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EVACUATION TESTS FROM AN SST MOCK-UP

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EVACUATION TESTS FROM AN SST MOCK-UP

I. INTRODUCTION.

The increased passenger-carrying capacities of transport aircraft have complicated the problem of establishing adequate emergency evacuation procedures. Concern for the successful resolution of this problem has stimulated efforts to properly define and meet the needs of any given evacuation event. Studies to define and measure the characteristics and interwoven events of an emergency evacuation can provide data to: (1) improve the management of evacuating passengers, and (2) serve as a guide for the design of optimal locations and features of escape routes.

Considered as a system, an evacuation procedure should be evaluated for: (1) briefing of passengers, (2) prevention of crash injuries so that passengers are physically capable of escape, (3) effectiveness of crew members, (4) placarding, (5) emergency lighting, (6) access to exit areas, (7) absence of potential obstructions to exits (e.g., baggage), (8) size of exits, and (9) door-opening procedure, with associated emergency chute deployment. A successful evacuation depends upon keeping usable exits "fed" with passengers at maximum egress rates. The threat of fire, smoke, and explosion makes each second a lifesaving segment of time.

This study was designed to test and analyze the relative efficiencies of exits of four specific configurations, in terms of passenger flow rates. All tests were conducted using the full-scale supersonic transport mock-up, constructed by the Lockheed-California Company, Burbank, California, as a test vehicle. Volunteer subjects were used as passenger evacuees.

II. GENERAL DESCRIPTION.

The basic objectives of these tests were to: (1) evaluate the comparative passenger flow rates through Type I and Type A exits, using large groups of subjects, (2) supplement previous studies on the effects of door heights on evacuation flow for Type I exits with 48-inch and 60-inch heights, and (3) evaluate crew-positioning and management of passenger flow through Type A exits from a single aisle in the cabin. The information was gathered to supplement and compare with existing data on these exits, the ultimate goal being to either confirm the validity of, or recommend changes in, the current ratings of Type I and/or Type A exits. It should be pointed out that at present the Type I and/or Type A exit ratings have not been finalized. This matter is currently under consideration by FAA Flight Standards Service and involves evaluation of additional emergency evacuation data submitted by industry.

Test Vehicle. The supersonic transport (SST) mock-up was moved to the Civil Aeromedical Institute (CAMI), Oklahoma City, Oklahoma, during March 1967, to be used primarily as a general evacuation test vehicle. The mock-up (less 21 feet of the tail section) included the hinged nose, flight deck, and the 179-foot cabin area back to the aft cabin bulkhead. The mock-up was reassembled in a fenced enclosure with the cabin floor elevated 32 inches above ground level. Platforms simulating wing surfaces extended 20 feet outward on each side of the mock-up and along its length for 110 feet (from Seat Rows 20 to 58), as illustrated externally in Figure 1.

Inside the mock-up, 60 rows of seats, each five-abreast (three on the right, two on the left), were arranged as a one-class configuration for 280 passengers. The minimum aisle width of 15 inches specified for transport aircraft was maintained as nearly as practicable. A 34-inch fore-aft seat spacing, measured between similar points on each seat (seat pitch), was used throughout the cabin. Bulkheads divided the cabin into three sections.

A public-address system was provided in the cabin. A movable crew intracommunications system permitted plugging in at many crew stations within the cabin for different exit locations

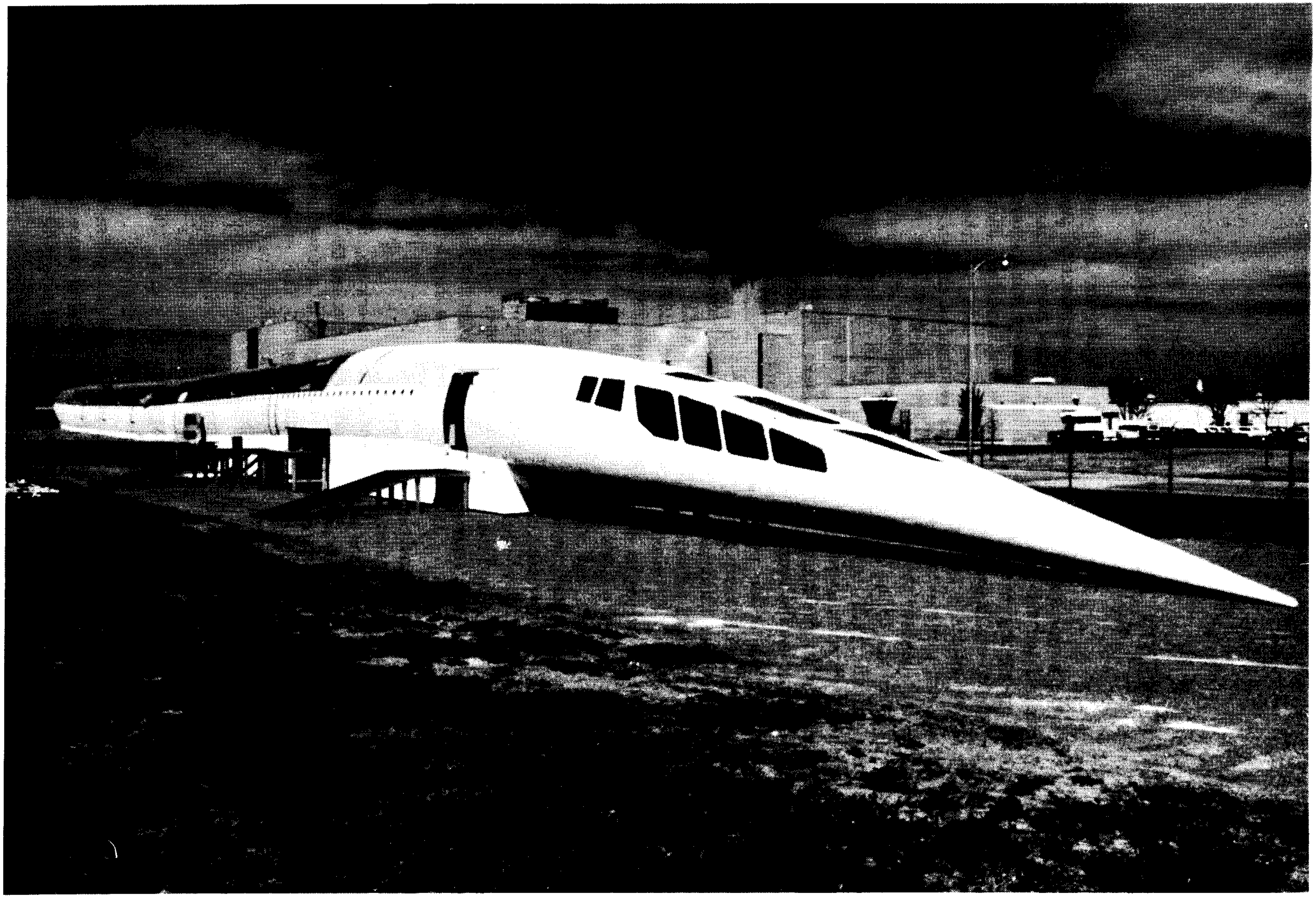


FIGURE 1. An external view of the supersonic transport mock-up, from the forward right side, containing the Type I and Type III exits. The 16-inch step-down and ramp from Exits 1 and 2 are visible.

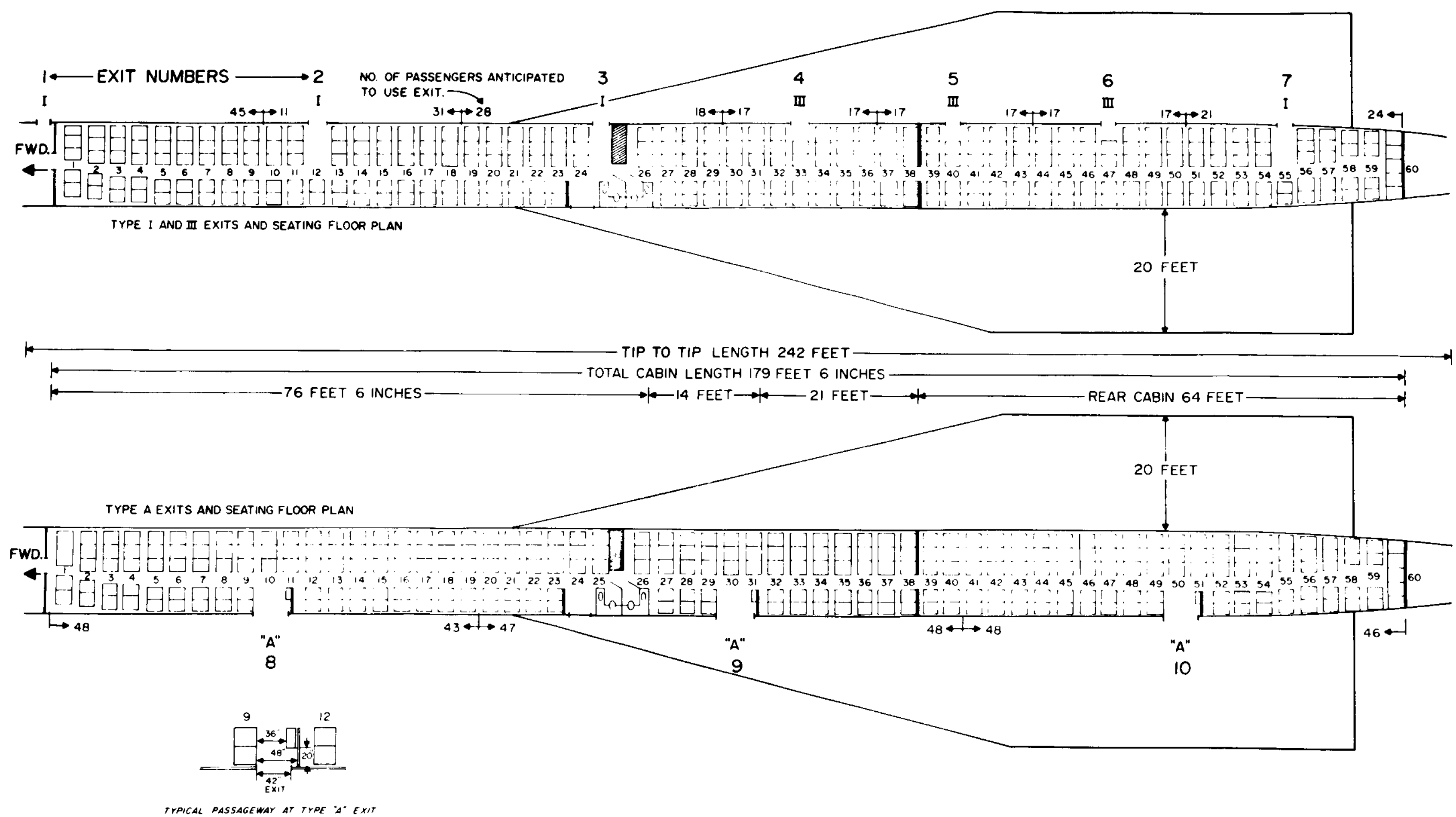


FIGURE 2. The seating pattern, exit arrangements, exit numbers, cabin lengths, and wing areas used in the tests.

and test configurations. Figure 2 shows the floor plans of the exit areas and the passenger seating arrangements.

Test Subjects. Two groups of subjects, each consisting of 280 volunteers, were made up of FAA Aeronautical Center employees, their families, friends, and neighbors, and approximately three official observers who filled vacancies created by "drop-out" subjects.

Each group was selected to simulate the normal passenger distribution aboard transport aircraft for evacuation demonstrations performed by air carriers. The following passenger distribution, prescribed in Federal Aviation Regulations (FAR) Part 121.291 (Appendix D), was adhered to:

(1) At least 30% females.

(2) At least 5% over 60 years of age (the percentage of females in this group being $\geq$30%).

(3) Between 5% and 10% children under age 12 (the percentage of females in this group also being $\geq$30%).

(4) 55–60% (i.e., the remainder) males between ages 12 and 60.

At least three life-size dolls simulating infants under 2 months of age were also stipulated in the FAR's, but additional children under the age of 6 were substituted in the present study.

Crew Members. The six cabin attendants were furnished by United Air Lines. These stewardesses served as cabin crew members in the management of the passenger load. Three experienced male flight crew members were obtained from the Air Carrier Operations Section, FAA Academy, Aeronautical Center, and performed the duties of flight deck personnel.

Observation Methods. Cabin activity was recorded by four microphones equally placed in the hat rack, two on each side of the fuselage. Motion picture cameras, 16 mm., documented the evacuations from both interior and exterior. Personnel with stop watches were stationed outside each exit as a redundant system to the electric clocks in view of the cameras. Further observations were gathered from the passengers by a questionnaire and also by a group of 22 special interviews with passengers selected throughout the fuselage for specific information.

III. GENERAL TEST CONDITIONS.

Standard Procedures. The volunteers were told to report for a test on the SST, being given no further details. Consecutively numbered jackets were placed in each seat, by rows, front to rear, with jacket numbers 1, 2, 3, 4, 5, and 6 in seats 1A, 1B, 1C, 1D, 1E and 2A, etc.

A magnetic tape played music over the public address system while passengers loaded. This was replaced by a sound-effects tape, audible to both passengers and crew, for the test. It included approximately 15 minutes of engine-start and taxi-out noises and seven seconds of take-off thrust, as heard (and recorded) from inside the cabin of a jet aircraft. About seven seconds after the beginning of the take-off thrust, crash noises were heard on the sound tape to create as much realism as practical—although, of course, the physical sensations normally experienced while one is seated in a moving vehicle were lacking. The end of the crash noises served as the start signal for the crew to initiate the evacuation procedure.

During the taxi-out portion of the sound-effects tape, the "A" stewardess gave the regular passenger briefing and announcements, followed by a seat belt check. The door and window exit plugs were pushed open from inside the cabin and immediately removed by assistants stationed outside the mock-up exits. Therefore, exit opening time and methods of opening were not planned as a factor in this study.

Each test simulated an aborted take-off crash with wheels up. All tests were performed in daylight, with no baggage obstructions or visibility problems.

General Instructions to Crew Members. Crew members were briefed on the complete test plans so that their performance would not constitute a variable on the tests. The tests were designed to compare the efficiency of exits relative to width and height and to determine rates of passenger flow, with the same flight deck and cabin crew members participating in all tests. The public address and intracommunications systems were demonstrated to the crew members for their use during normal passenger briefing and emergency procedures.

The stewardesses were asked to conduct the evacuations in accordance with their company's training and policies, but to exercise their professional judgment as particular situations developed during the evacuations. Stewardesses' duties included the normal briefing of passengers for oxygen use, seat belt instructions, and flight destination information. No indication was given to the passengers of the events to come.

Duties of the male crew members were coordinated with those of the cabin attendants through pretest discussions. The Captain would leave his cockpit position after a short delay following the start signal and assist the evacuation from inside the forward cabin. The copilot's assignment was to expedite evacuation from outside the aircraft by soliciting the help of male passengers at exits and generally maintaining passenger flow away from exits on the outside. The flight engineer was instructed to leave the cockpit at the test signal and proceed aft inside the cabin as far as possible. This procedure was included to evaluate the ability of a crew member to move aft through the passenger flow and reach the rear door exit.

IV. TEST 1.

Conditions. The right side of the mock-up was equipped with four Type I and three Type III minimum-size exits, according to FAR 25.807(a) for a passenger seating capacity of 280. The exits were distributed in relation to passenger density and exit rating (passengers per minute). Access to Type I exits was provided by removal of the adjacent triple seat unit and the window seat adjacent to the Type III exits. Descriptions of the seven exits appear in Table I. There were no corresponding exits on the left side of the mock-up.

The basic purpose of Test 1 was to document escape patterns with the required combination of Type I and III exits that could be designed into large aircraft. These data were to be compared with those of a later test using the required number of Type A exits for a similar passenger load (Test 2), which could also be designed into large aircraft, shown in Table II.

TABLE I.–Exit type, dimensions, exit number, and step-down distances used in tests 1 and 1A

Seat Row Location	Type Exit	Exit Dimensions (inches)	Step-Down Distance (inches)	Exit Number
3 ft. forward, Row 1	I	24 x 48	16	1
Row 12	I	24 x 48	16	2
Row 25	I	24 x 48	7	3
Row 33	III	20 x 36	27	4
Row 40	III	20 x 36	27	5
Row 47	III	20 x 36	27	6
Row 55	I	24 x 48	7	7*

*This exit has a removable insert to provide either 48-inch or 60-inch door heights.

TABLE II.–Exit type, dimensions, exit number, and step-down distances used in tests 2 and 2A

Seat Row Location	Type Exit	Exit Dimensions (inches)	Step-Down Distance (inches)	Exit Number
Row 10	A	42 x 72	16	8
Row 30	A	42 x 72	7	9
Row 50	A	42 x 72	7	10

Following a short delay after the start signal, the Captain gave a prepared statement, "Get them out the right side—fire on the left!" over the public-address system. This indicated that passengers were to evacuate the mock-up through right side exits only. Stewardesses were seated on the forward and center jump seats, and in Seats 55B and 60B.

General Observations. There were wide variations in how clearly passengers heard and how accurately they interpreted the stewardesses' commands of "Grab ankles," and "Stay down until the plane stops." Statements made by the passengers indicated that even when commands were heard, they were difficult to interpret. This also applied to the later command, "Leg-body-leg." The commands seemed unfamiliar and/or unexpected, and, therefore, failed to elicit the expected responses from passengers. Apparently, the stewardesses' commands were not heard and/or understood more than eight rows of seats forward of the stewardess stations. Commands to the rear of these stations were audible for only three or four rows, depending upon such factors as bulkheads, passenger proximity to loudspeakers (from which crash sounds were coming), and how much the stewardess turned her head aft while giving commands. When the crash noises ceased, crew commands were more readily heard, as found in special passenger interviews.

Passengers in the area of Exit 2 (Row 12) were approximately 12 rows from either of the two nearest stewardess stations. Since they could hear neither stewardess clearly enough to follow directions, they immediately opened the exit and

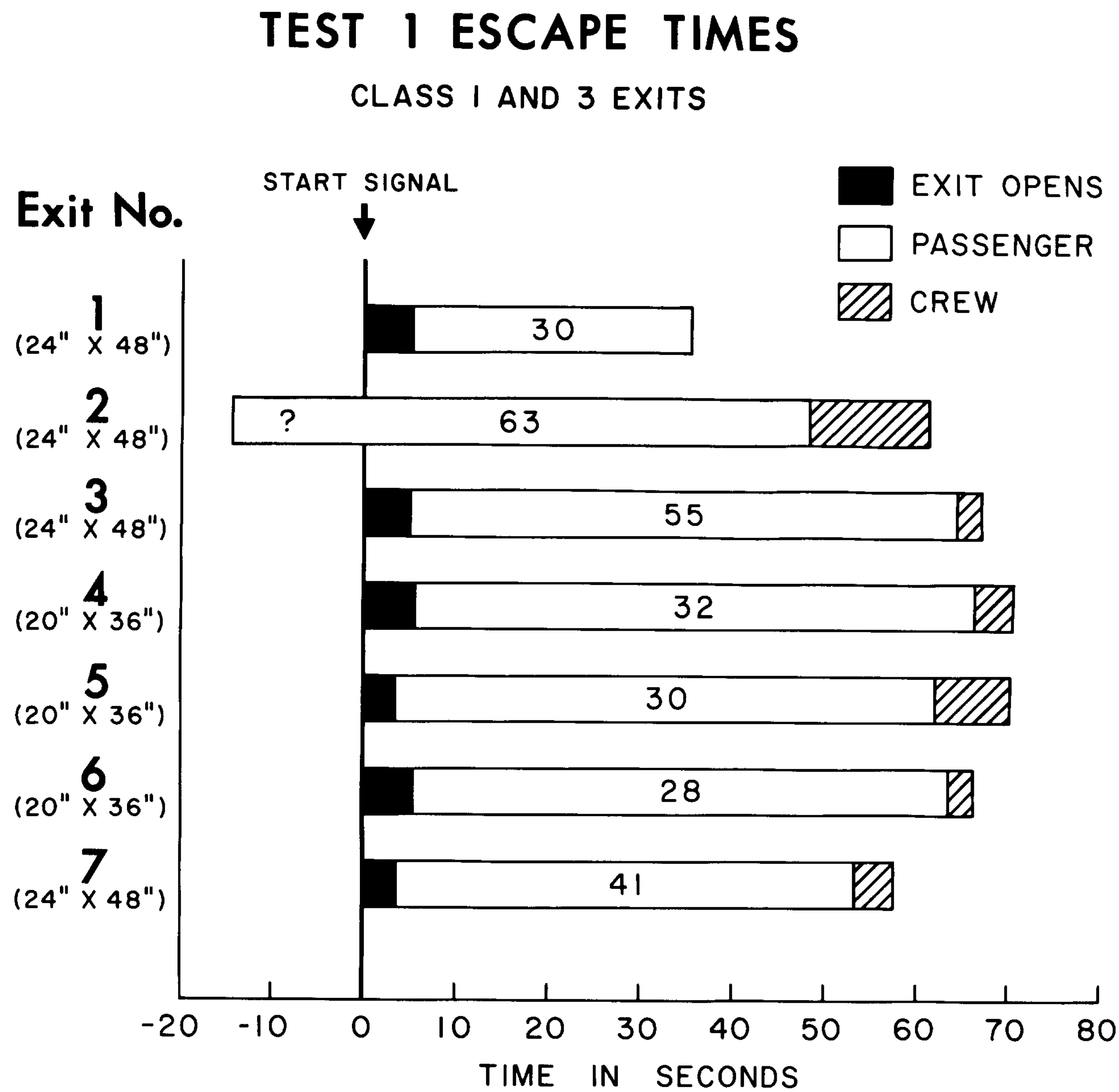


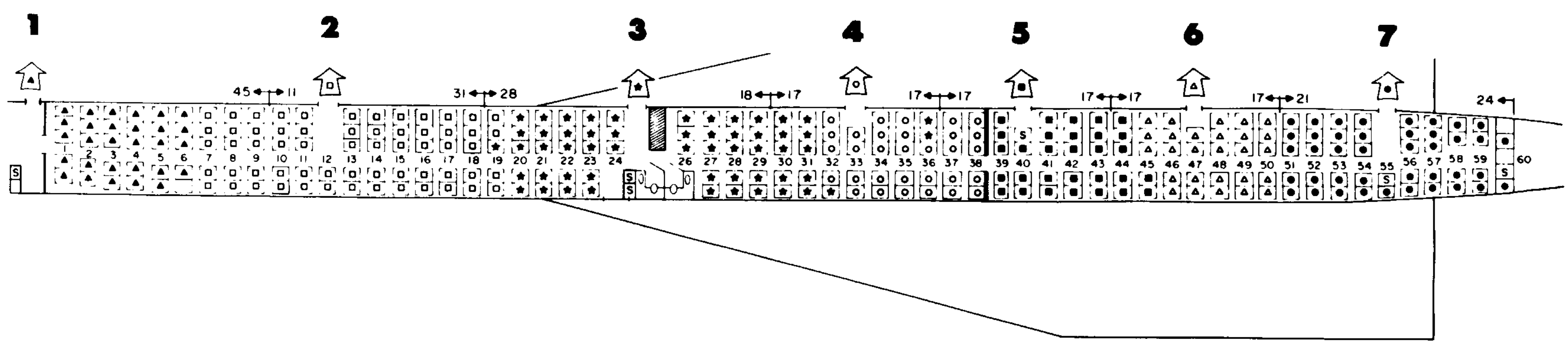
FIGURE 3. Escape times for Test 1 are shown for all seven exits. Number of passengers (excluding crew members) using each exit. Also shown—15 passengers evacuating during the crash sounds at Exit 2 within a 14-second time period before the start signal.

started evacuating when the crash noises began on the sound-effects tape. Fifteen passengers evacuated through this exit before the "C" stewardess effectively got the remaining passengers to "stay in your seats until the plane stops." At the other six exits used in Test 1, passengers remained in their seats until the crew gave directions to evacuate. Passengers assumed the brace-for-impact ("grab ankles") position only in the area of Exit 7 (aft cabin), apparently because the cabin attendants in seats 55B and 60B could be heard.

Passenger lines to all exits were continuous until evacuation was complete. However, at Exit 3, space between escapees occurred near the end as crew members redirected a group from the overwing window exits to Exit 3 to speed the evacuation.

TEST I

ALL RIGHT SIDE EXITS



1	▲	24"x 48"	16" step down
2	□	24"x 48"	16" step down
3	★	24"x 48"	7" step down
4	○	20"x 36"	27" step down
5	■	20"x 36"	27" step down
6	△	20"x 36"	27" step down
7	●	24"x 48"	7" step down

FIGURE 4. The passenger exit routes for Test 1 are shown by symbols indicating each exit. Step-down distances listed for the exits are from the window or door sills to the wing or ramp outside.

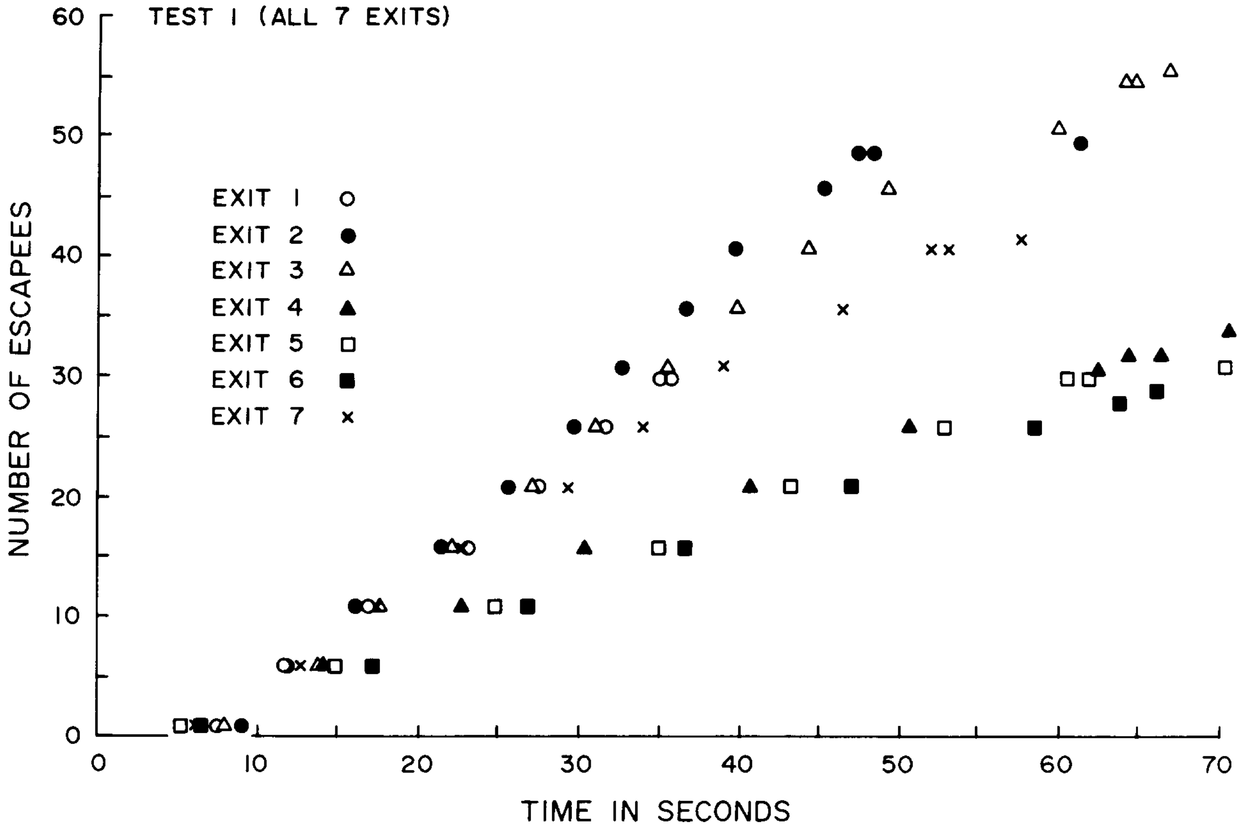


FIGURE 5. A plot of the number of escapees and time shows relationship of the seven exits in Test 1. Exits 4, 5 and 6 are window, overwing, exits with a 27-inch step-down to the wing surface which is evident by the rate of escapees for these Type III exits compared to the four Type I exits.

A noticeable lower number of passengers used the Type I exits located at each end of the cabin. Thirty passengers used Exit 1 and 41 used Exit 7 compared to 63 and 55 passengers for Type I exits 2 and 3, respectively.

Evacuation Times. All passengers and crew members evacuated the fuselage through the seven exits on the right side in 70.7 seconds, the last person, a stewardess, leaving at Exit 4. The last passenger was out in 66.6 seconds. Evacuation times for each exit are shown in Figure 3.

Exit-opening times (Figure 3) determined from the start signal until the exit was perceivably "cracked open", averaged 4.5 seconds, with a range of 3.2–5.0 seconds, for six of the seven exits (excluding Exit 2, prematurely opened). These exit-opening times are about 60% less than the average of 11–14 seconds found in an analysis of airline evacuation demonstrations performed for certification of various aircraft.

Flow Patterns. Passengers chose to use the nearest available exit for their routes of escape, the exceptions being those who were directed to other exits by crew members. All units, except Exits 3 and 7, maintained a fairly even and steady flow rate until all passengers were outside. Exits 3 and 7 had gaps between escapees near the end of the evacuation until some were directed to these exits from the lines back up at the window exits. Motion pictures of the evacuation tests revealed that crew members directed passengers to exits with shorter lines in their management of the evacuation. The passenger flow pattern and exit routes are shown in Figure 4. Moving aft, the flight engineer passed by Exit 3 during the 32nd second, from the start signal, and arrived at Exit 4 during the 39th second. After diverting a mother and two children from Exit 4 to Exit 3, he made his way aft and arrived at Exit 6, 51 seconds from the start signal. He gave assistance at Exit 6 until near the end of evacuation at which time he went out Exit 4.

Figure 5, an escapee-time plot of all seven exits, shows that the three window exits (Exits

4, 5 and 6) had slower flow rates. Among the four Type I exits, Exit 2 maintained the highest flow rate, with Exit 7 lagging slightly behind Exits 1 and 3. A further analysis of Test 1 flow rates (Table III) documents the evacuation times for three different time segments for the evacuation. Also, groups of 20 consecutive evacuees were timed during the evacuation at each exit to determine variations in flow rates as the evacuation progressed (Table IV).

TABLE III.—Flow rates at each exit in passengers per minute on test 1, calculated within 3 different intervals of the evacuation*

Exit Number	Passengers Per Minute: Start Signal to End of Evacuation	Start Signal to Last Passenger Out**	First Passenger In Exit to Last Passenger Out**
1	50.2	58.7	63.9
2	48.7	60.8	68.5
3	44.7	50.9	57.9
4	28.9	28.8	32.5
5	26.4	29.0	31.7
6	26.3	26.3	29.2
7	43.7	46.2	52.3

*Flow rate was determined by the number of escapees within each time interval and calculated for rate per minute.

**Excludes crew members.

TABLE IV.—Flow rates of segments of 20 passengers tabulated in passengers per minute to observe variations in the rate during the evacuation at each exit (Test 1)

Passenger Segment	Passengers per Minute — Exit Number: 1	2	3	4	5	6	7
1–21	59.97	72.29	26.47	36.10	31.47	29.48	51.79
6–26*	60.10				31.58	29.03	
11–31*				31.18			
21–41*		85.29	69.81				52.93
26–46*		77.17					
31–51*		49.02					

*The groups of 20 passengers were not chosen in consecutive order due to the small number of evacuees through an exit in some cases, resulting in overlapping of groups.

V. TEST 1A.

Conditions. The basic purpose of this test was to evaluate the effect of a 12-inch difference in door height (i.e., raised from 48 inches to 60 inches) for minimum standards on Type I exits. Door width remained the same (24 inches). Data obtained from this test supplemented other test data based on the same height difference under other conditions. Thus, the aft right exit (Exit 7 with a 7-inch step-down outside) was converted from 48 inches to 60 inches in height for Test 1A and passengers were reloaded who, a few minutes before, had evacuated the aircraft during Test 1. The exit plugs were previously removed and not used in the test.

All conditions for Test 1A were similar to those in Test 1, except that the passengers were instructed to use Exits 2 and 7 and the sound tape began running at take-off thrust, about one minute before the start signal. The objective was simply to evaluate the flow of a large number of passengers through two specific size openings.

General Observations. The egress lines moved steadily, with practically no gaps in the passenger flow. The copilot, assigned to assist outside, was the 62nd person out of Exit 2, and arrived at the aft exit as the 65th person was leaving. The fifth passenger, a man, out Exit 2 turned around and assisted other passengers out until the end of the evacuation. No passengers assisted at Exit 7 from outside.

Evacuation Times. The evacuation time for Exit 2 was 114.0 seconds (137 persons) and for Exit 7 was 112.1 seconds (133 persons) (Figure 6). Excluding crew members, the passenger evacuation times were 108.1 seconds (132 passengers) and 110.2 (130 passengers) for Exits 2 and 7, respectively.

Flow Patterns. Passenger separation occurred within Seat Rows 29 and 33 toward the two exits shown by the exit routes in Figure 7. The

TABLE V.—Flow rates of segments of 20 passengers tabulated in passengers per minute to observe variations in the rate during the evacuation at each exit (test 1A)

Passenger Segment	Passengers per Minute — Exit Number: 2	7
1–20	70.63	71.86
21–40	90.70	78.00
41–60	89.89	82.70
60–80	72.95	78.33
81–100	66.74	82.25
101–121	79.21	75.66
111–131*	86.10	
121–131*		72.20
	Average: 79.46	Average: 77.29

*The groups of 20 passengers were not chosen in consecutive order due to the varying numbers of evacuees through an exit in some cases, resulting in overlapping of groups.

"C" stewardess directed 20 passengers to the rear exit who had initially started toward Exit 2 from the center area of the cabin. The escape-time plot in Figure 8 shows similar rates for the two exits. Table V gives the variations in flow rates of groups of 20 passengers at intervals throughout the evacuation. Table VI lists the overall evacuation flow rates tabulated from the three points in the evacuation.

TABLE VI.—Flow rates at each exit in passengers per minute in test 1A, Calculated within 3 different intervals of the evacuation*

Exit Number	Passengers Per Minute		
	Start Signal to End of Evacuation	Start Signal to Last Passenger Out**	First Passenger In Exit to Last Passenger Out**
2	75.5	75.5	78.1
7	72.8	72.4	76.6

*Flow rate was determined by the number of escapees within each time interval and calculated for rate per minute.
**Excludes crew members.

It is noteworthy that the passenger flow rates for these same two exits in Test 1 were significantly lower (Table III), Exit 2 having an overall flow rate of 48.7 passengers per minute compared to 75.4 in Test 1A. Exit 7 increased similarly in flow rate from 43.7 to 72.8 in Test 1A. The apparent reasons for the increased rate in Test 1A, based on passenger and crew statements and on the motion pictures, are:

1. Passengers moved more vigorously in Test 1A.

2. The passengers' and crew members' previous experiences in Test 1 enhanced Test 1A flow rates.

3. Unbroken evacuee lines were maintained in Test 1A to each exit until the last person was out.

4. Crew members had more time, since the use of only two exits increased the total time, to direct passengers to balance the evacuee lines to both exits.

The 12-inch increase in height of Exit 7 (to 60 inches, compared to 48 inches at Exit 2) showed no significant influence on passenger flow rates, although the physical conditions of Exit 7 favored a high flow rate because of the greater height of the opening and shorter step-down distance outside (7 inches). Personal interviews and film evidence indicated that: (1) the vigor-

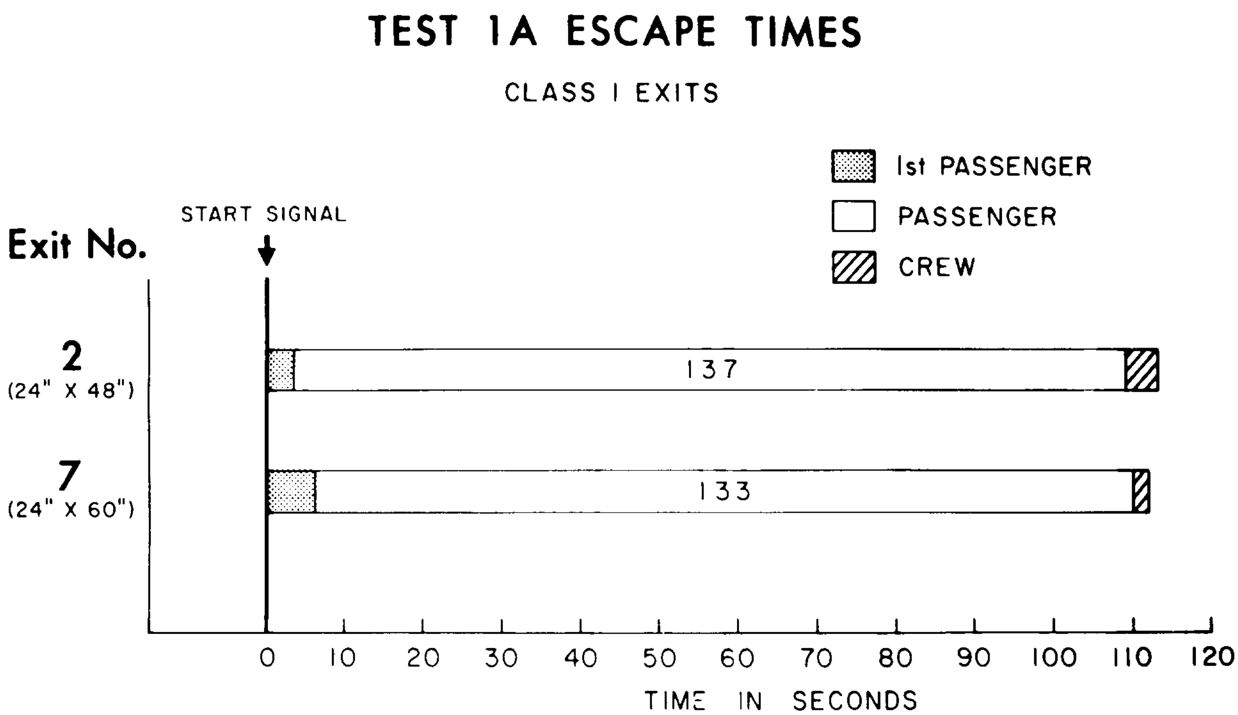


FIGURE 6. The number of passengers evacuating and a time graph of Test 1A (Exits 2 and 7) shows the similarity of two Type I exits, one 48 inches high (16-inch step-down) and the other 60 inches high (7-inch step-down) both 24 inches wide.

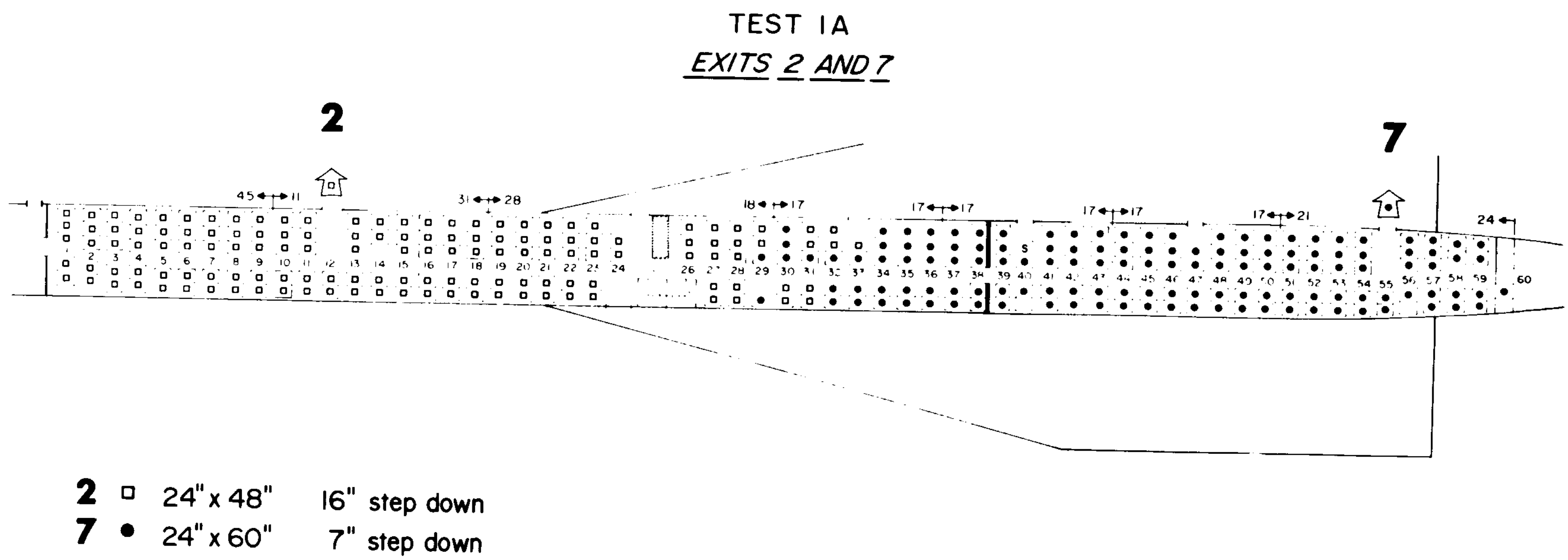


FIGURE 7. The passenger escape routes for Test 1A using Exits 2 and 7 shown by indicating symbols. Passengers split in the center cabin area within Seat Rows 29 through 33.

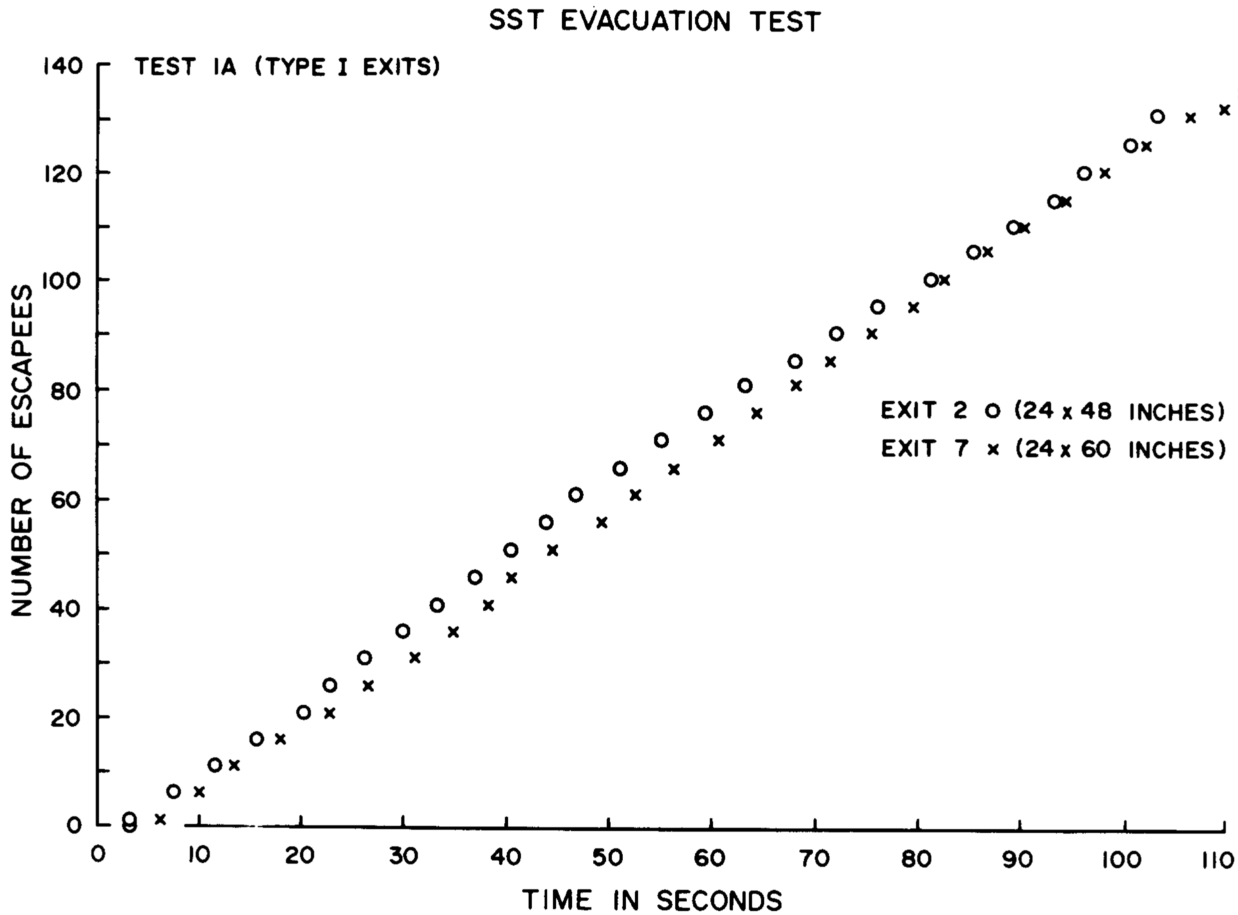


FIGURE 8. The escapee-time plot of Test 1A through Exits 2 and 7 shows very little difference in evacuation flow rates. The 12-inch difference in exit height was under evaluation in this test.

ous physical contact by the stewardess on each passenger at Exit 2 improved the egress rate; (2) passengers and crew had more experience and confidence resulting from Test 1; and (3) due to location, Exit 2 received escapees from two aisle directions for a longer period than Exit 7, which was located only four rows from the aft bulkhead.

The chart of time and number of escapees in Figure 8 shows the similar flow patterns at the two exits.

VI. TEST 2.

Conditions. The plan for Test 2 was to use all Type A (double width) exits for the evacuation and compare the efficiency of Type A exits with that of Type I exits (Test 1) under the same conditions. Another group of 280 passengers was recruited for Test 2, with the same passenger age and sex ratios as for Test 1. Stewardesses were seated on the three jump seats by each exit.

Three Type A exits are required for a passenger load of 280 according to the revised FAR 25.807(a)(7). This requirement defines the exit as a floor level opening with a minimum width of 42 inches and height of 72 inches. In addition, a 36-inch unobstructed passageway is required from the nearest main aisle. In Test 2, an additional 12-inch space was provided on each side of the Type A doors, at Exits 9 and 10, to permit crew members to assist passengers and not interfere with the stream of passenger flow. This additional "assist" space was not provided at the forward side of the door at Exit 8, as a condition under evaluation. A 12-inch space was provided aft of the Exit 8 opening. Table II and Figure 2 illustrate the Type A exit dimensions, locations, and step-down distances.

The test conditions changed from Test 1 were: (1) right-side exits were not usable (in contrast to left exits in Test 1); (2) seat units were removed on the left of Type A exits to provide the 36-inch passageway, and the right side seat units removed for Test 1 were reinstalled (Figure 2); (3) cabin attendant stations (public-address and intracommunications systems) were moved to the Type A exit locations; and (4) the Captain's emergency announcement was changed to "Get them out the left side—fire on the right!"

General Observations. After the experience gained from Test 1, the stewardesses conscientiously shouted their commands in unison during the crash sequence. The unison command, "Bend over, grab your ankles, stay in your seats until the plane stops," appeared to have been heard and understood better than the commands in Test 1, resulting in all passengers bending over into brace position. It was surprising to learn from special personal interviews that, even though all passengers assumed the brace position, many failed to hear the commands clearly. Some passengers apparently responded by copying others and not entirely by hearing commands.

Evacuation Times. Complete evacuation through the three Type A double-doors (42 x 72 inches) was accomplished in 47.4 seconds. Total

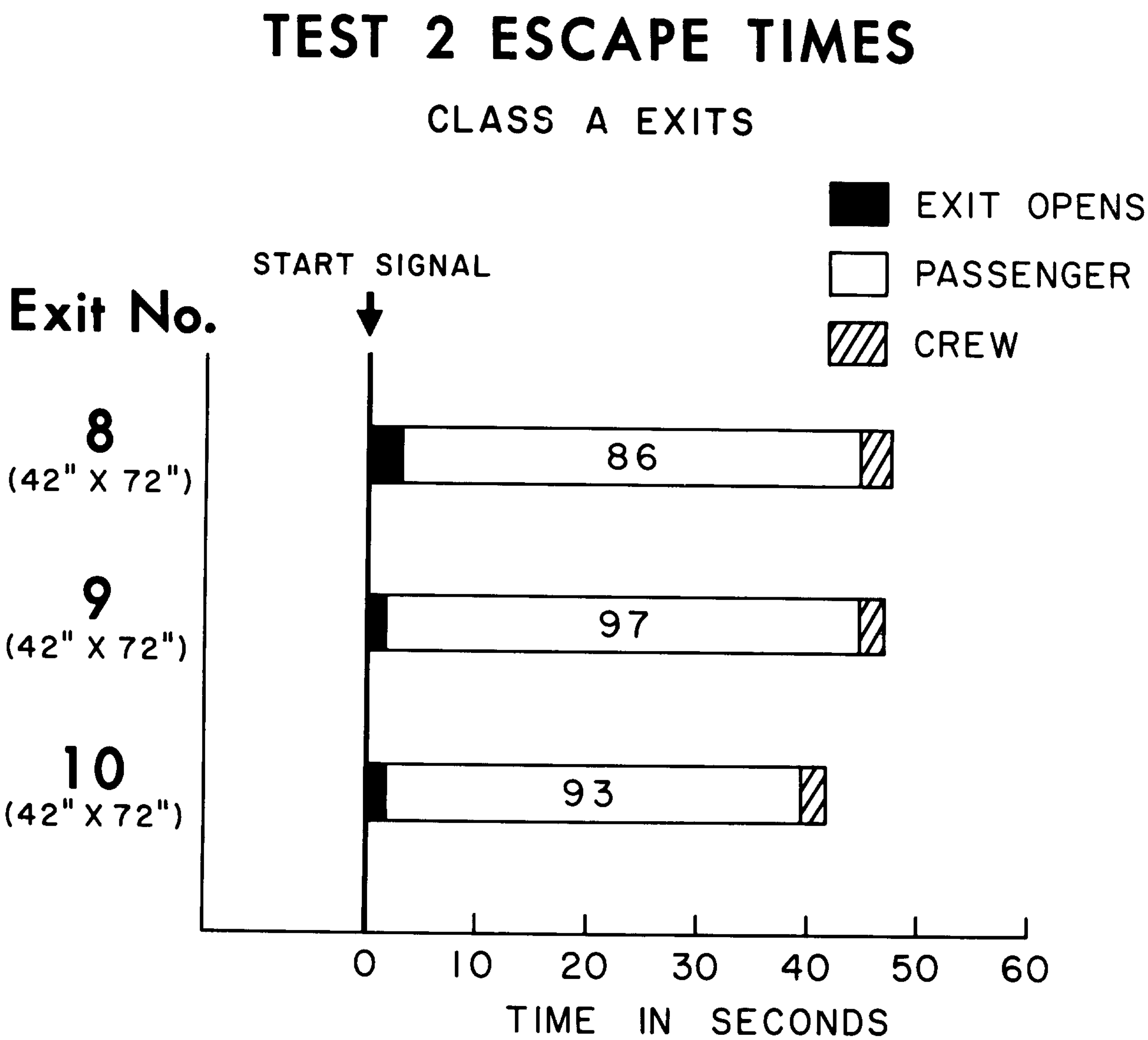


FIGURE 9. The comparative total evacuation times with numbers of passengers through each Type A double-door exit.

evacuation times for Exits 8, 9 and 10 were 47.4, 46.9 and 41.3 seconds. The last passengers (excluding crew) cleared each exit at 44.4, 44.6 and 40.1 seconds, respectively (Figure 9).

Flow Patterns. Under the conditions of the test, without escape chutes and in an ideal environment, the flow rates were 113.9, 126.7 and 138 passengers per minute (Table VII). The escapee-time chart (Figure 10) shows Exits 9 and 10 to have similar rates, each with a 7-inch step-down onto the wing surface. Exit 8, with a 16-inch step-down, had a slower flow rate, with approximately 14 fewer passengers evacuating per minute throughout the evacuation. Table VIII depicts variations in flow rate by timing groups of 20 passengers during the evacuation.

TABLE VII—Flow rates at each exit in passengers per minute in test 2, calculated within 3 different intervals of the evacuation*

Exit Number	Passengers Per Minute		
	Start Signal to End of Evacuation	Start Signal to Last Passenger Out**	First Passenger In Exit to Last Passenger Out**
8	113.9	116.1	134.6
9	126.7	130.5	142.4
10	138.0	139.2	156.0

*Flow rate was determined by the number of evacuees within each time interval and calculated for rate per minute.

**Excludes crew members.

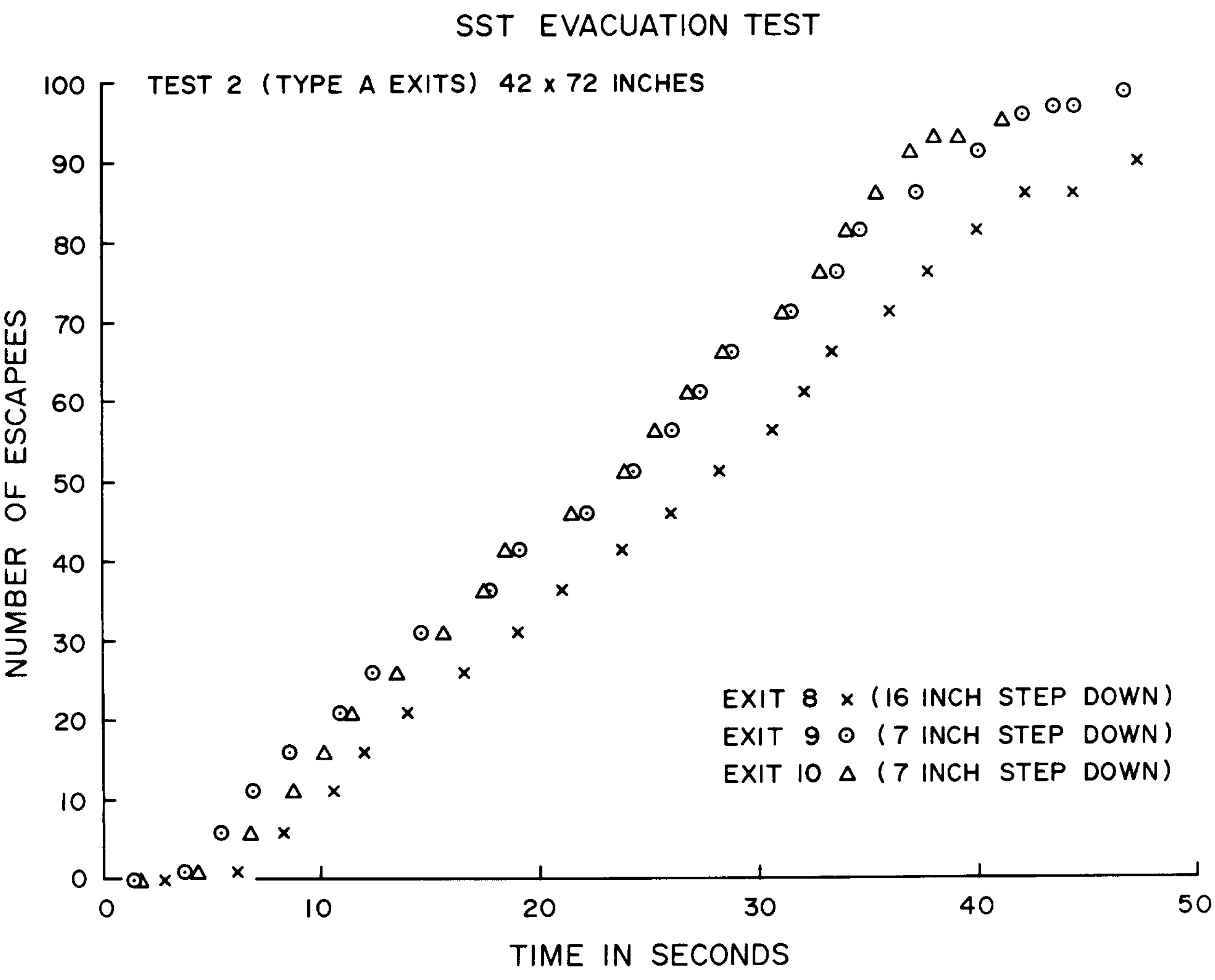


FIGURE 10. The number of escapee-time plot of Test 2 through three Type A door exits shows comparative efficiencies. The lag in evacuation rate of Exit 8 is apparently due to the highest step-down distance (16 inches) of the three exits and a slight passageway restriction by the forward stewardesses.

TABLE VIII.—Flow rates of segments of 20 passengers tabulated in passengers per minute to observe variations in the rate during the evacuation at each exit (Test 2)

Passenger Segment	Passengers Per Minute		
	Exit Number		
	8	9	10
1–20	155.6	168.8	170.7
21–40	120.7	146.9	170.0
41–60	143.2	144.8	144.1
60–80	152.3	162.8	163.0
66–86*	137.0		
71–91*		139.9	
76–96*			202.4

*The groups of 20 passengers were not chosen in consecutive order due to the varying numbers of evacuees through an exit in some cases, resulting in overlapping of groups.

During Test 2, Stewardess "D" left her seat by Exit 9 and immediately stood up in the right aisle seat (30C) as soon as the passenger occupant was out of the way. She accomplished her role in the evacuation by directing passengers coming from both directions to Exit 9 from this position. (Figure 11 shows her location, as well as escape routes of passengers.) An analysis of the motion pictures and personal interviews with passengers using this exit revealed that this on-the-seat position of the stewardess was effective for several reasons. First, she could be easily seen above passengers. Second, her instructions could be heard further down the aisle in both directions as she turned alternately fore and aft, continually giving commands interspersed with enthusiastic admonitions to "Get moving!," etc. Finally, from her position above the passengers, the stewardess could observe evacuee lines feeding the exit and thus more effectively control passenger movement.

Passengers at Exit 9, with only one stewardess at the double door, evacuated at a rate comparable to that at the other two Type A doors (Figure 10). However, an evacuation from a normal landing emergency with escape chutes in use was not conducted. Conclusions on the effectiveness of just one cabin attendant at a double-door in this condition would require further testing.

Other observations on passenger flow included the following: (1) positions of the three Type A exits proved good for effective passenger egress, as indicated by the steady, even flow from fore and aft aisles to each of the exits throughout the evacuation procedure, (2) under the existing ideal conditions, aisle width (minimum 15 inches) and seat pitch (34 inches) did not delay or directly affect the evacuation flow to the exits; no gaps occurred as passengers cleared the exits and a continuous line was maintained, (3) some evacuees entered the double door in the center, thereby creating a single door effect for a short interval of time. Table IX shows percentages of positions used in the doorway by passengers.

TABLE IX.—Percentages of passengers using the forward, center or aft portions of the double, 42-inch wide, type A door for egress through the opening. For study, the opening was divided into 3 portions. (Test 2)

Exit Number	Percentage of Passengers			Total No. Passengers Using Exit
	Section of Door Used			
	Forward	Center	Aft	
8	38	22	40	86
9	49	7	44	97
10	54	7	39	93

The stewardesses' positions at the three Type A exits were under observation. At the forward left Type A exit (Exit 8), an assist space was provided on the aft side of the door for the stewardess to conduct the evacuation. At the forward edge of the door (Exit 8), the seat backs of Row 7 were even with the forward edge of the door, with no assist space. The passageway between the two stewardesses working at the door was 32–34 inches, or 2–4 inches short of the required 36-inch passageway. At Exits 9 and 10 there was a 12-inch spacing at both fore and aft edges of the door opening. This allowed full 36-inch passageways to the exits between the two girls working at these positions. Twenty-two per cent of the passengers using Exit 8, compared to 7% of those using Exits 9 and 10 (Table IX), occupied the center position of the door opening for a short interval, thereby making it function essentially as a single door. Motion pictures showed that passengers were forced to the center of Exit 8 more frequently than at the other two doors because an assist space for the stewardess was not provided at the forward edge of the exit. Her position at this exit blocked a portion of the opening. The stewardess was backed up against the seat backs of Row 7, leaning backwards, trying to minimize her interferences with passengers moving into the door opening.

The flight engineer left his cockpit seat on the start signal after releasing his seat belt. He reached approximately Row 9 before passengers

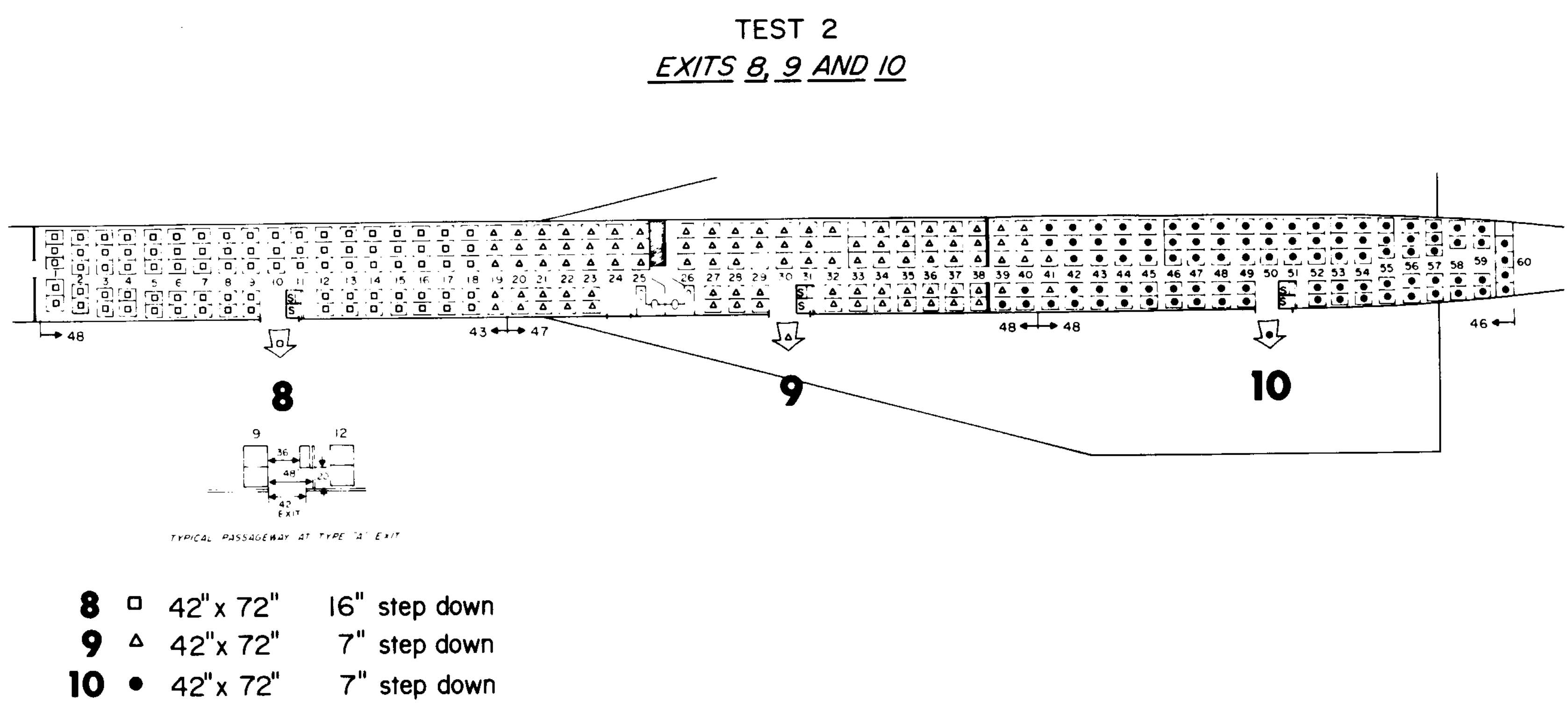


FIGURE 11. Egress routes are indicated by symbols on Test 2 through three Type A exits. Areas where passengers split for escape are shown at Rows 18 and 40.

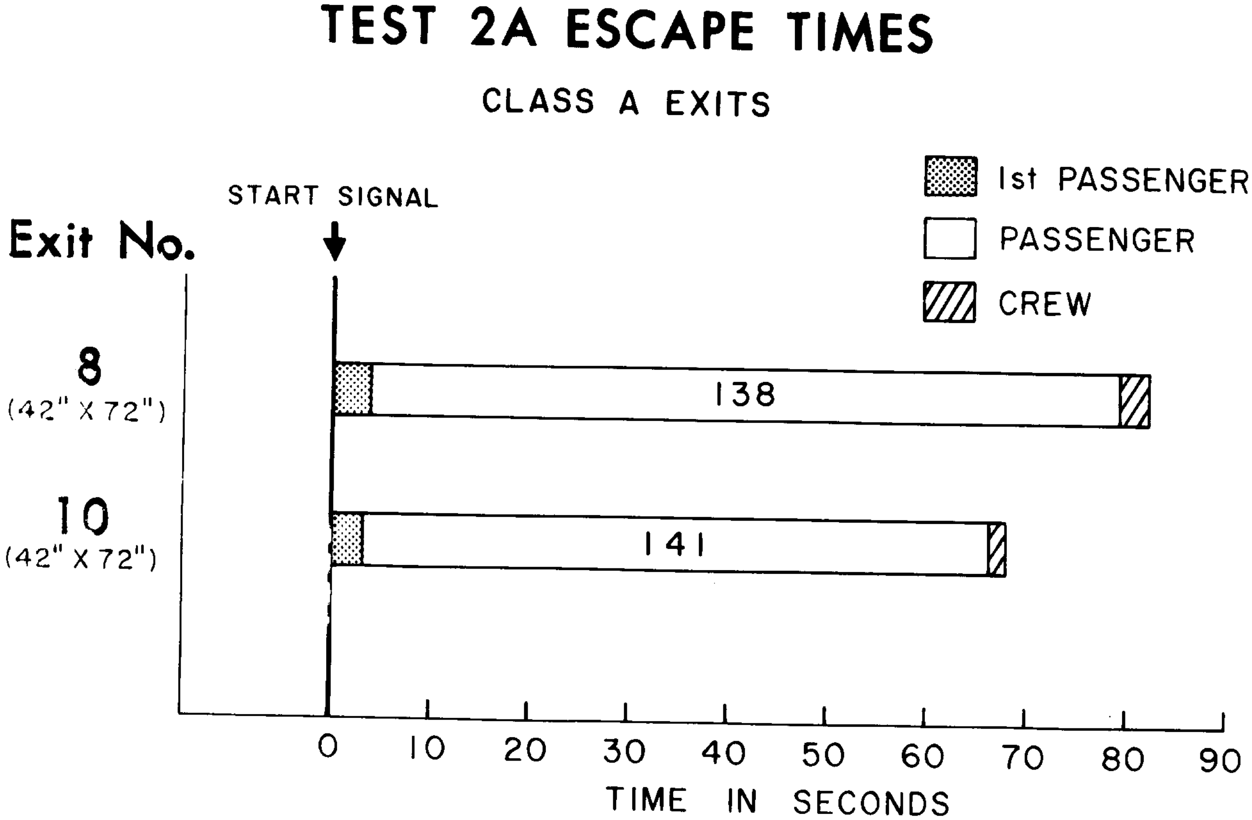


FIGURE 12. Total evacuation times of Test 2A are shown with numbers of passengers using each exit. Exit 8 had a 16-inch step-down; Exit 10 had a 7-inch step-down distance. The door plugs were left out for this test and time was taken when the first passenger appeared in the doorway from the start signal.

filled the aisle, causing him to continue his way aft by walking on the seats. He was able to reach Row 23 by the end of the evacuation (47.4 seconds from the start signal).

VII. TEST 2A.

Conditions. The fore and aft Type A exits (Exits 8 and 10, each located nine rows from the ends of the cabin) were used to evaluate what happens to the evacuation pattern when one line of passengers "feeding" the exits terminates before the other from a single-aisle configuration. Therefore, Exit 9 (center Type A exit), which would ordinarily be available during an emergency situation, was rendered inoperable for the test. The passengers who had just evacuated for Test 2 were reloaded and informed of the exits to be used during Test 2A.

General Observations. As a result of their experience in Test 2, passengers responded to crew direction very well. The test was conducted with the door plugs removed at the start signal for observation of continuous passenger flow rates with a large passenger sample.

The two stewardesses at each of the two exits directed the evacuation from positions on each side of their respective doors. There was no apparent restriction of passenger flow; however, as previously mentioned, the stewardess at the forward side of Exit 8 had insufficient standing space, resulting in a 34-inch passageway between the two stewardesses performing the evacuation. An analysis of passenger positions in the door opening, including the forward, center, or aft portions of the exit opening, showed that 50% of the passengers at Exit 8 and 40% of those at Exit 10 used the center portion during egress (Table X). These percentages partially reflect the fact that the exits were being fed from only one aisle direction during the last of the evacuation, thus functioning as a single door. Utilization of Exit 8 as a single door was comparatively higher, apparently due to the slight restriction of the passageway between stewardesses at the door.

TABLE X.—Percentages of passengers using the forward, center or aft portions of the double, 42-inch wide, type A door for egress through the opening. For study, the opening was divided into 3 portions. (Test 2A)

Exit Number	Percentage of Passengers — Section of Door Used: Forward	Center	Aft	Total No. Passengers Using Exit
8	29	50	21	138
10	31	40	29	141

Evacuation Times. The total evacuation time for Test 2A was 81.8 seconds. One cabin attendant did not participate in Test 2A because of an injury sustained in a fall outside the mock-up at the end of Test 2. The last passenger passed through Exit 8 at 79.2 seconds. Total evacuation time through Exit 10 was 67.8 seconds, with the last passenger out in 66.1 seconds (Figure 12). An escapee-time plot is presented in Figure 13.

Flow Patterns. The evacuation flow rate in Test 2A is of interest because exits were located nearer the ends of the cabin than in previous tests. The average flow rates for Exits 8 and 10, in passengers per minute, were 104.1 and 127.5 seconds, respectively (Table XI). The difference

TABLE XI.—Flow rates at each exit in passengers per minute in test 2A, calculated within 3 different intervals of the evacuation*

Exit Number	Passengers Per Minute — Start Signal to End of Evacuation	Start Signal to Last Passenger Out**	First Passenger In Exit to Last Passenger Out**
8	104.1	104.5	109.7
10	127.5	128.1	134.2

*Flow rate was determined by the number of evacuees within each time interval and calculated for rate per minute.

**Excludes crew members.

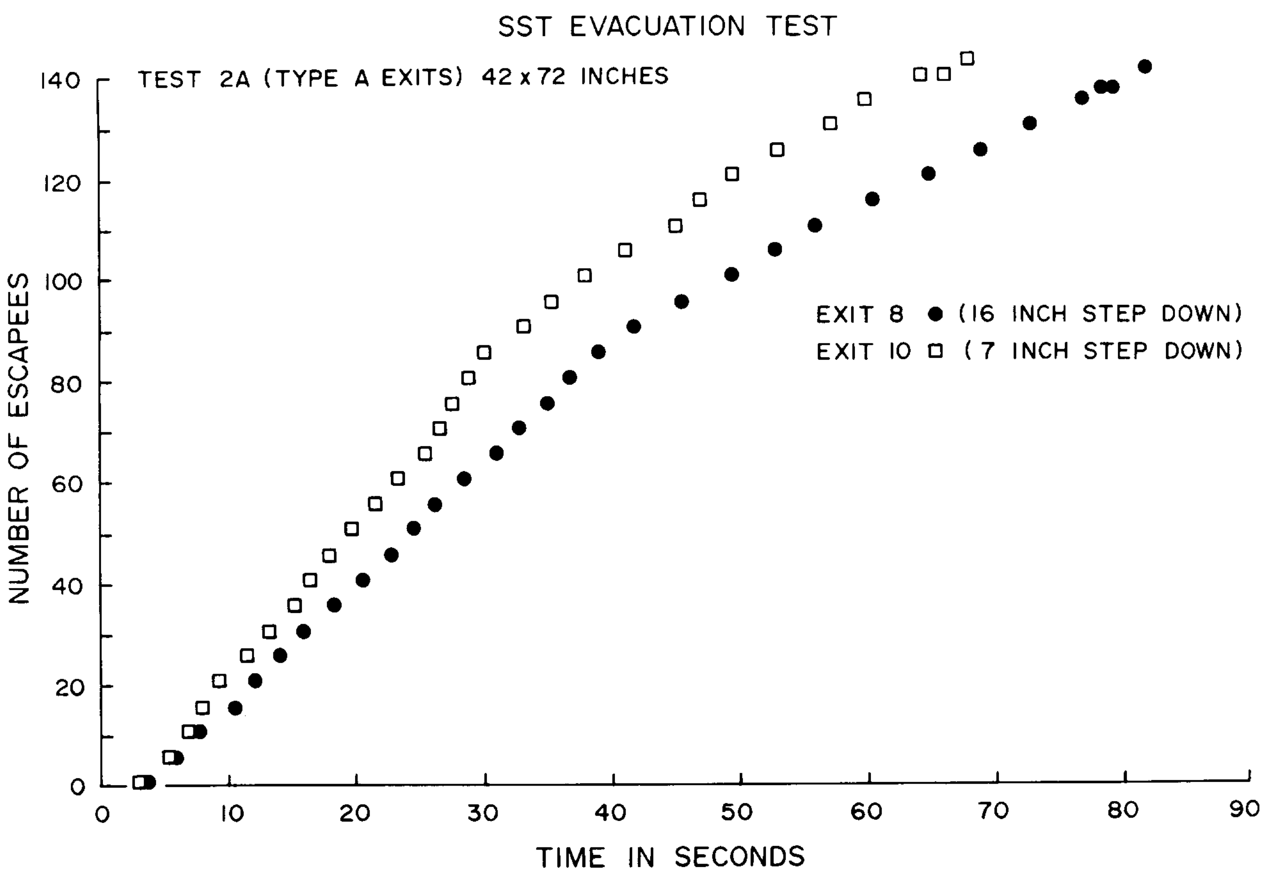


FIGURE 13. The escapee-time plot on Test 2A shows effects of the 16-inch step-down at Exit 8 and where the exits began to be fed with evacuees from only one aisle at approximately the halfway point during the evacuation.

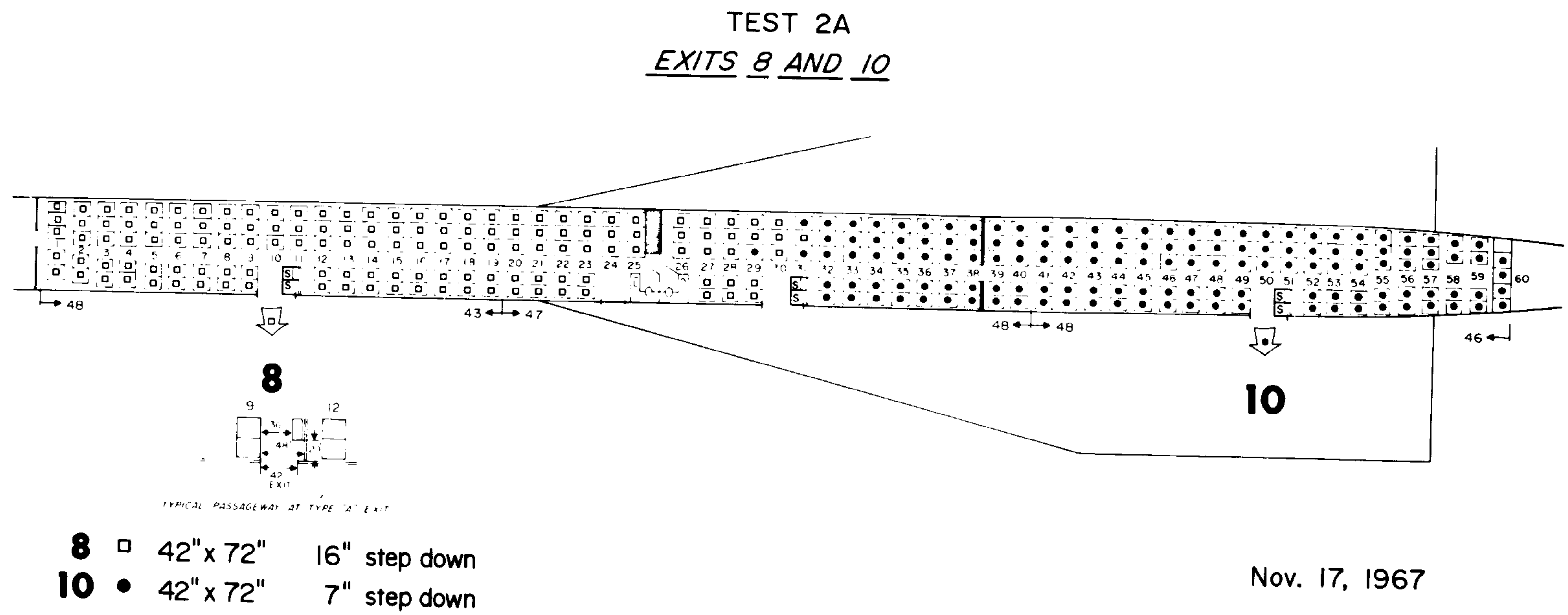


FIGURE 14. The escape routes are shown by symbols for each passenger on Test 2A. The dividing line for the escape was almost the center cabin (Row 31) for the two exits.

in flow rates was apparently due to the step-down distance being 16 inches outside the fuselage at Exit 8, and only 7 inches at Exit 10.

An escapee-route flow pattern for Test 2A appears in Figure 14. The passenger load divided at Row 30, the center of the cabin, to the two exits. Figure 13 escapee-time plot shows decreases in the flow rate after about 40 seconds, when one of the passenger lines to the exits ended, leaving a single-line flow. This decrease in flow rate is shown in Table XII, in the analysis of groups of 20 passengers tabulated for the evacuation in passengers per minute.

TABLE XII.—Flow rates of segments of 20 passengers tabulated in passengers per minute to observe variations in the rate during the evacuation at each exit (Test 2A)

Passenger Segment	Passengers Per Minute — Exit Number 8	Passengers Per Minute — Exit Number 10
1–20	142.2	192.3
21–40	144.4	167.6
41–60	150.7	174.7
60–80	143.0	212.8
81–100	95.2	133.0
101–120	77.6	104.4
116–136	73.2	
121–141		72.3

NOTE: The groups of 20 passengers were not chosen in consecutive order due to the varying numbers of evacuees through an exit in some cases.

VIII. DISCUSSION.

Tests 1 and 2 provide a direct comparison of the effectiveness of Type I (single) and Type A (double) minimum-size exits under similar conditions. The test conditions were ideal, without problems of visibility, baggage in the escape routes, escape slides, aircraft attitude (flat belly landing) or many other factors encountered in actual crashes. In theory, at least, introduction of one or more of these encumbrances within the same environment would increase evacuation times over those obtained in these tests.

In all tests, many passengers failed to hear and comprehend the stewardesses' commands above the "crash noises" being played on the public-address system. Passengers in some areas of the long SST cabin, located between stewardess stations, heard overlapping commands. Commands during Test 2 were shouted in unison by the girls, sitting together on jump seats by the Type A exits. The words "bend over" were added to the command "grab ankles" for the impact/brace position; this addition to the command phrase solicited full passenger response. Evidence from motion picture film shows all passengers in brace position during most of the crash-sound period. Personal interviews revealed that some assumed the brace position from the example of others.

The average flow rate of the four Type I exits in Test 1 was 46.8 passengers per minute, individual rates ranging from 43.7 to 50.2 passengers per minute. In contrast, the average flow rate of the three Type A exits in Test 2 was 126.2 passengers per minute, ranging from 113.9 to 138.9 (Tables III and VIII). From these rates, the comparative passenger egress ratio is calculated to be 1 to 2.69 for Type A and Type I exits, respectively, based upon the total test times. Excluding crew members, the same ratio was 1 to 2.37.

For Test 1A, in which reloaded passengers evacuated their second time, the flow rate increased by 37.5% in passengers per minute. Comparatively, the rate in Test 2A increased only 13% during the time the door was fed from both aisle directions. After passenger flow from one aisle direction ended, the rate decreased to nearly one-half because of the single-row effect of evacuees using Type A exits. Increases in both tests are attributed to passenger experience and confidence from the previous tests.

A comparative escapee-time chart (Figure 15) presents exit times for Exits 2 and 8 from all four tests. Both of these exits had a 16-inch step-down outside the fuselage to a ramp with

TABLE XIII.—An aggreagate listing of evacuation times from all four tests with number of passengers and crew evacuating from each exit

Exit Number	Test Number	Total Time (seconds)	Number Passengers	Crew
1	1	35.7	30	IM*
2	1	61.5	48	1F
2	1A	113.1	137	3F–3M
3	1	67.1	55	2F
4	1	70.7	32	2M
5	1	70.4	30	1F
6	1	66.2	28	1F
7	1	57.7	41	1F
7	1A	112.1	133	3F
8	2	47.4	90	2F–1M
8	2A	81.8	142	2F–3M
9	2	46.9	99	2F
10	2	41.3	95	2F
10	2A	67.8	144	3F

*Male crew member in passenger line.

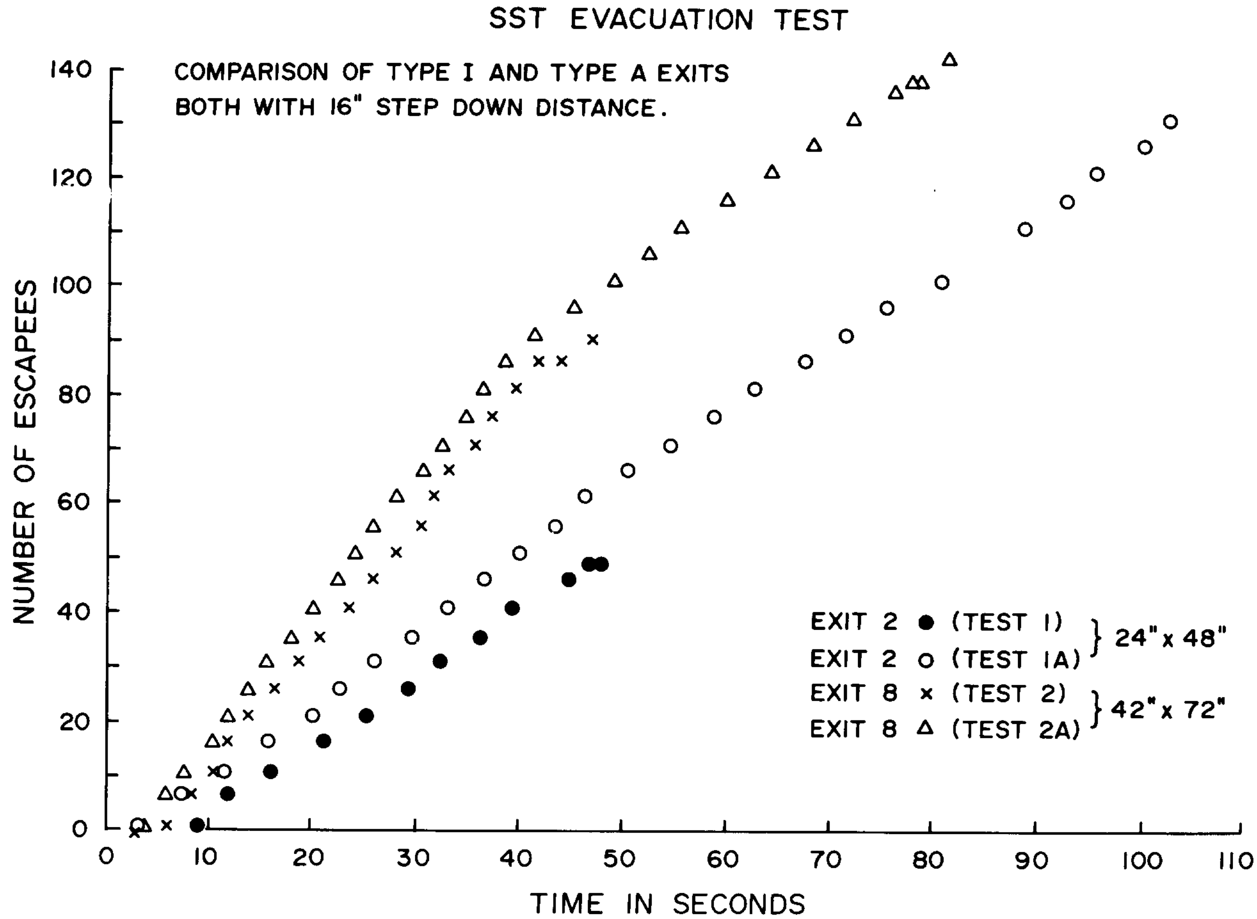


FIGURE 15. A Type I (Exit 2) and a Type A (Exit 8) door from all four tests are plotted together for direct comparison of flow rates during evacuations. Step-down distance was 16 inches.

minimum required openings for Type I exits (24 x 48 inches) and Type A exits (42 x 72 inches).

An aggregate table of times and the number of passengers and crew using each exit is given in Table XIII. Door-opening times were simulated and were not considered too realistic for actual conditions, but merely to help create the atmosphere and environment desired.

IX. CONCLUSIONS.

Because of the inaudibility of verbal communications during the crash sequence, emergency public-address systems need to be considered and studied for use in large aircraft with high passenger-seating capacities.

Commands should be informative, concise, clearly spoken, and readily interpretable by passengers not familiar with emergency procedures.

Crew "assist" spaces are an important consideration at Type A doors to allow crew members to remain out of the required 36-inch passageway for passenger egress during evacuation. Locations of Type A exits in an aircraft should provide ample cross-aisles or routes to maintain two continuous lines from two different sources, thus adequately feeding the two openings.

Passenger flow rates through Type I exits of 48-inch and 60-inch heights did not show a significant difference in this study (and in others), to indicate a change in the minimum Type I door height requirement.