.A.	6	2	12	12
Australia	0	0	0	2
Canada	0	0	1	0
France	2	0	1	3
Italy	3	0	1	2
W. Germany	1	1	0	2
Ethiopia	2	0	1	0
India	0	0	1	0
Philippines	0	0	0	1

	Survived	Died
"English-Speakers"	8	27
"Non-English-Speakers"	9	12

Chi-square=2.483, not significant

Survival Gradients in the Rome Accident. The passengers of the Rome accident can be divided into three groups: (1) survivors, (2) offboard fatalities, and (3) onboard fatalities. The 17 survivors represent those passengers who had put enough distance between themselves and the aircraft to escape the later—more intense—explosion. The 19 whose bodies were found outside the aircraft and the 2 who died later in hospitals had succeeded in finding an exit but were still too close to survive the second blast and flash fire. The 24 fatalities found onboard had been unable to get to an exit when the explosion occurred. Figure 38 presents the seat-exit distance, adult sex ratios, and ages of male adults of the three categories.

Four children died onboard; two died offboard and none survived. Among the adult females, a similar decline is noted with 15 fatalities onboard, 7 offboard, and 3 survivors. In adult males, the gradient is reversed with 5 fatalities onboard, 12 offboard, and 14 survivors. Stated differently, the ratio of adult males to adult females increases from 0.33 for onboard fatalities to 4.67 for survivors with the offboard fatality ratio intermediate at 1.71. Among males, a similar gradient exists in respect to age, with the ratio of those under 40 to those over 40 being 0.20 for onboard fatalities, 1.00 for offboard fatalities and 2.50 for survivors. Mean values for seat-exit distance decline from 4.6 among onboard fatalities to 4.5 for offboard fatalities, and 4.1 for survivors.

Thus, the existence of such gradients within the passenger population of a single accident provides some internal support of the overall findings that age, sex, and seat-exit distance interact to determine survival probability.

Test Evacuations and Accidents. Many safety regulations, as well as exit configurations, equipment requirements, and evacuation procedures are based on the study of simulated evacuations conducted by FAA and industry. Conduct and de-

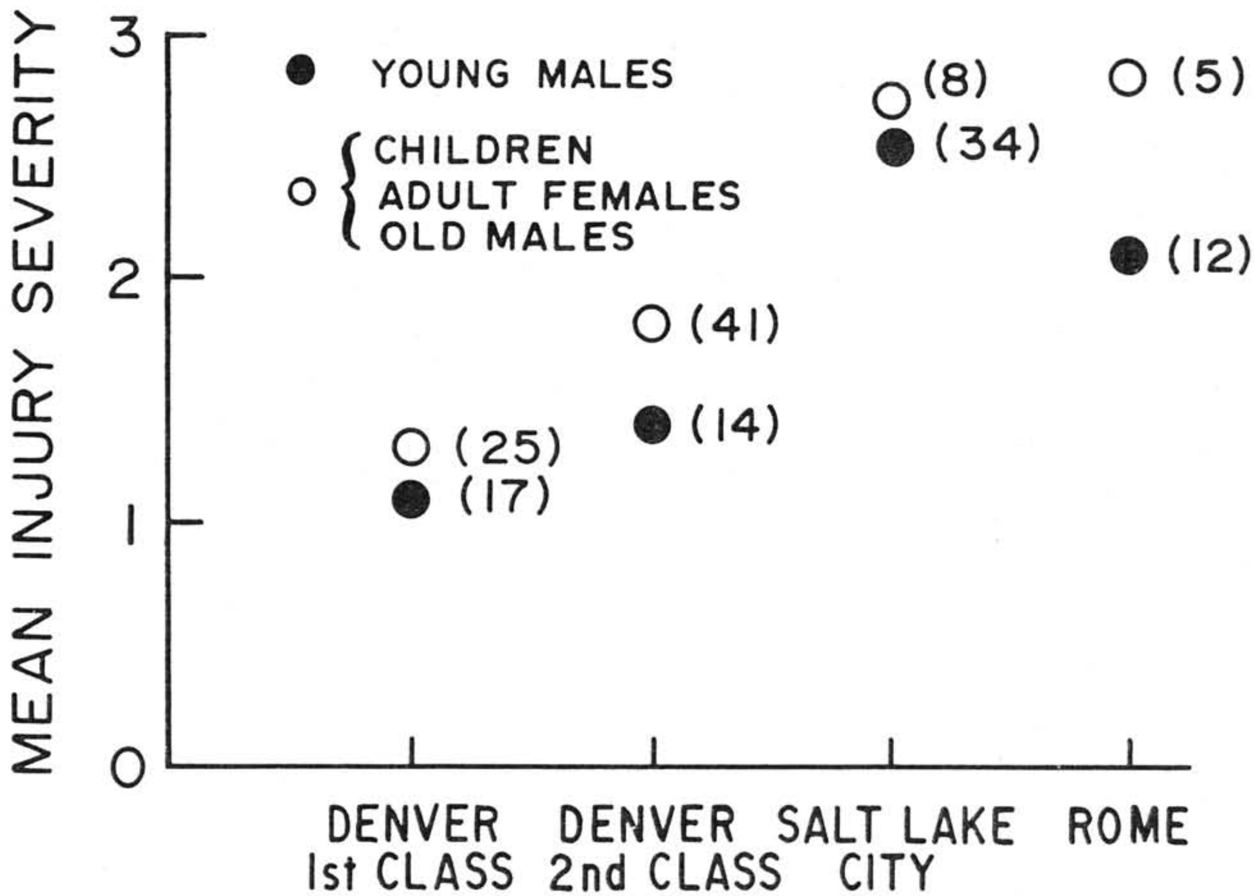


FIGURE 37. Mean injury severity ratings of young males (16–55 years) compared to combined mean for children, females, and old males (56+years). (Numbers in parentheses=N.).

sign of these tests vary but, in general, they conform to certain criteria regarding composition of passenger load, test procedure and environmental simulation set forth by the Federal Aviation Administration.[13] While every reasonable attempt is made in such tests to simulate actual emergency conditions, it is obvious that they must necessarily fall short in some respects. The volunteer subjects, for example, to some extent must be prebriefed or otherwise aware of the test's purpose; the use of real fire and smoke is also, naturally, out of the question. In general, haste, but not panic is the human behavioral element elicited but, as we have seen, it is the confusion, disorder, and panic of actual emergency that influences the outcome of emergency evacuation in terms of the differential survival rates among various segments of the passenger population.

To compare accident and test evacuations, data were taken from two of a series of evacuation studies conducted by FAA's Civil Aeromedical Institute (CAMI) in 1967. The purpose of these tests was to evaluate the comparative effectiveness of existing single-door and window exits with a new, double-door (Type A) exit. A detailed description of the test procedures has been given elsewhere.[16] Here it is sufficient to note that 280 unpaid volunteers were used in each test. In both tests, evacuation was conducted from a wooden mock-up of the Lockheed version of the proposed SST,* wooden ramps were substituted for escape slides, and evacuation was controlled by professional airline stewardesses and flight-deck crew. Age and sex composition of the passenger loads were within limits (70% male, 30% female, 5–10% less than 12 years, 5% above 60 years) prescribed in FAR 121:291. In the first test, evacuation was from the right side of the aircraft using all seven available exits (4 door and 3 window); in the second test, evacuation

*This version is very similar in interior seating arrangement to the Boeing SST under construction.

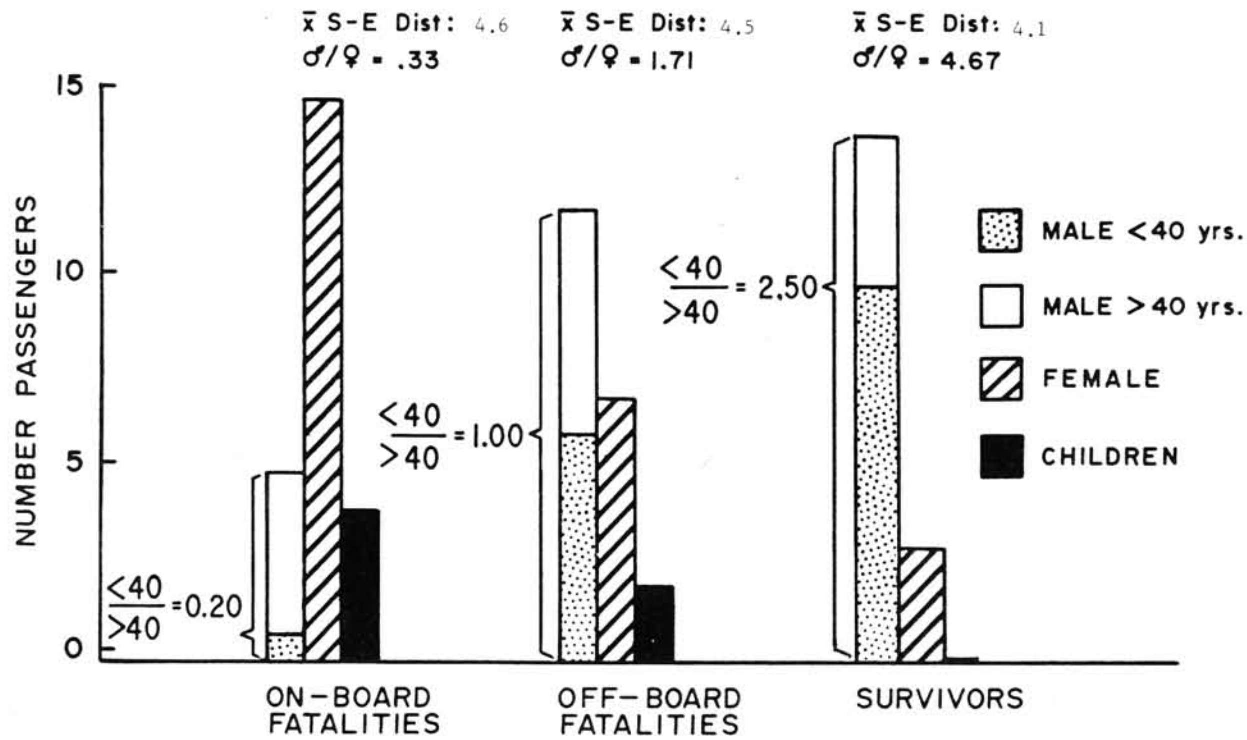


FIGURE 38. Distribution of adult male and female Rome passengers showing gradient in sex and age according to casualty status.

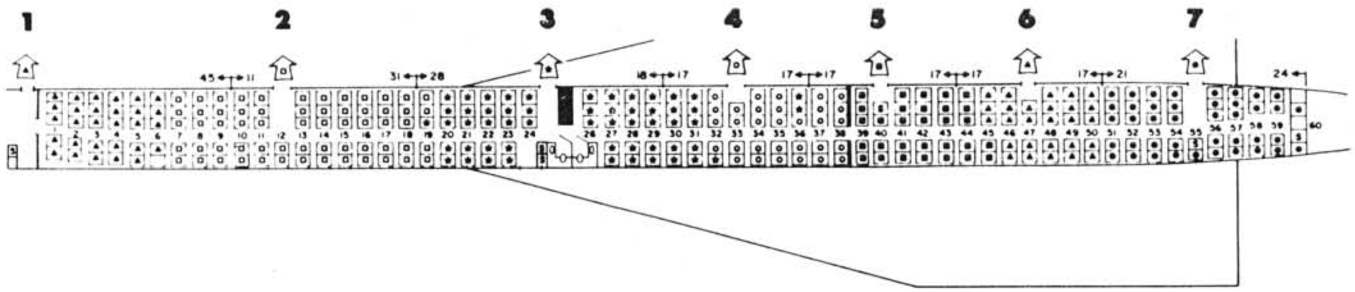
was from the left side using three double-door exits (Fig. 39). Passengers and crew were clear of the aircraft in 70.6 seconds in the first test and 49.0 seconds in the second test. The evacuation order from each exit was documented by high-speed motion pictures with individual passengers identified by numbered chest placards. Initial seating within the cabin was random except that families were allowed to sit together.

The SED and SUD distances have not been computed and compared for these two tests, but inspection of the seating diagrams in which each occupant is coded according to the exit he used makes it apparent that evacuation was orderly. In general, the passengers broke into clean-cut blocs, each proceeding to the nearest exit. Of the 560 passengers involved, only two, the occupants of seats E and F, row 36, of the first test appear to have traveled unnecessarily far to reach an exit. This orderliness contrasts strongly with the patterns of exit selection observed in the accidents considered in this study.

Using the filmed evacuation sequences, the passengers were divided into groups of ten decile units according to their order off the aircraft. The number of adult males, adult females, and children within each decile unit was then determined. The cumulative percentages of adult females (Fig. 40a) and children (Fig. 40b) were then plotted against those of the adult males. If sex and age play no part in determining the order of evacuation, we would expect the relationship to be isometric and linear. In other words, when a given percentage of adult males were outside the aircraft an equal percentage of the more vulnerable groups should also have been deplaned. An examination of the figures shows that, in the tests, this appears to be the case. For example, when 55% of the adult males had evacuated, about 50% of the adult females were outside the aircraft in the first test and about 60% in the second. In both tests, about 60% of the children were off the aircraft at this point. Had an explosion occurred at this point killing those still inside the cabin, a little better than a fair and proportionate share of women and children would have survived. In contrast, at Salt Lake City when 55% of the adult males had escaped, only 25% of the adult females and none of the children were outside the aircraft. At Rome, about 85% of the adult males (including those who died outside) were out of the air-

TEST I

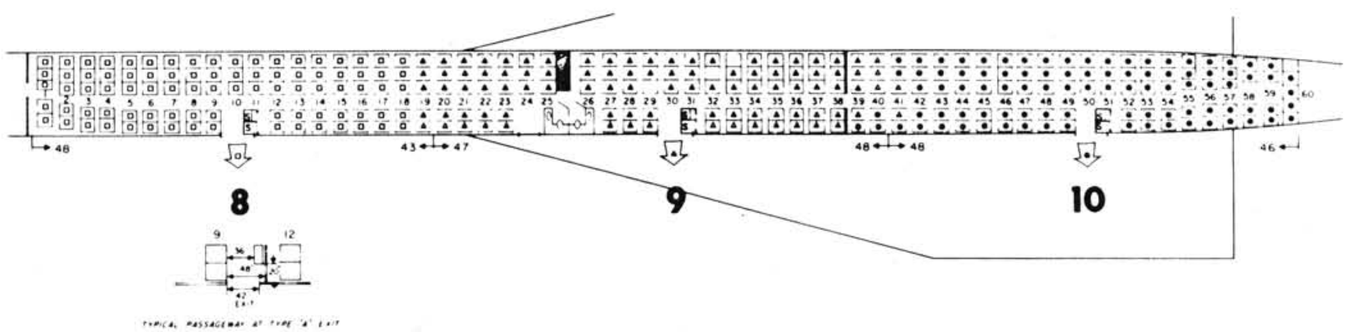
ALL RIGHT SIDE EXITS



1 ▲ 24"x48" 16" step down
2 □ 24"x48" 16" step down
3 ★ 24"x48" 7" step down
4 ○ 20"x36" 27" step down
5 ■ 20"x36" 27" step down
6 △ 20"x36" 27" step down
7 ● 24"x48" 7" step down

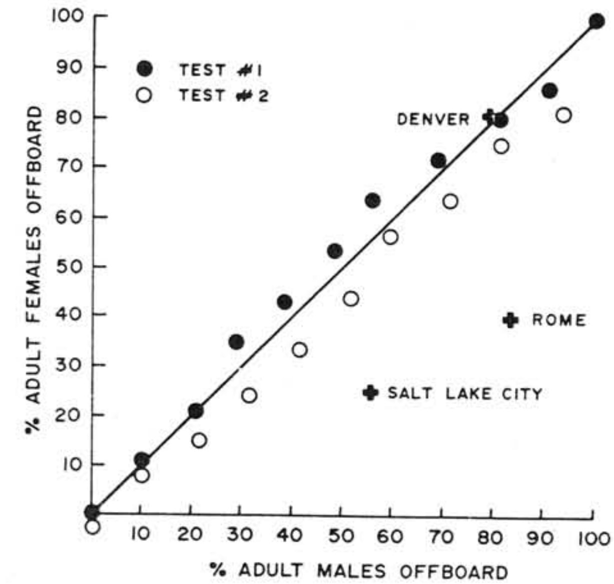
TEST 2

EXITS 8, 9 AND 10



8 □ 42"x 72" 16" step down
9 △ 42"x 72" 7" step down
10 ● 42"x 72" 7" step down

Figure 39. Exit configuration, step-down distance, and passenger load distribution of simulated evacuation tests.



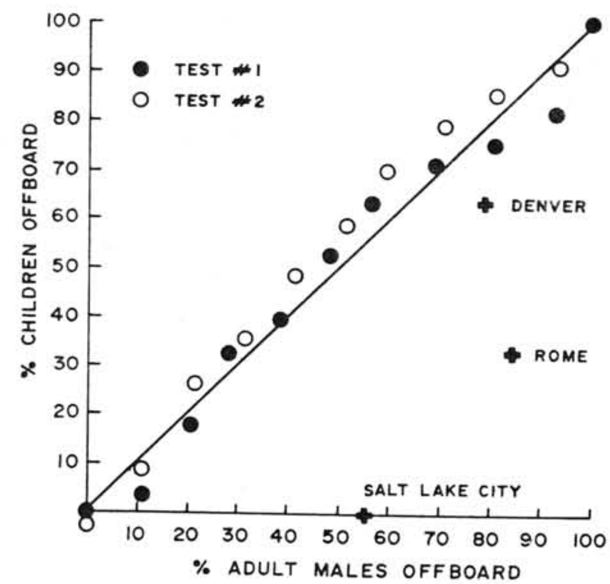


FIGURE 40.a.b. Cumulative percentage of adult females (upper figure) and children (lower figure) evacuated as a function of adult males evacuated in SST evacuation tests. The inset points represent corresponding percentages in the three accidents.

craft when the explosion occurred but only 40% of the adult females and one-third of the children had deplaned at this time. Among Denver 2nd-class passengers, however, the point for adult females falls nearly on the regression line and that of the children only a little below. In other words, Denver passenger behavior appears similar to that of the test subjects insofar as it is reflected in these statistics.

The final figure (Fig. 41) shows the differences in mean age of those adult males still onboard and those already outside the aircraft during the two test evacuations. At any stage of the evacuation, points falling above the line indicate that those who had deplaned were older than those still onboard; points falling below the line indicate the reverse. For example, when 50% of all adult male passengers had been deplaned, the mean age of those males outside was about 1 year less than those still inside in the first test, but about 2 years greater in the second. With the exception of the mid-portion of the first test, older males tended to have precedence in evacuation. At Salt Lake City and Rome, in contrast, the mean age of those fatalities still onboard the aircraft exceeded that of the survivors by 6–8 years. Denver, again, conforms closely to the evacuation test observations with younger fatalities and older survivors.

IV. Summary and Conclusions.

In aircraft accidents in which decelerative forces do not result in massive cabin destruction and overwhelming trauma to passengers, survival is determined largely by the ability of the uninjured passenger to make his way from a seat to an exit within time limits imposed by the thermotoxic environment. In this paper, three such "evacuation accidents" have been analyzed from the standpoint of biobehavioral factors influencing escape. Based on descriptive evidence, the three accidents could be graded into a series based on the environmental lethality: (1) *mild:* Denver DC–8, "primarily smoke," (2) *intermediate:* Salt Lake City 727, "smoke and cabin fire," and (3) *extreme:* Rome 707, "fire and blast." This continuum is also objectively reflected in the overall death tolls, the severity of survivor injuries, and inversely, in the blood carboxyhemoglobin values of the fatalities. Judging from subjective assessments, based on witness statements, passenger behavior generally paralleled the environmental intensities, being relatively calm at Denver and extremely panicky at Rome.

In all three accidents, the distance between initial seat location and the nearest usable exit tended to be greater among fatalities than survivors. This leads to the not unsurprising conclusion that it is better to sit closer to an exit than farther away. Of more significance, how-

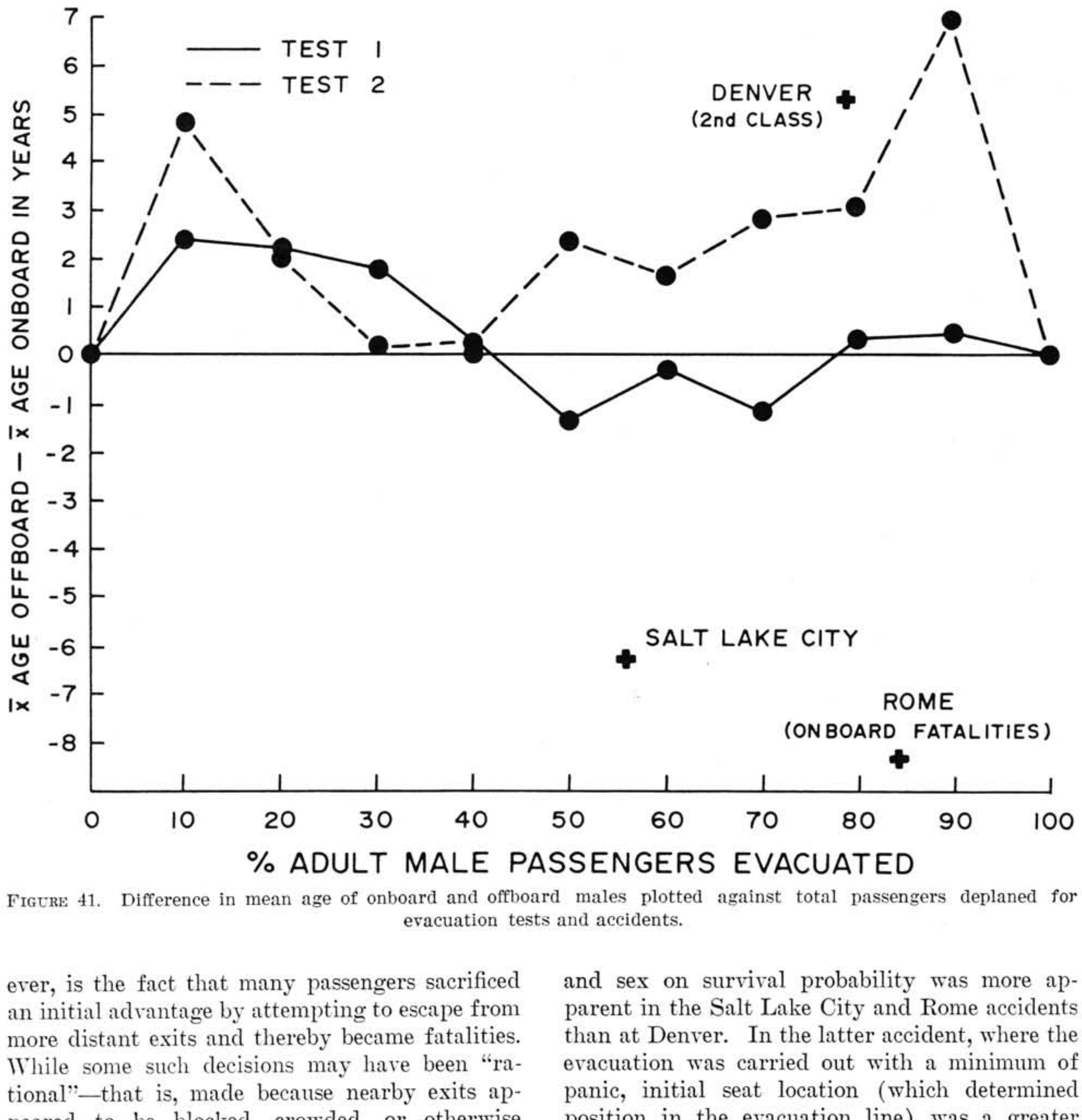


FIGURE 41. Difference in mean age of onboard and offboard males plotted against total passengers deplaned for evacuation tests and accidents.

ever, is the fact that many passengers sacrificed an initial advantage by attempting to escape from more distant exits and thereby became fatalities. While some such decisions may have been "rational"—that is, made because nearby exits appeared to be blocked, crowded, or otherwise inaccessible, evidence indicates that many were based on lack of familiarity with exit configurations or through panic. Such findings suggest that more intensive preflight briefings on exit use and location are important. They also reflect the necessity of positive and direct crew assistance throughout the actual evacuation.

In general, young adult males are the best survival risks; adult females, elderly males, and children are more prone to injury and also more apt to become fatalities. The influence of age and sex on survival probability was more apparent in the Salt Lake City and Rome accidents than at Denver. In the latter accident, where the evacuation was carried out with a minimum of panic, initial seat location (which determined position in the evacuation line) was a greater factor than age and sex in determining fatalities.

When the reconstructed evacuation patterns of these three accidents are compared to the simulated emergencies of evacuation tests, shortcomings of the latter become apparent. The tests, despite elaborate attempts to simulate the real situation, fall far short if the factors of age and sex as related to evacuation order are used as indices in determining the disorder and confusion of actual emergency evacuations. While such tests are valuable in establishing minimum evacuation times for a given configuration, the findings of the present study should encourage extreme caution in any attempt to extrapolate test results to actual emergencies. At present, test subjects generally make for the nearest exit when the signal for evacuation is given. That they do so almost unerringly is apparent from a detailed examination of Figure 39 which shows that with a few exceptions the nearly 300 occupants in each test divided themselves into clear-cut blocs based on the location of the nearest opened exit. Missing in the tests is the confusion and chaos produced through many passengers choosing more distant exits. Perhaps more realistic and valuable data could be obtained if some disorder were "programed" into such tests by randomly preassigning exits to subjects without regard to their initial seat locations.

The three accidents considered here do not form a random sample of emergency evacuations. Each year, several dozen passenger aircraft are evacuated under emergency conditions with the occupants escaping unharmed or with injuries limited to relatively minor mechanical trauma. The stimuli triggering such emergencies are usually minor or non-existent—small cabin fires or suspected bombs are examples. Extreme events, as occurred at Denver, Salt Lake City, and Rome, are fortunately rare but, unfortunately, are the ultimate tests of the effectiveness of the engineering and human factors which interlock to form an evacuation system. The results offer no cause for complacency on one hand nor despair on the other. These accidents occurred in the early 1960's; had they happened a decade earlier—when ropes were still in vogue as escape devices and crew training in emergency procedures a sometimes neglected and haphazard process—the toll of injury and death would have undoubtedly been higher.

However, the results must also be measured against the future as well as the past. Given the thermotoxic environment of these three accidents in the 1970's, will the escape devices and crew procedures now available be sufficient?

Inflatable slides may be taken as a specific example. From the time of their introduction in the late 1950's to the present, steady improvement in mounting and inflation methods have significantly decreased the time required for their deployment. Yet in these three accidents, less than 15% of the 261 passengers involved were able to escape on fully-inflated and functioning slides (about 20 at Denver, through 2nd-class galley door; about 15 at Salt Lake City, through front passenger loading door; none at Rome). Several of the slides exploded and burned after they were deployed and at Denver, in particular, the burning slide debris below the threshold contributed significantly to the injuries of later passengers who were forced to jump. Larger, longer, and more rapidly inflatable slides have been developed for the larger aircraft of the 1970's and, while technologically impressive, merely represent a "scaling up" necessary to meet the requirement of higher threshold-to-ground distances and bigger passenger loads. Significant progress in fire-proofing materials used in slides has not been made. Such scaled-up slides, once deflated and burning, will provide larger fires into which passengers will be forced to jump from greater heights.

The findings that females, the elderly, and children face greater survival risks is not unexpected and is probably not a peculiarity of aircraft disasters. "Women and children first" is a cry, that down through the ages, has undoubtedly been more often uttered than honored and in ship wrecks, fires and natural disasters these more vulnerable individuals have probably always contributed disproportionately to the toll of victims. Yet the statistical evidence demonstrates that chances of survival are to some extent affected by as yet ill-understood biobehavioral factors. For example, are adult females poorer survival risks merely because they are smaller and less strong than competing males, because they wear more flammable attire, or because they react differently in crisis situations? If the latter hypothesis is found to be true, are the sexual differences in behavior due to less passenger experience and lack of familiarity with the aircraft or to deeper psychosocial and cultural factors? The solution of such problems will require more intensive "in depth" studies of passenger behavior in actual crisis. The potential contribution of behavioral scientists as direct participants in the investigation of accidents such as these will be valuable.

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