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AIRCRAFT EVACUATIONS: COMPETITIVE EVACUATIONS IN CONDITIONS OF NON-TOXIC SMOKE

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ABSTRACT

In 1987 the United Kingdom Civil Aviation Authority (CAA) commissioned Cranfield Institute of Technology to conduct a programme of research into passenger behaviour in aircraft emergencies. The results from the programme suggested that passenger motivation and changes to the configuration in the cabin adjacent to the exits, would influence the rate at which passengers would be able to evacuate the aircraft in an emergency (Ref 1).

In 1989, the CAA extended the programme of evacuation research at Cranfield to include a preliminary investigation of the influence of the presence of non-toxic smoke in the cabin. The results from the experimental programme indicated that the presence of non-toxic smoke in the cabin significantly reduced the rate at which volunteers were able to evacuate the aircraft. The initial results also appeared to indicate that in the presence of non-toxic smoke, changing the configuration of the cabin adjacent to the exits may influence the rate at which passengers are able to evacuate an aircraft in an emergency (Ref 2).

In this paper a further investigation is reported in which the influence of changes to the cabin configuration adjacent to the exits to the ability of volunteers to evacuate an aircraft cabin was investigated. In this study, non-toxic smoke was present in the cabin and passengers were motivated to compete with one another in an attempt to simulate an emergency situation. It was found that as the width of the aperture between the bulkheads was increased the rate of egress tended to increase, although the differences did not reach statistical significance. However, a significant difference in egress rates was found when four alternative vertical projections between seats adjacent to a Type III exit were tested.

The results from this programme of evacuations were compared with those from the non-competitive evacuations previously performed in non-toxic smoke. The presence of a competitive element was found to have had a significant effect upon egress rates for the evacuations through the bulkhead, whilst the competition did not effect the evacuation rate through the Type III exit. In the latter case, the four vertical projections between seats were found to explain the differences in escape times. Additional analyses were performed upon items derived from the questionnaires administered to participants. It was found that adoption of an escape strategy did not aid egress rates and that volunteers mainly relied upon the sense of touch to assist in their evacuation of the aircraft.

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1 INTRODUCTION

1.1 Background

In 1987 the United Kingdom Civil Aviation Authority (CAA) commissioned the Cranfield Institute of Technology to conduct an experimental programme of research into passenger behaviour in aircraft emergencies. The main objective was to investigate the influence of changes to the cabin configuration adjacent to the emergency exits on the rate at which passengers could evacuate a stationary aircraft. The configurations investigated included a range of widths for the passageway through the bulkhead leading to floor level exits, and a range of seating configurations adjacent to a Type III overwing exit. The configurations were evaluated: (a) when passengers were competing to evacuate the aircraft, as can happen in an accident when the conditions in the cabin become life threatening; and (b) when passengers were evacuating in an orderly manner as occurs in aircraft certification evacuations and in some precautionary evacuations and accidents.

When the influence of changes to the width of the aperture between the bulkheads was evaluated, the data suggested that the blockages known to occur in some emergency evacuations, can be significantly reduced when the passageway through a bulkhead is increased from 20" to 30". The minimum seating configurations specified by the Civil Aviation Authority in Airworthiness Notice No 79 in 1986 were shown to have significantly increased the rate at which passengers can evacuate through Type III overwing exits in an emergency. Blockages at the overwing exit were also found to occur in evacuations involving a three inch vertical projection between the seats (a pre-AN79 configuration). The six inch vertical projection with the outboard seat removed (an AN79 configuration) led to a rapid evacuation flow rate but had a tendency to give rise to blockages and the opening and disposing of the exit was found to be more difficult in this configuration. The results suggested that the optimum distance between the seat rows bounding the exit would involve a vertically projected distance between the seat rows of between 13" and 25".

A report in which a description of the methodology and results obtained from the programme was published in November 1989 (Ref 1).

In 1989, the CAA extended the programme of passenger evacuation research. They commissioned a preliminary programme of evacuation trials to investigate the influence of the presence of non-toxic smoke in the cabin on the rate at which passengers could evacuate an aircraft.

Concern was expressed by members of the Cranfield Ethics Committee and the CAA Fire Service that volunteer members of the public could panic on finding themselves in smoke on an aircraft. For this reason, it was decided that in the initial investigation volunteers should be instructed to evacuate as quickly as possible but that no incentive payments would be made.

The results from these evacuations indicated that the presence of non-toxic smoke significantly reduced the rate at which volunteers were able to evacuate the aircraft (Ref 2). In these evacuations, although the volunteers were instructed that their primary task was to evacuate the aircraft as quickly as possible, they moved through the cabin to the exits in an orderly manner. There were no instances of people pushing past others and blockages at exits caused by people trying to egress as quickly as possible. The earlier series of evacuations without smoke or competition had produced a similar behaviour pattern. There were no instances of volunteers from the public showing panic in the smoke.

In 1990 the CAA commissioned Cranfield to conduct an additional series of evacuations with a smoke filled cabin in which a system of bonus payments was used in order to increase the individual motivation of the volunteers to get out of the aircraft as quickly as possible. This was done in an attempt to simulate the behaviour which can occur in an accident when conditions in the cabin become life threatening.

1.2 Objectives

(a) To determine the influence of increasing the width of the passageway through the floor to ceiling bulkhead leading to Type I exits, on the time taken for passengers to evacuate the aircraft when they are competing to egress from a non-toxic smoke filled cabin.

(b) To determine the extent to which an increased distance between the seat rows adjacent to the overwing exit, or the removal of the outboard seat beside the overwing exit, would improve the rate at which passengers could pass through the exit when they are competing to egress from a non-toxic smoke filled cabin.

2 METHOD

2.1 Research Design

The Trident Three aircraft permanently sited on the airfield at Cranfield Institute of Technology, used in previous investigations for the CAA, was also used for the evacuations reported here. Volunteers from the public were recruited in groups of approximately 40 to take part in evacuations from the Trident. The aircraft provided an element of realism which was considered necessary and had a similar cabin layout to many of the narrow bodied aircraft in operation at the time of the investigation.

2.1.1 *Evacuations through the Bulkhead*

The following configurations were assessed:

(i) A bulkhead which is typically seen on aircraft, a width between the galley units of 24" (61cm);

(ii) A width between the galley units of 30" (76cm);

(iii) A width between the galley units of 36" (91cm);

(iv) Port galley unit totally removed (72" or 183cm).

The configurations are illustrated in Appendix A.

The flow of volunteers through the bulkhead was of prime importance in the evaluation of the optimum width between the galley units. It was therefore essential that the number of volunteers attempting to reach the bulkhead was not influenced by a blockage at an exit downstream of the bulkhead. Consequently, both of the port Type I exits forward of the vestibule were utilised in all of the evacuations through the bulkhead (See Appendix C).

In order to direct the volunteers in a way which would ensure that the only restriction to the rate of evacuation was that of the aperture between the bulkheads, a member of cabin staff was positioned in the vestibule area forward of the bulkhead to enable passengers to be directed to the exits.

To avoid any interaction between the seating configuration at the overwing exit and the evaluation of the impact of the width between the bulkheads, the seating layout throughout the aircraft remained constant during all of the evacuations through the bulkheads.

The behaviour of passengers using evacuation chutes and their associated flow rate was not within the scope of this investigation. The use of ramps, rather than chutes, eliminated this variable from the design. It also removed the risk of volunteers being injured whilst using a chute.

2.1.2 *Evacuations through the Type III Overwing Exits*

In 1986 the CAA introduced Airworthiness Notice No 79 in which it was stated that two alternate minimum requirements would apply to the seating beside the overwing exit (Ref 3). The following seating configurations adjacent to the Type III Exit were assessed, including both Airworthiness Notice No 79 configurations.

(i) The CAA standard in Airworthiness Notice No 79 paragraph 4.1.2 (Ref 3) in which 'Seats may only be located beyond the centre line of the Type III exit provided there is a space immediately adjacent to the exit which projects inboard from the exit a distance no less than the width of a passenger seat and the seats are so arranged as to provide two access routes between seat rows from the cabin aisle to the exit'. In the research programme the seat row adjacent to the exit had the outboard seat removed and the seat rows fore and aft of the Type III exit were at a seat pitch of approximately 32" (81.2cm), with the vertical projection between the seat rows being 6" (15.2cm).

(ii) The CAA standard, specified in Airworthiness Notice No 79, paragraph 4.1.1 (Ref 3), in which 'All forward or aft facing seats are arranged such that there is a single access route between seat rows form the aisle to a Type III exit, the access shall be of sufficient width and located fore and aft so that no part of any seat which is beneath the exit extends beyond the exit centre line and the access width between seats vertically projected, shall not be less that half the exit hatch width including any trim, or 10", whichever is the greater'. In the research programme the seats fore and aft of the Type III exit were at a seat pitch of approximately 39" (99 cm), with the vertical projection between the seat rows being 13" (33cm).

(iii) A configuration in which the access to the exit between the seat rows vertically projected was approximately 18" (46.1cm), with a corresponding seat pitch of 44" (111cm).

(iv) A configuration in which all of the seats located in line with the exit were removed, leaving a pitch of approximately 60" (152cm) between the seats fore and aft of the exit. The resultant vertical projection between the seat rows was 34" (86.3cm).

The configurations are illustrated in Appendix B.

2.2 Equipment

The modifications which were made to the structure of the Trident Three aircraft in order to make it a suitable test vehicle for the previous series of evacuations (Ref 1) were retained.

These included the removal of the port galley unit and the introduction of wooden sections which allowed the four bulkhead widths under consideration to be produced. Modifications to the overwing hatch included bringing its height to the minimum standard (43") and installing a lower handle to the inside of the hatch to enable the operator to open the exit as quickly as possible.

On all civil aircraft, individual blocks of seats (three on the Trident aircraft) are positioned on tracks on the floor. It was therefore possible to manoeuvre the seats adjacent to the overwing exit along the tracks on the floor in order to achieve the correct vertical projection for three of the four seating configurations. To achieve the CAA standard specified in Airworthiness Notice No 79, in which the seat row beside the exit must have the outboard seat removed (configuration (i)) a double seat unit was constructed. The unit was located on a metal base which provided stability together with the correct vertical projection.

The seat back strength on the rows adjacent to the exit was increased to a standard higher than the minimum specified in Airworthiness Notice No 79. Additionally, the webbing and springs supporting the cushions were covered by a diaphragm. These steps were taken to prevent the risk of injury to volunteers caused by either the seats being broken or by people falling between the support webbing in their attempts to egress.

In order to allow comparisons to be made with the previous series of evacuations the seats available for the volunteers were restricted to the aft cabin, with the seven rows at the rear of this section of the aircraft being boarded off. 'Passengers' were therefore seated between rows 8 and 19 (see Appendix C).

The alterations which were made to the structure were designed to be as unobtrusive as possible. The modifications to the bulkhead and the false wall at the rear of the cabin were decorated in order to resemble the original aircraft decor. Additionally, the double seat unit utilised in the evaluation of the configuration adjacent to the Type III exit was constructed from Trident seating stock.

In addition to the modifications to the structure of the aircraft, exit ramps were constructed on scaffolding which enabled subjects to evacuate quickly and safely. The ramps were mounted on the port side of the aircraft, outside both the Type I doors and the Type III exit. Hand rails and a non-slip surface were utilised on each ramp in order to reduce the risk of injury to disembarking passengers.

Audio equipment was installed on the Trident which allowed the aircraft engine sounds and instructions from the 'captain' and 'cabin staff' to be relayed to the volunteers. In order to identify individual volunteers on the video recordings, and to be aware of their seat location prior to the evacuation, white cotton vests were worn by volunteers throughout the evacuations. Each vest was stencilled with a number which indicated the seat to which they had been allocated for that evacuation.

The non-toxic smoke was produced using three generators, two located at the rear of the cabin and one in front of the starboard galley unit. These were operated until a relatively homogenous visual environment with an optical density of approximately 0.5 per foot had been obtained. An optical density of 0.5 per foot is calculated to be the density that occurs during fires associated with a maximum survivable temperature for a period of 90 to 120 seconds (Refs 5 & 6).

Two heat sensitive cameras were employed in order to monitor the progress of volunteers through the cabin in the smoke and to enable members of the research team to rapidly locate and assist any volunteers experiencing difficulties.

2.3 Procedure

Volunteers were recruited in groups of approximately forty to take part in each experimental session which comprised four evacuations from the Trident aircraft. In two of the evacuations, all of the volunteers passed between the bulkheads and evacuated from the aircraft through either of the two Type I exits. In the other two evacuations, all of the volunteers evacuated through the port Type III overwing exit. The four bulkhead configurations at the entrance to the vestibule area and the four seating configurations adjacent to the overwing exit were each tested on eight occasions. The test programme involved sixteen separate test days with four evacuations on each day. In order to account for the possible effect of practice, the order in which the configurations under review were tested was systematically varied using a counterbalanced design. The volunteers were told that they would be required to take part in some evacuations from the aircraft, in conditions of non-toxic smoke. However, they were not given any information about the configurations under review, nor the order in which the evacuations would be performed.

The volunteers were members of the public. Recruitment was done via local advertising and all volunteers were paid a £10 attendance fee after they had completed the four evacuations. The volunteers were instructed that their task was to evacuate the aircraft as quickly as possible once the exits had been opened by the Cranfield staff. In addition, a £5 bonus was paid to the first 75% of the volunteers to pass through the exits which were used on each evacuation. In the previous series of competitive evacuations conducted for the CAA in clear air (Ref 1) bonus payments had been made to the first half of the volunteers to evacuate the aircraft. Increasing the percentage of bonus payments from 50% to 75% was done in an attempt to develop a system which would produce some motivation to compete, without some of the extreme forms of behaviour witnessed in the previous test series.

The bonus payments were made immediately after each evacuation. The seating plans which were developed for the volunteers on the four successive evacuations from the aircraft gave every volunteer an equal chance of receiving the monetary incentives over the four evacuations in which they were involved. Volunteers were not allowed to take part in a test session more than once in any six month period (this requirement is also specified for volunteers taking part in evacuations for aircraft certification).

The safety of volunteers was an important consideration. To this end, only volunteers who claimed to be reasonably fit and were between the ages of 20-50 were recruited. On arrival, all volunteers were given a medical examination. They were also asked to complete a questionnaire indicating that: (i) they had fully understood the purpose of the evacuations; (ii) the medical information which they had supplied was correct; and (iii) that they were satisfied with the insurance cover. A doctor and the airfield fire service were present at all times. A system of alarms was employed to stop any evacuation should a real emergency occur or should there be concern for the safety of anyone. Volunteers were given a briefing before boarding the aircraft in which they were advised not to take part in the evacuations if they were at all concerned about the presence of the non-toxic smoke.

In order to introduce as much realism as possible, not only did the evacuations take place from an aircraft, but on their arrival at the airfield the volunteers were met by members of the research team trained and dressed as cabin staff. After boarding the aircraft, they were given a standard pre-flight briefing by the cabin staff, they then heard a sound recording of an aircraft starting up and taxiing to a runway. This sequence of recording lasted for approximately five minutes before giving way to the simulated sounds of an aborted take-off. This sequence was subsequently followed by a period of silence in which time the pilots were supposedly shutting down engines and communicating with the cabin staff. The shut down period was pre-determined for each evacuation, being either 7 or 25 seconds. The variation ensured that the subjects could not anticipate the precise time at which the call to evacuate would be given. Two seconds before the end of the shut down period non-toxic smoke was rapidly pumped into the cabin, this was followed by the command 'Undo your seatbelts and get out', at which time the appropriate exits were opened by research personnel and volunteers evacuated the aircraft.

After each evacuation, all of the volunteers were required to complete a questionnaire indicating the route which they had taken from their seat to the exit, whether any person or object had hindered their progress and their assessment (using a scale ranging from 1 to 10) of the difficulty of their evacuation. Demographic information relating to each volunteer's sex, age, height and weight was also collected.

Before volunteers left the site they were given a debriefing in which they were reminded of the safety of air travel and advised that they should get back in touch with Cranfield if they experienced any physical or mental problems as a result of the evacuations.

3 RESULTS

3.1 Test Programme

A total of 64 evacuations were carried out, 8 for each of the 4 bulkhead configurations, and 8 for each of the 4 overwing configurations. For the main evacuation programme, 669 volunteers took part, a mean of 41.8 per trial day, of which 79.2% were male. Four of the evacuations (6.3%) were deemed by the safety officers to have become too dangerous to allow continuation, and were therefore abandoned. Three of these were bulkhead evacuations when the 24", 30" and port galley removed configurations were in operation. The abandoned overwing evacuation was one in which a vertical projection between the seats of 13" was used. Brief qualitative analyses of these abandoned evacuations can be found in Appendix D.

Bonus payments were given to the first 75% of volunteers to evacuate the aircraft and Table 1 (below) gives the number of volunteers who received each of the possible number of bonuses (with the percentages in parentheses), along with their mean ages and the proportion of males.

Table 1 Age & Sex of Volunteers Receiving Bonus Payments

Number of Bonuses	*Percentage of Volunteers*	*Percentage of Males*	*Mean Age (Years)*
0	0.4	0.0	33.7
1	4.6	64.5	26.7
2	29.6	70.2	29.3
3	42.5	80.3	27.0
4	22.9	92.8	27.5
Overall	100.0	79.2	27.8

Although the distribution of the proportion of volunteers receiving each possible number of bonuses conformed with expectation, it is interesting to note that a higher proportion of males received more bonuses. This corresponds to the findings of the competitive evacuations in clear air (Refs 1,2), implying that males were generally more successful at obtaining bonus payments than females. The mean ages of volunteers receiving the differing numbers of bonus payments showed no noticeable effect. The group receiving no bonuses at all were found to be older than the mean, but the small number of such cases prevents reliable conclusions from being drawn.

3.2 **Evacuations through the Bulkhead**

The mean times for the first 30 volunteers to evacuate the aircraft, measured from the call to evacuate command, were calculated for each of the four bulkhead configurations. These times are represented graphically in Figure 1 (over). As bonus payments were only available to the first 75% of volunteers to reach the exits, usually around 30, it was assumed that this point marked the end of the perceived competitive aspect of the evacuations. Therefore the time for the 30th person to evacuate was felt to be the most appropriate measure of escape rates under competitive conditions. Table 2 (below) shows the mean times (and accompanying standard deviations) for the 30th person to evacuate under each of the bulkhead configurations. However, it was felt that a small number of evacuations with extreme times were obscuring the data set for both 'bulkhead' and 'overwing' evacuations, and therefore Table 2 also presents the mean escape times for the 30th person for each configuration with any 'outlying' cases removed (only one in this case). Further elaboration of these outlying cases and of this technique for the removal of outlying cases is provided in Appendices D and E. Plots of the individual escape times for 30 volunteers during the bulkhead evacuations are shown for each configuration in Appendix F.

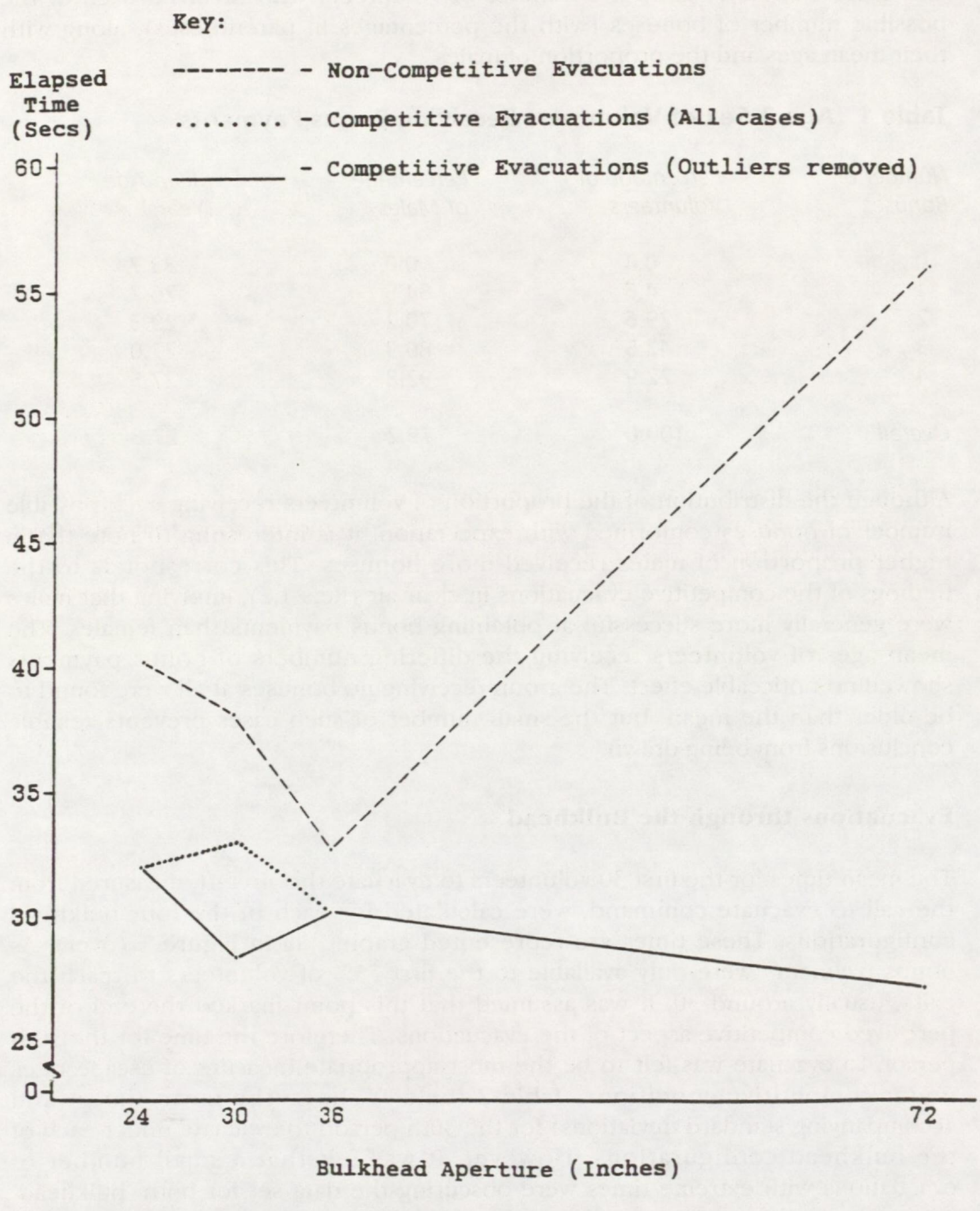

Figure 1 Mean Evacuation Times for 30 Volunteers: Competitive and Non-Competitive Evacuations in Non-Toxic Smoke – Bulkhead Evacuations

Table 2 Mean Evacuation Times for 30 Volunteers to Evacuate the Aircraft – Bulkhead Evacuations

Mean Evacuation Times for 30 Volunteers:

	All Evacuations:			Evacuations with Outliers Removed:		
Bulkhead Aperture	*Mean Time (Seconds)*	*SD*	*N*	*Mean Time (Seconds)*	*SD*	*N*
24"	32.0	6.1	7	32.0	6.1	7
30"	32.9	12.5	7	28.3	3.1	6
36"	30.1	5.1	8	30.1	5.1	8
PGR (72")	26.8	3.1	7	26.8	3.1	7

NB: PGR = Port galley unit removed
SD = Standard deviation
N = Number of cases

The table reveals that for all evacuations, the quicker evacuation rates were achieved with the widest configuration. It is interesting to note that the narrowest aperture did not quite produce the slowest mean time. The higher mean time for the 30" configuration was accompanied by a higher standard deviation, and the altered mean time when the outlying case had been removed show that this effect was due to an extreme case distorting the data. Indeed, removal of this outlying case revealed a slightly different pattern, with the only discrepancy from a uniform reduction in escape time with an increase in aperture width was for the 30" and 36" configurations.

The mean times with outliers removed, as shown in Table 2, were subjected to a one-way analysis of variance (see Appendix G) in order to ascertain whether the alternative configurations gave rise to significantly different escape rates. The resultant F-Ratio was found to be non-significant ($F_{3,24} = 1.65$ – NS), and it must be concluded that in spite of the trend, there were no significant differences between the evacuation rates for 30 people as a function of the changes to the width of the aperture between the bulkheads.

3.3 Evacuations through the Overwing Type III Exit

The mean times for the first 30 individuals to evacuate through the overwing exits for each of the 4 vertical projections between seats used were also calculated and investigated in a similar manner to those for the bulkhead evacuations. Table 3 (below) shows the mean times, along with the standard deviations and number of cases for each overwing exit configuration for all evacuations along with the equivalent figures when two outlying cases had been removed. Once again, a plot of these times can be found in Figure 2 (over), whilst plots for each individual evacuation can be found for all configurations in Appendix F.

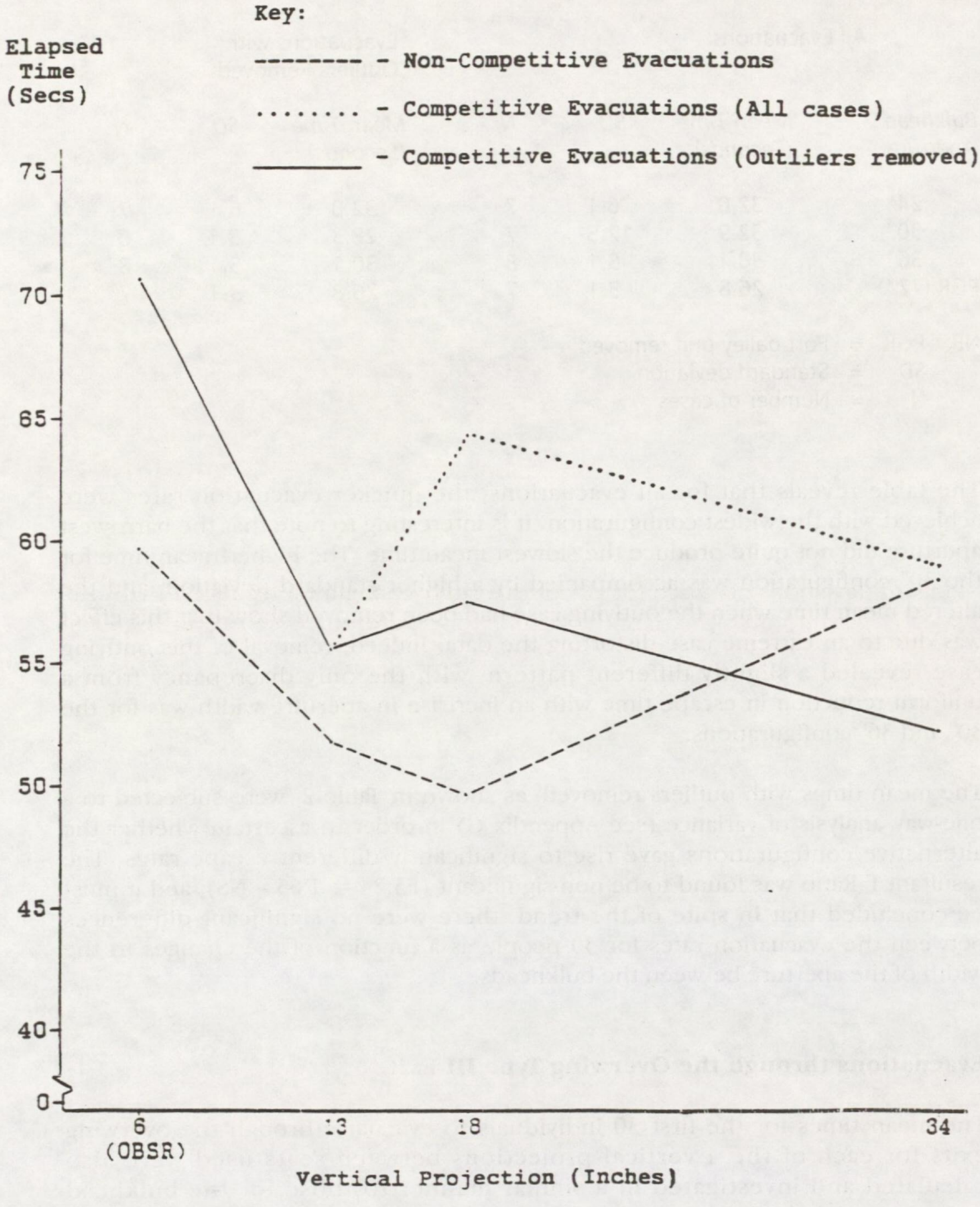

Figure 2 Mean Evacuation Times for 30 Volunteers: Competitive and Non-Competitive Evacuations in Non-Toxic Smoke – Overwing Evacuations

Table 3 Mean Evacuation Times for 30 Volunteers to Evacuate the Aircraft – Overwing Evacuations

Mean Evacuation Times for 30 Volunteers:

	All Evacuations:			Evacuations with Outliers Removed:		
Vertical Projection	*Mean Time (Seconds)*	*SD*	*N*	*Mean Time (Seconds)*	*SD*	*N*
6" (OBSR)	70.7	16.2	8	70.7	16.2	8
13"	55.3	9.2	7	55.3	9.2	7
18"	64.1	20.5	8	57.2	6.7	7
34"	58.2	19.7	8	51.5	6.2	7

NB: OBSR = Outboard seat removed
SD = Standard deviation
N = Number of cases

When the times from all of the evacuations are included in the data set, the slowest mean evacuation rate was found when a 6" vertical projection was used in conjunction with the removal of the outboard seat, whilst the most rapid was obtained when a 13" vertical projection was used. However, the relatively high standard deviations obtained for all but this latter configuration suggest that there was a large amount of variability in times for different trials using the same configuration confusing the overall pattern. This was largely confirmed by the removal of the outlying cases, and the adjusted mean evacuation times generally showed a decrease as the vertical projection increased, although the times for the 18" configuration were marginally slower than those for the 13" configuration. Further elaboration of the outlying cases may be found in Appendix D.

An analysis of variance was performed on the means after outliers had been removed, as in the previous section. Full details of this analysis can be found in Appendix G. On this occasion, the means were found to differ significantly ($F_{3,25} = 4.68$, $p.=0.01$). This implies that the use of different between-seat vertical projections had a significant effect upon competitive evacuation rates for 30 volunteers. Paired comparisons, using the Newman-Keuls method, were made between the means for the four vertical projections, and details of this analysis are presented in Appendix G. The results show that the vertical projection in conjunction with the removal of the outboard seat produced a significantly different (at the 5% level) mean escape time for 30 volunteers from those escape times obtained for each of the remaining configurations.

3.4 Analyses of Questionnaire-Based Items

Volunteers were asked to complete a questionnaire after each evacuation and the following sections provide a brief guide to the main findings from the analysis of this questionnaire information.

3.4.1 *The Effect of Adoption of an Evacuation Strategy*

After the final evacuation, volunteers were asked to report on any strategies which they had adopted prior to the call to evacuate for each of the evacuations. The mean time to escape for those who did not adopt any strategy and those who adopted some strategy, regardless of the type, were compared using a t-test. Table 4 (below) presents the details of this analysis.

Table 4 Comparison of Mean Evacuation Times for Volunteers Adopting, and Not Adopting, an Escape Strategy

	Mean Evacuation Time (Secs)	*t*	*Significance*
Strategy	34.9	0.07	0.95 NS
No Strategy	34.8		

Table 4 reveals that adoption of an escape strategy prior to the call to evacuate had no effect upon volunteers' time to evacuate the aircraft, the mean times for the two groups being virtually identical. Despite this, almost 70% (69.9%) of volunteers stated that they would subsequently adopt an escape strategy upon boarding an aircraft. Just under 15% (14.5%) said that they would form a mental image of the layout of the aircraft, the location of the exits and the optimum route to them, whilst 13.5% stated that their strategy would begin on the ground in the form of requesting seat locations near exits or adjacent to the aisle.

3.4.2 *Senses Relied Upon to Locate Operational Exit(s)*

Volunteers were also asked to indicate which sense, or combination of senses, they relied upon to find their way to the operational exit(s). Table 5 (below) shows the proportion of volunteers reporting each option.

Table 5 Senses Volunteers Reported Relying Upon to Locate Exit(s)

Sense(s) Used:	*Frequency of Citation (%):*
Hearing & touch	22.7
Hearing, touch & sight	21.2
Sight & touch	14.5
Sight & hearing	13.7
Touch	11.1
Sight	7.6
Hearing	5.5
Other	3.7

The table shows that touch was the single most useful sense, particularly when used in conjunction with the auditory or visual (or both) sense. It was found from an additional question that 95.1% of volunteers did not use the floor proximity lighting. Of the 4.9% who did report using the lighting, 67.5% felt that it did not aid their evacuation. The main reasons given for not using the lighting were: 'not being able to see them' (48.6%); and 'not needing them' (13.9%). An additional 22.1% stated that they did not attempt to look for the lighting.

3.4.3 *Evacuation Times as a Function of Exit Route Selected*

3.4.3.1 Bulkhead Evacuations

Analysis of the questionnaires revealed that respondents reported using nine basic routes to obtain access to the two Type I exits in use during the 'bulkhead' evacuations. The mean times for these escape routes are displayed in Table 6 (below), along with the analysis of variance statistics for the comparison of these means.

Table 6 Evacuation Times for each Escape Route Adopted Bulkhead Evacuations

Route:	*Mean Evacuation Time (Secs)*
Aisle	21.8
Over seats	22.8
Aisle & seats	26.9
Aisle – aft exit	19.9
Aisle – front exit	22.2
Over seats to aft exit	21.5
Over seats to front exit	23.3
Aisle & seats – aft exit	25.0
Aisle & seats – front exit	33.1

The table shows that there was a significant difference (at the 0.05 level) in the evacuation times for volunteers using different routes to get to one of the two operational exits. In general, volunteers who climbed over collapsed seats had slower times, although this may have been a function of seating position, not accounted for in the analysis. Not surprisingly, escape times were generally greater for those volunteers using the front exit rather than the mid-Type I exit, regardless of the route chosen.

3.4.3.2 Overwing Evacuations

As with the previous section, it was felt that it would be useful to investigate the effect of escape route upon evacuation times for the overwing evacuations. Table 7 (over) lists the mean escape time for volunteers using each of the four main categories of route to the overwing Type III emergency exit.

Table 7 reveals a highly significant difference between escape times for volunteers using the four listed routes to the Type III exit. The fastest times were noted for those volunteers electing to climb over the seats, although their times were slowed when also using the aisle. However, as with the previous analysis, this does not take initial seating position into account.

Table 7 Evacuation Times for each Escape Route Adopted Overwing Evacuations

Route:	*Mean Evacuation Time (Secs)*
Aisle	48.1
Over seats	36.0
Aisle followed by seats	55.9
Seats followed by aisle	46.2

3.4.4 *Individual Differences in Evacuation Times*

Differences in escape time as a function of age, weight and height factors were investigated but no significant results were found. However, males were found to have a faster evacuation rate than females (33.9 secs and 37.7 secs respectively), significant at the 0.05 level ($t=2.17$, $p.=0.03$).

3.5 Comparison of the Competitive and Non-Competitive Non-Toxic Smoke Evacuations

The data from the competitive evacuations in smoke, as outlined in Sections 3.2 and 3.3, were compared with those obtained in previous evacuations (Ref 2) using the same configurations in smoke under non-competitive conditions. Mean times for the 30th person to evacuate obtained during the non-competitive and competitive smoke trails were compared for the 4 common bulkhead configurations (Section 3.5.1) and 4 common overwing configurations (Section 3.5.2).

3.5.1 *Comparison of the Competitive and NonCompetitive Non-Toxic Smoke Evacuations Bulkhead Evacuations*

Table 8 (below) shows the mean time (and standard deviation) for 30 volunteers to evacuate for each bulkhead configuration used in the competitive and non-competitive smoke trials. These means are also shown in Figure 1 (over). Once again, the figures presented for the competitive evacuations are the adjusted means after outliers had been removed.

Table 8 Mean Times for 30 Volunteers to Evacuate for the Non-Competitive and Competitive Smoke Evacuations – Bulkhead Configurations

Mean Evacuation Times for 30 People:

	Non-Competitive:			Competitive – Smoke:		
Bulkhead Aperture	*Mean Time (Seconds)*	*SD*	*N*	*Mean Time (Seconds)*	*SD*	*N*
24"	40.1	2.9	2	32.0	6.1	7
30"	38.0	4.4	2	28.3	3.1	6
36"	32.6	7.0	2	30.1	5.1	8
72" (PGR)	55.9	2.0	2	26.8	3.1	7

Table 8 reveals that the mean evacuation times for 30 volunteers during the bulkhead evacuations were generally faster when there was a competitive element. A 2-way analysis of variance (using configuration and competition as the independent variables) was carried out on these times to determine the major sources of variance in the escape times. The full details of the analysis can be found in Appendix G. It is interesting to note that, when the competitive factor was taken into account, the alternative bulkhead apertures produced no significant differences ($F3,28 = 1.19$, NS) between evacuation times for 30 people. However, there were significant differences noted due to competition ($F1,28 = 44.20$, $p<0.001$) and the interaction between configuration and competition ($F3,28 = 9.88$, $p<0.001$).

3.5.2 *Comparison of the Competitive and Non-Competitive Non-Toxic Smoke Evacuations – Overwing Evacuations*

Table 9 (below) shows the mean time (and standard deviation) for 30 volunteers to evacuate for each overwing configuration used in the competitive and non-competitive evacuations in non-toxic smoke. Figure 2 (page 10) shows a graph of these mean times.

Table 9 Mean Times for 30 Volunteers to Evacuate for the Competitive and Non-Competitive Non-Toxic Smoke Evacuations – Overwing Configurations

Mean Evacuation Times for 30 Volunteers:

	All Evacuations:			Evacuations with Outliers Removed:		
Vertical Projection	*Mean Time (Seconds)*	*SD*	*N*	*Mean Time (Seconds)*	*SD*	*N*
6" (OBSR)	59.7	9.9	2	70.7	16.2	8
13"	51.7	14.9	2	55.3	9.1	7
18"	49.5	7.0	2	57.2	6.7	7
34"	57.9	3.2	2	51.5	6.2	7

Unlike the bulkhead evacuations, the mean evacuation times for 30 volunteers through the overwing Type III exit were generally slower when they were competing to escape. A 2-way analysis of variance (see Appendix G for full details), equivalent to the one which was described in the previous section, was performed on this data. The results reveal interesting differences from those found for the bulkhead evacuations. Although there were shown to be no significant differences due to competition ($F1,37 = 0.95$, NS) and the interaction between competition and configuration ($F3,37 = 0.83$, NS), the mean times for 30 people to escape through the Type III exit due to the vertical projection adjacent to the exit were found to differ significantly ($F3,37 = 4.64$, $p = 0.01$).

4 DISCUSSION

4.1 Evaluation of Test Procedure

The planned programme of competitive evacuations in non-toxic smoke was successfully completed with none of the volunteers sustaining serious injuries or becoming upset. This indicates that with adequate medical screening and a thorough briefing, it is possible to conduct this type of evacuation test using members of the public without placing them at serious risk.

The use of bonus payments to produce competitive behaviour was certainly effective. As in previous research (Ref 1), there was a noticeable rush for the exits with the result that on several occasions, people became trapped and the evacuation had to be halted to avoid serious injuries. The effectiveness of the safety officers and the use of thermal imaging equipment was instrumental in the ability to detect problems and halt evacuations when necessary.

4.2 The Effects of Bulkhead Apertures on Evacuation Times

Changes to the widths of the aperture between the bulkheads were found to have no significant effect upon the rate at which thirty volunteers were able to escape from the aircraft. Nevertheless, the most rapid mean escape time was found for the widest configuration, i.e. for which the port-side galley had been removed, suggesting that the increased amount of available space did not allow blockages to build up. It is interesting to note that the two intermediate configurations produced the slower times, implying that these conditions did produce bottlenecks at the bulkhead aperture.

Removal of an outlying case produced a fairly consistent pattern in the evacuation times, with the escape times for thirty people almost uniformly increasing as the aperture size was reduced, largely confirming the findings of previous research (Ref 1). However, the fact that the differences were not found to be significant suggests that the alternative configurations did not affect the rate at which 30 volunteers could evacuate competitively in smoke. Nevertheless, the relatively small number of cases means that additional evacuations would be required in order to clarify this issue.

4.3 The Effects of Vertical Seat Projection Adjacent to the Type III Exit on Evacuation Times

Unlike the bulkhead evacuations, significant differences were found between the mean times for the escape of the thirtieth individual due to the alternative vertical seat projections adjacent to the overwing emergency exit. The slowest mean time was found when the vertical projection was at its narrowest. However, the fact that this configuration also had the outboard seat removed may have contributed to this effect. In a previous study (Ref 1), it was found that, although removal of the outboard seat produced two competing streams of people in 'clear air' conditions, this configuration produced the most rapid egress rates. This implies that the difference here must be due to the presence of the non-toxic smoke, and it is possible that the lack of visibility had a detrimental effect upon people's ability to conform to the neat stream-merging behaviour pattern as previously found.

In general, a larger vertical projection was associated with the quicker evacuation rates. However, there was one exception to this finding and the evacuations involving an 18" vertical projection produced slower evacuation times than the 13" configuration. It is possible that the 18" condition caused the volunteers to erroneously perceive the gap between the seats to be wide enough to allow more than a single person through to the exit without creating a bottleneck. The 13" vertical projection may have been perceived as being only wide enough to allow a single person through at a time, and volunteers may have 'held back' to allow others through, creating a faster overall evacuation. However, it should be noted that the differences in evacuation times between the 13" and 18" configurations were not significant, and this 'effect' may disappear if a larger number of evacuations using these configurations were performed.

4.4 Removal of Outlying Cases

The behaviour of passengers in accidents is known to vary as a function of the dynamics of the particular group and similar differences were observed to exist between the behaviour of groups in the experimental evacuations. It is suggested that in the cases which produced extreme escape times, there were factors which produced a set of circumstances not present in the majority of the other comparable evacuations. Indeed, this is largely confirmed by the qualitative descriptions contained in Appendix D. It is interesting to note that the causal factors behind the abandoned and outlying 'overwing' evacuations were very similar (merely differing in degrees of severity), whilst the factors requiring that the three bulkhead evacuations were abandoned were different to those contributing to the single outlying 'bulkhead' trial.

The fact that the escape times for 30 volunteers in the outlying trials were excessive for all configurations in that class of evacuation (i.e. either 'bulkhead' or 'overwing') suggests that it is not the specific configuration used that produced the circumstances leading to the extreme escape time. Instead, it is hypothesized that other factors were in evidence and the qualitative analyses contained within Appendix D appears to confirm this. For example, the outlying 'overwing' evacuations were unusually long due to blockages in the exit door frame as two or more people attempted to evacuate simultaneously. This is more likely to be due to the nature of the people who arrive at the exit at the same moment and it is suggested that changes in the seat configuration can only minimise the probability of such circumstances appearing. If they do appear, it is likely that the evacuation will be delayed regardless of the particular seat configuration.

Therefore, it is suggested that the removal of the outlying cases serves a useful function in that it enables the effect of cabin configuration on escape times to be determined when the evacuation procedure goes relatively smoothly. When other factors such as a person falling over in the aisle appear, it is likely that the evacuation will be very much delayed regardless of the specific configuration in use. Ideally, evacuations in which this behaviour occurred would be subjected to separate analysis. However, only three outlying cases were obtained in this experimental programme and a reliable analysis of these special cases would require more examples.

4.5 Evaluation of Questionnaire Analyses

Analysis of a number of the questionnaire items produced some interesting findings. It was particularly surprising to discover that adoption of an evacuation strategy had no effect upon volunteers' subsequent evacuation times, suggesting that the use of such escape plans in smoke will not aid egress rates. One of the problems with planning such strategies is that they need to be able to account for the movements of other people within the aircraft, and it is likely that any unpredictable behaviour patterns will detract from the effectiveness of a strategy. However, seating position may also affect the ability of volunteers to successfully execute a strategy in some circumstances, with intended routes becoming blocked before the person could escape.

Another interesting finding from the analysis of the questionnaire data was the number of volunteers who reported using touch as their main evacuation aid. In conditions of limited visibility this is not particularly surprising, but it does serve to emphasise the point that it may be necessary to recognise this reliance upon tactile sensations in the design of aircraft interiors. For example, the locations of exits could be marked using some easily recognisable tactile cue that could be pointed out to passengers in the preflight safety briefing.

When escape times as a function of route taken to reach the exits were considered, it was found that staying in the aisle generally produced faster times for the evacuations through the aperture at the bulkhead, but that climbing over the seats was a more effective method of escaping during the evacuations through the overwing exit. However, as previously noted, these analyses did not take seat position into account, and therefore firm conclusions cannot be drawn.

The fact that males had a faster mean escape time than females was confirmed by the analysis of the number of bonus payments received by volunteers over the course of the four evacuations in which they participated. A higher proportion of males were found to receive the higher number of bonuses, and along with the shorter evacuation times, suggests that the male volunteers were generally more competitive than the female volunteers, confirming the finding in previous research (Ref 1).

4.6 Comparison of Competitive Evacuations in Non-Toxic Smoke with Previous Research

Comparisons were made between the times for thirty volunteers to evacuate during the bulkhead and overwing evacuations for each of the two types of trials carried out in non-toxic smoke: competitive and non-competitive. For the evacuations through the aperture between the bulkheads it was found that changes to the aperture width had no significant effect upon escape times, but that the introduction of a competitive element ensured significantly faster evacuations. A significant interaction effect between the configuration and competition was found, suggesting that the introduction of competition alters the way in which bulkhead apertures affect escape times. It is of particular interest to note the differences between the escape times for the condition in which the port galley unit was removed for the two types of evacuation. During the competitive evacuations, this configuration produced the fastest escape times, yet the same configuration was found to produce much slower rates of egress than other configurations in the non-competitive evacuations.

This latter point was previously believed (Ref 2) to be a result of the volunteers not having any solid structure with which to guide themselves to the exit, but the fact that this configuration produced the quickest evacuation rates suggests that this may not be true. It is hypothesised that the effect may have been a function of the small number of evacuations performed under non-competitive conditions. However, it is also possible that the large amount of space available when the port galley was removed allowed blockages to be formed when volunteers were moving relatively slowly, but that a generally faster rate of evacuation did not allow these bottlenecks to form. Further tests involving non-competitive evacuations through this bulkhead configuration would enable this issue to be clarified.

The overwing evacuations produced a completely different pattern, with the alternative vertical projections adjacent to the Type III exit producing significantly different escape times, whilst the introduction of competition had no effect. It had previously been found (Ref 1) that evacuations through the Type III exit in clear air were faster when volunteers were not competing than when incentives were offered, and the same was found to be generally true in non-toxic smoke, the only exception being when a vertical projection of 34" was used. This suggests that the three narrower configurations produced blockages when volunteers were competing to escape, but that the 34" configuration was sufficiently wide to prevent blockages forming, thus producing faster egress rates in competitive conditions.

5 CONCLUSIONS

5.1 The successful completion of the series of passenger evacuations reported in this paper revealed that it was possible to introduce a competitive element to evacuation tests with limited visibility without endangering the participants.

5.2 The four bulkhead apertures providing access to the two floor-level Type I exits did not produce any significant differences in escape times for 30 people, although, upon removal of outlying cases, the evacuation times were found to decrease almost uniformly with an increase in the width of the aperture between the bulkheads.

5.3 The four vertical projections between the seats adjacent to the Type III emergency overwing exit produced a significant difference in egress rates for 30 people when outlying cases were removed. The configuration in which the outboard seat was removed produced the slowest times, whilst the 34" vertical projection produced the fastest.

5.4 The reasons for evacuations being abandoned and the factors contributing to evacuations with outlying escape times were subjected to qualitative investigation. The abandoned 'bulkhead' trials were all halted due to a volunteer falling over and becoming trapped whilst the outlying 'bulkhead' evacuation was found to be a result of a blockage outside the aircraft cabin. In contrast, the reasons for the 'overwing' evacuations being both abandoned and removed due to outlying values were found to be a result of volunteers becoming stuck in the Type III exit door frame. The former evacuations only differed from the latter in their degree of severity. Unfortunately, further analysis of any characteristics unique to these evacuations with outlying escape times would require more examples than the three obtained in this research programme.

5.5 As in previous research (Ref 1), males were found to be more competitive and generally more successful at escaping from the aircraft than females.

5.6 The egress rates for volunteers who reported using escape strategies were not found to significantly differ from the rates of those who did not report using such strategies.

5.7 The use of tactile information was found to be the main sensory aid to evacuations reported by the volunteers.

5.8 When the data generated in this study was compared with that obtained for the non-competitive evacuations performed in non-toxic smoke, it was found that the evacuations through the bulkhead aperture were generally faster when volunteers were competing, but that the competitive overwing evacuations were generally slower than the noncompetitive evacuations.

6 CONTRIBUTORS TO THE RESEARCH

6.1 The programme was initiated and funded by the UK Civil Aviation Authority.

6.2 Dr H Muir, from the Applied Psychology Unit, was responsible for the management of the project.

6.3 D Bottomley, from the Applied Psychology Unit, was responsible for volunteer recruitment and collection and analysis of the data.

6.4 Ms J Hall, from the Applied Psychology Unit, provided assistance with the collection and analysis of the data during the first half of the programme.

6.5 The support of the Applied Psychology Unit and other members of the College of Aeronautics and the Airfield Fire Service should also be acknowledged.

6.6 The professional services of the Doctors from Asplands Surgery are gratefully acknowledged.

6.7 Cranfield Institute wish to express their thanks to Mr R Small, owner of the Trident Aircraft used for the evacuations and to the many volunteers who took part in the experiment.

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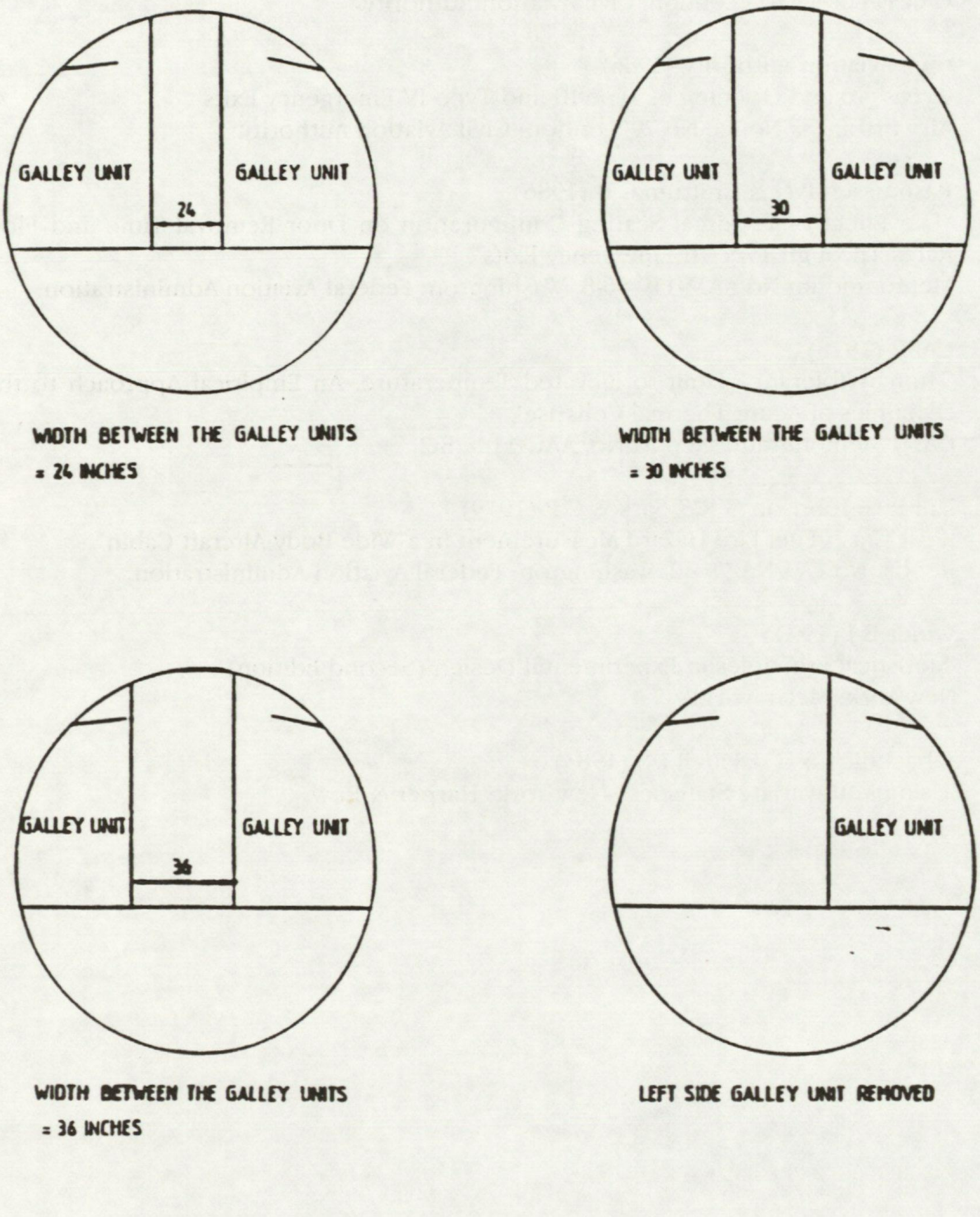

Figure A1 The Configurations used during the Evacuations through the Bulkhead

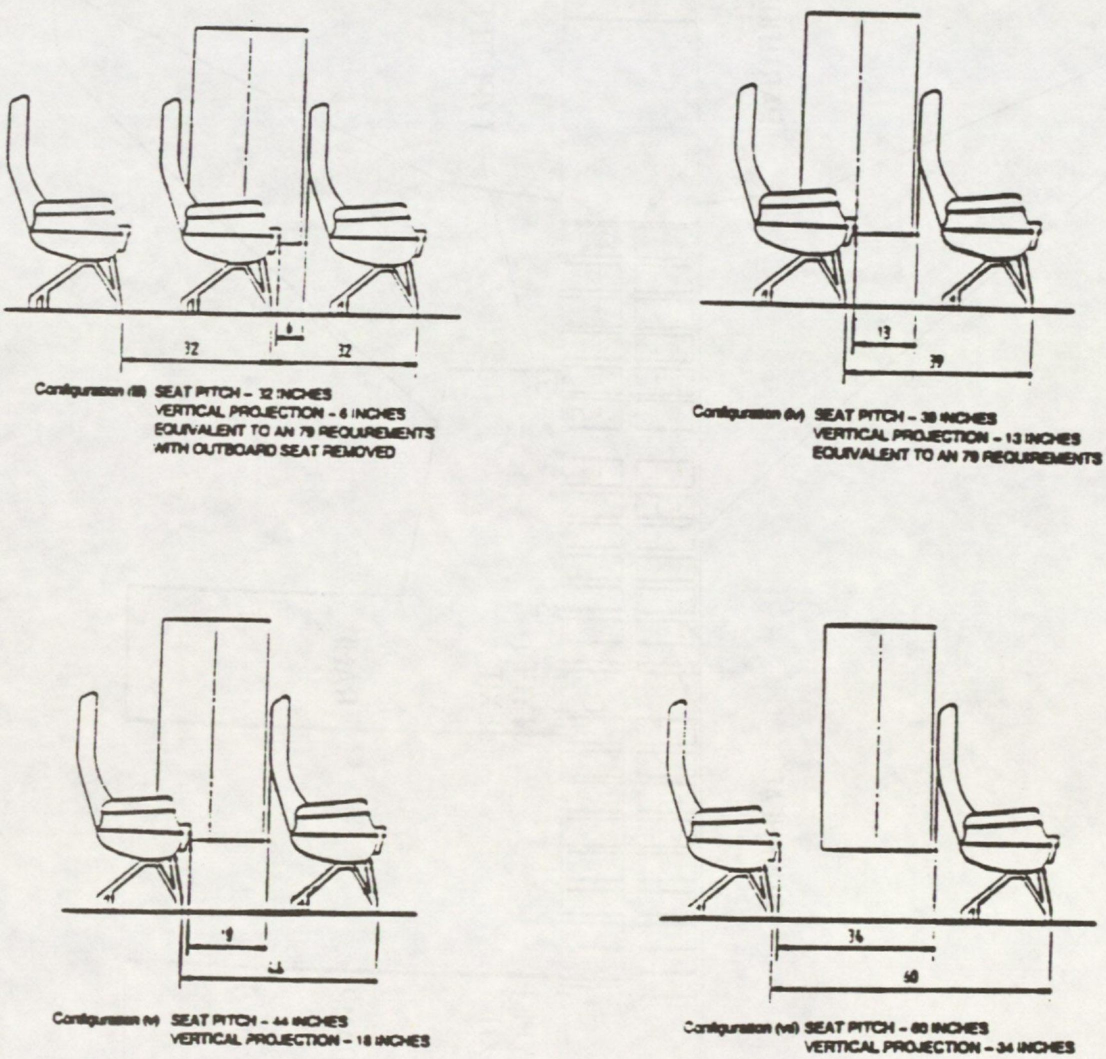

Figure B1 **The Configurations used during the Evacuations through the Type III Exit**

APPENDIX C

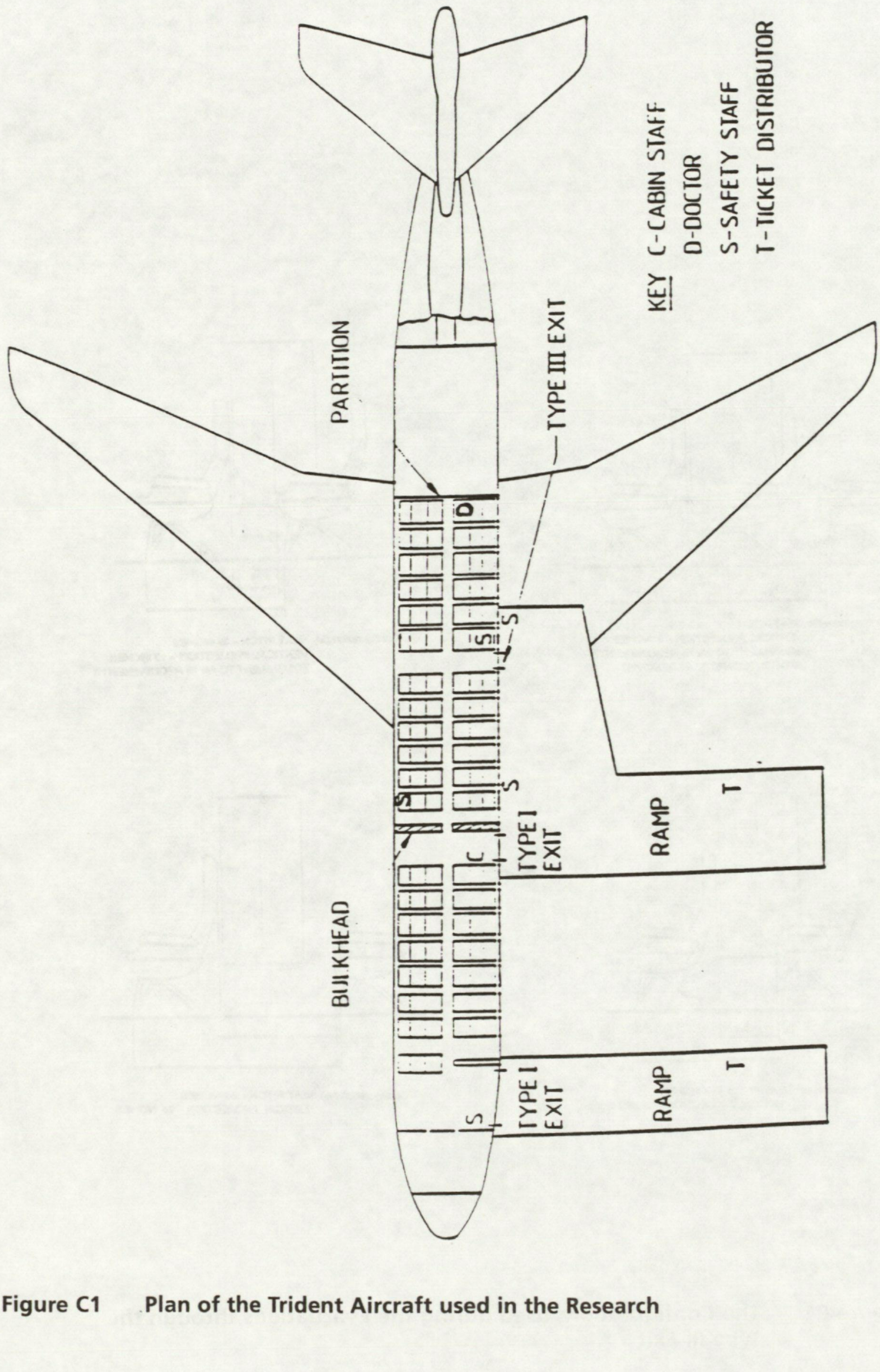

Figure C1 Plan of the Trident Aircraft used in the Research

QUALITATIVE DESCRIPTIONS OF ABANDONED & OUTLYING EVACUATIONS

Section D.1 provides brief descriptions of the four evacuations that were abandoned by the safety officers. In each case, the point at which the trial was abandoned and the reason for the abandonment are given. Following on, in Section D.2, brief descriptions of the three evacuations that were removed from the data set due to outlying values are described. For each of these, an attempt was made to ascertain the main cause of the delay in the time taken to evacuate 30 volunteers.

D.1 QUALITATIVE DESCRIPTION OF ABANDONED EVACUATIONS

Bulkhead Evacuations:

B1 – 24" bulkhead aperture:

This evacuation was abandoned by a safety officer located within the cabin 25.3 seconds after the call to evacuate at which point 25 volunteers had managed to egress. The reason for the abandonment was that a volunteer was pushed against a seat back and became trapped due to the force of people behind. This person shouted out and was judged by the safety officer to be distressed enough to warrant calling off the evacuation.

B2 – 30" bulkhead aperture:

Similarly, this evacuation had to be abandoned by a safety officer inside the cabin, 14.1 seconds from the call to evacuate. At the moment of abandonment, 11 people had egressed from the aircraft. There appears to have been considerable congestion in the aisle resulting in one volunteer being pushed into the back of a seat whilst simultaneously trapping their leg under the seat behind. People following up behind this person began to trample over them and a safety officer judged that they were at risk of sustaining an injury if the evacuation continued, therefore giving the abandonment signal.

B4 – 72" bulkhead aperture (port galley unit removed):

This evacuation was abandoned very early on in the proceedings, a mere 8.8 seconds from the call to evacuate, and after only 3 volunteers had managed to leave the cabin. The signal to abandon the evacuation was first given by the safety officer in charge of the thermal imaging camera and this was quickly backed up by a signal from the member of 'cabin staff' located at the centre Type I exit. As with the previous abandonment, a volunteer (initially located in seat 9E) had been pushed face down into the back of a seat in the row in front (8D) and had her leg trapped under the seat behind (9D). The safety officer who initially sounded the alarm spotted this very quickly and abandoned the evacuation after the woman had screamed. Although the woman initially appeared to have injured her leg, she was able to walk off the aircraft within a few minutes with no difficulty.

Overwing Evacuation:

O2 – 13" vertical projection between seats:

This evacuation, the only 'overwing' evacuation to be abandoned, was sustained until almost a minute (54.8 seconds) from the call to evacuate. However, by this time, only 11 volunteers had managed to egress, 10 of which had exited in the first 33 seconds. The reason for the abandonment was that the door frame had become blocked with volunteers and immediately prior to the alarm signal, four people were jammed in the exit aperture, unable to move. These volunteers were being continually pushed by the mass of people still in the aircraft cabin and, immediately prior to the signal, this group fell face-down onto the ramp. At this point, one additional volunteer evacuated over the backs of this group and the safety officers located outside the exit decided to abandon the evacuation in order to prevent serious injury to these four volunteers, none of whom sustained an injury.

D.2 QUALITATIVE DESCRIPTION OF OUTLYING EVACUATIONS

Bulkhead evacuation:

B2 – 30" bulkhead aperture:

This evacuation, the only bulkhead trial to be removed from the data set as a result of its outlying time, began to differ from the other bulkhead trials using the same configuration after between 15 and 20 volunteers had evacuated. This was mainly due to a bottleneck which built up at the top of the ramp outside the mid-Type I exit. For an unspecified reason, a small group of volunteers did not immediately descend the ramp and this led to a build up of people behind them who were unable to squeeze past. Although the members of the research team located on the ramp moved them on, the delay was sufficient to ensure that the evacuation took considerably longer than usual.

Overwing evacuations:

O3 – 18" vertical projection between seats:

This was notable in that the evacuation was delayed from the outset. The first person to emerge had been seated in 13A, suggesting that those located in row 14 (normally the first to evacuate) did not respond quickly enough and may have led to congestion somewhere in the vicinity of the exit. Progress of volunteers was also hampered by several blockages in the exit aperture, although none were considered serious enough to warrant cancellation of the evacuation. It is interesting to note that the initial delay was not noted by any of the respondents located near to the exit in their responses to the questionnaire items.

O4 – 34" vertical projection between seats:

Finally, this overwing evacuation began to display an abnormal pattern somewhere between the 5th and 10th volunteers to evacuate. This was undoubtedly primarily caused by an exit blockage in which two males attempted to exit simultaneously and, as one of them was extremely heavily built, became stuck in the exit aperture. This will have been compounded by an additional couple of minor blockages, none of which were considered serious enough to necessitate abandonment.

APPENDIX E

JUSTIFICATION & DESCRIPTION OF TECHNIQUE ADOPTED TO REMOVE OUTLYING CASES

Winer (Ref. 7) recommends that observations which are relatively extreme in comparison with the majority of observations may be attributable to sources of error other than those due to sampling. For instance, volunteers may not follow instructions correctly during one particular trial and it is clear that this may have a considerable effect upon interpretation of the data unless the information for that trial is considered in isolation. Indeed, in the research reported here, it was felt that the presence of some cases was distorting the overall mean evacuation times in some conditions and that this would be best rectified by removing these cases from the data set. It is suggested that these outlying cases represent evacuation situations which are qualitatively different from those found to occur in the majority of cases. However, rather than ignoring these cases once removed, it is recommended that they are treated separately.

In evacuation tests such as these, and possibly also in equivalent real-life situations, certain factors may be present on some occasions that do not usually occur. For example, in Appendix D it was noted that several evacuations when evacuating through the Type III exit were found to have extreme evacuation times due to severe blockages in the exit aperture which were not felt to be serious enough to warrant abandonment of the test. It is suggested that these cases produced extreme escape times as a result of events unique to that particular evacuation (such as personal characteristics of the volunteers, for example), rather than due to the effect of the configuration in use. It is therefore argued that to have retained those cases in the data set would have presented a distorted image of the influence of configurations upon evacuation rates and this latter phenomenon is best understood when these cases are removed. The precise method by which this removal was carried out is detailed below.

According to Winer, there are two methods by which outlying cases may be removed. 'Trimming' involves removal of the lowest and highest observations from the sample in which outlyers are suspected. The reduced sample is then considered to constitute the sample data. Alternatively, the process of 'winsorization' requires that the high and low extreme values are replaced by the next highest and next lowest values respectively.

In the research reported in this paper, trimming would have been unsuitable because in conditions which could also have contained an abandoned trial, removal of an additional two data points would have left only five cases to include in the analyses. In addition, due to the nature of the evacuations, only high extreme values were recorded and removal of the case with the lowest value would result in the inappropriate loss of a 'genuine' case. Therefore, neither of the techniques suggested by Winer were adopted.

An alternative technique, suggested by Tabachnick and Fidell (Ref. 8) was adopted to detect the outlying observations in this research. These authors suggest identification of outlying cases can be achieved by using their standardized (or z-) scores. A standardized score is a measure that gives an idea of the relative status of a case in a particular group of scores. The mean of that group is assigned a value of 0 and the standardized scores for each case are obtained by calculating the number of 'standard deviations' from the mean for each score. For example, the mean evacuation time for 30 volunteers in the O1 overwing condition (6" vertical projection between seat rows) was found to be 70.7 seconds with a standard deviation (a measure of the variability of scores in this condition) of 16.2 seconds. The highest escape time in this condition was found to be 89.8 seconds. Therefore the standardized score for this case is given by:

$$z = 89.8 - 70.7 = 1.18 \quad 16.2$$

i.e. 1.18 standard deviations above the mean. Similarly, the lowest score obtained in this condition was 49.6 seconds and standardized score for this observation is given by:

$$z = 49.6 - 70.7 = -1.30 \quad 16.2$$

i.e. 1.30 standard deviations below the mean.

The important issue is therefore to decide where the cut-off point should lie. In other words, how extreme should a value be before it can be considered to be having an unreasonably distorting effect? For the purposes of this research, it was decided that any case with a standardized score greater than 1.96 or less than –1.96 would be removed. This threshold was selected as it represents the point at which a case can be said to have only a 5% probability of being a 'member' of that group. In other words, only 5% of cases with such extreme times would be expected under normal circumstances. Although this is a somewhat conservative threshold, it is felt to be justified given the small number of cases present in each condition and examination of the plots in Appendix F reveals that the cases removed using this criterion do indeed appear to have considerably different characteristics to the remaining cases. The standardized scores for the three cases removed are shown over.

Condition:	*Case Value: (secs.)*	*Sample Mean:*	*Sample SD:*	*Standardized Score:*
B2	60.5	32.9	12.5	+ 2.21
O3	112.3	64.1	20.5	+ 2.36
O4	104.9	58.2	19.7	+ 2.37

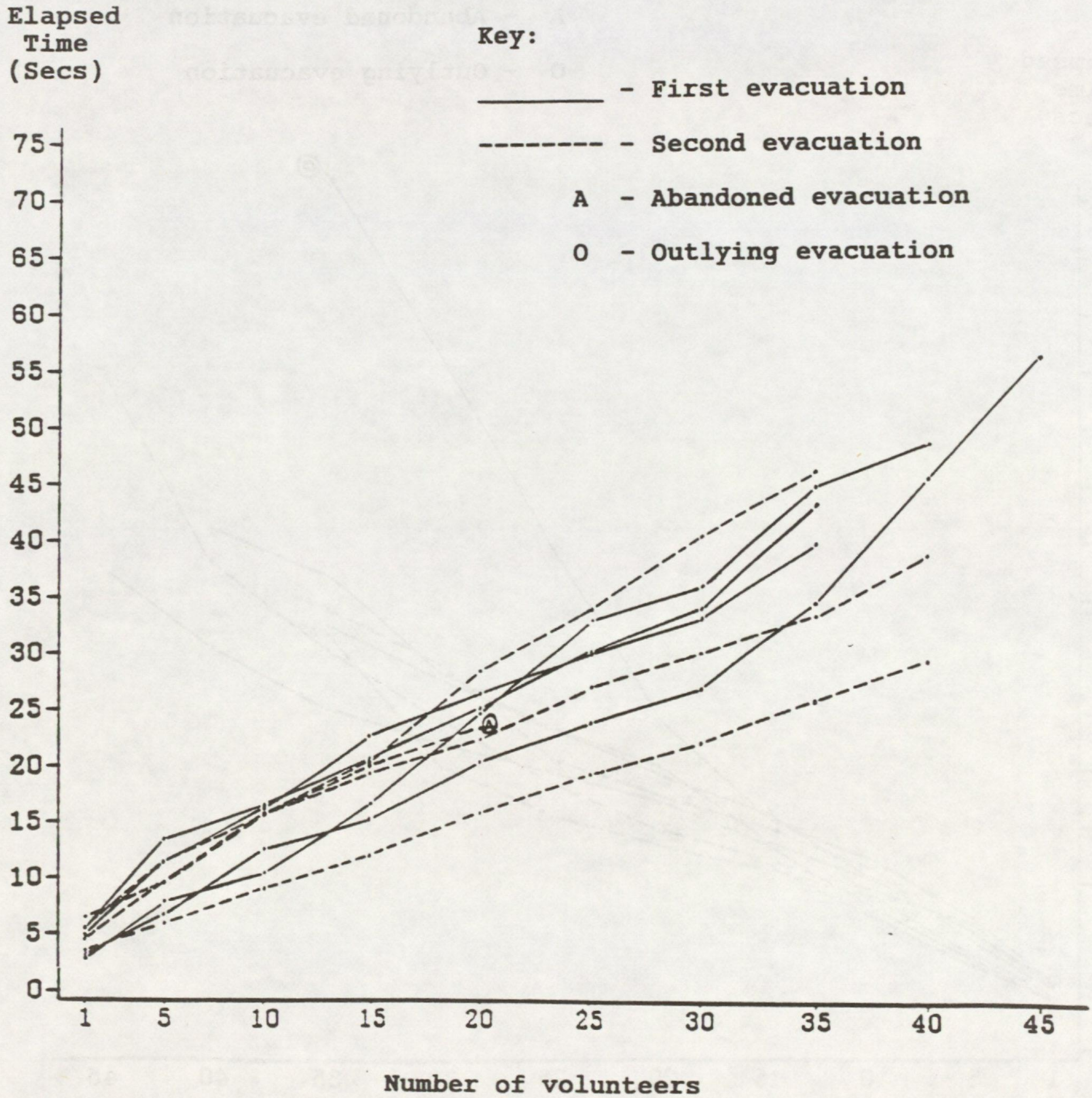

Figure F1 Plots of Individual Evacuations – 24" bulkhead aperture

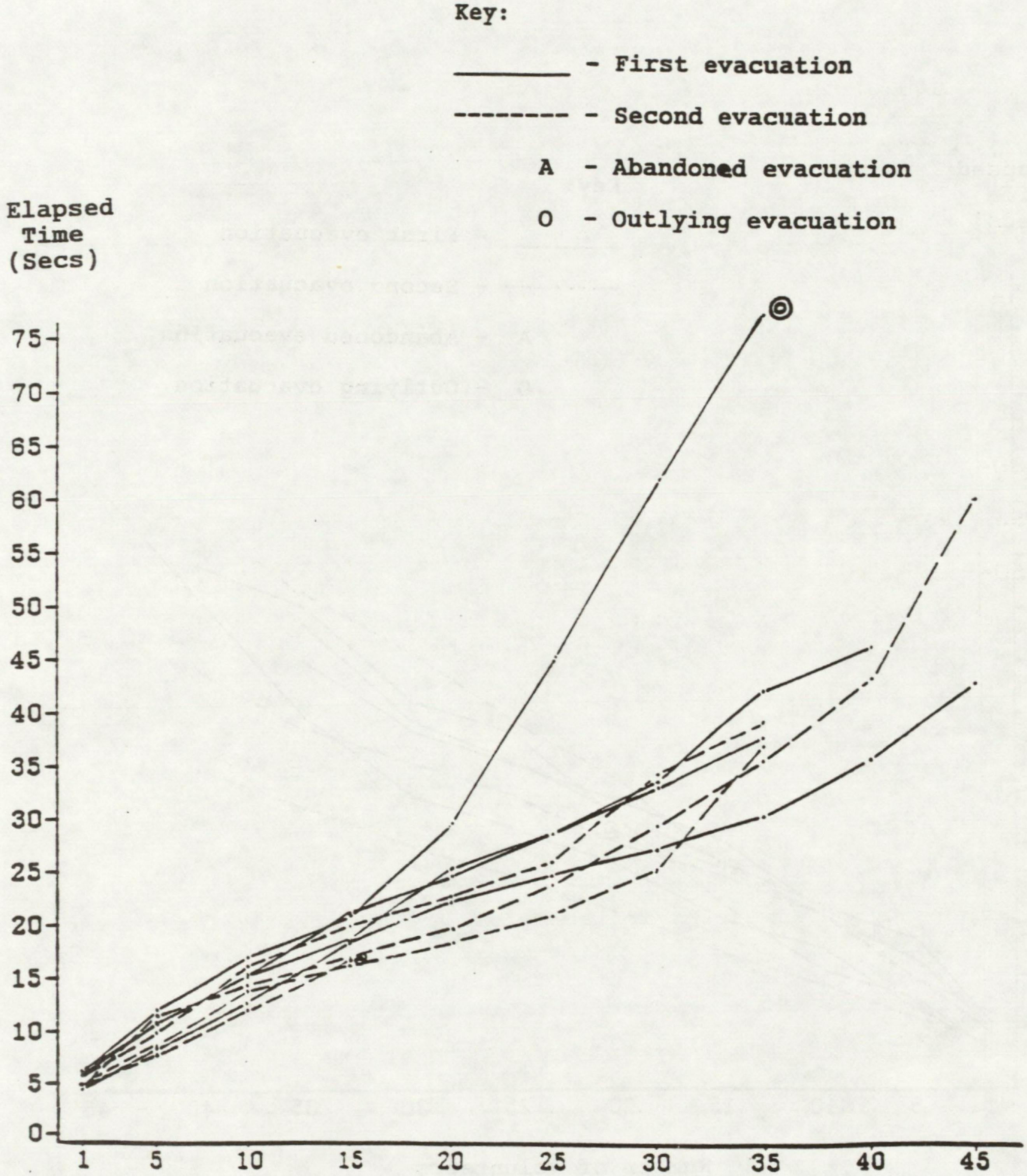

Figure F2 Plots of Individual Evacuations – 30" bulkhead aperture

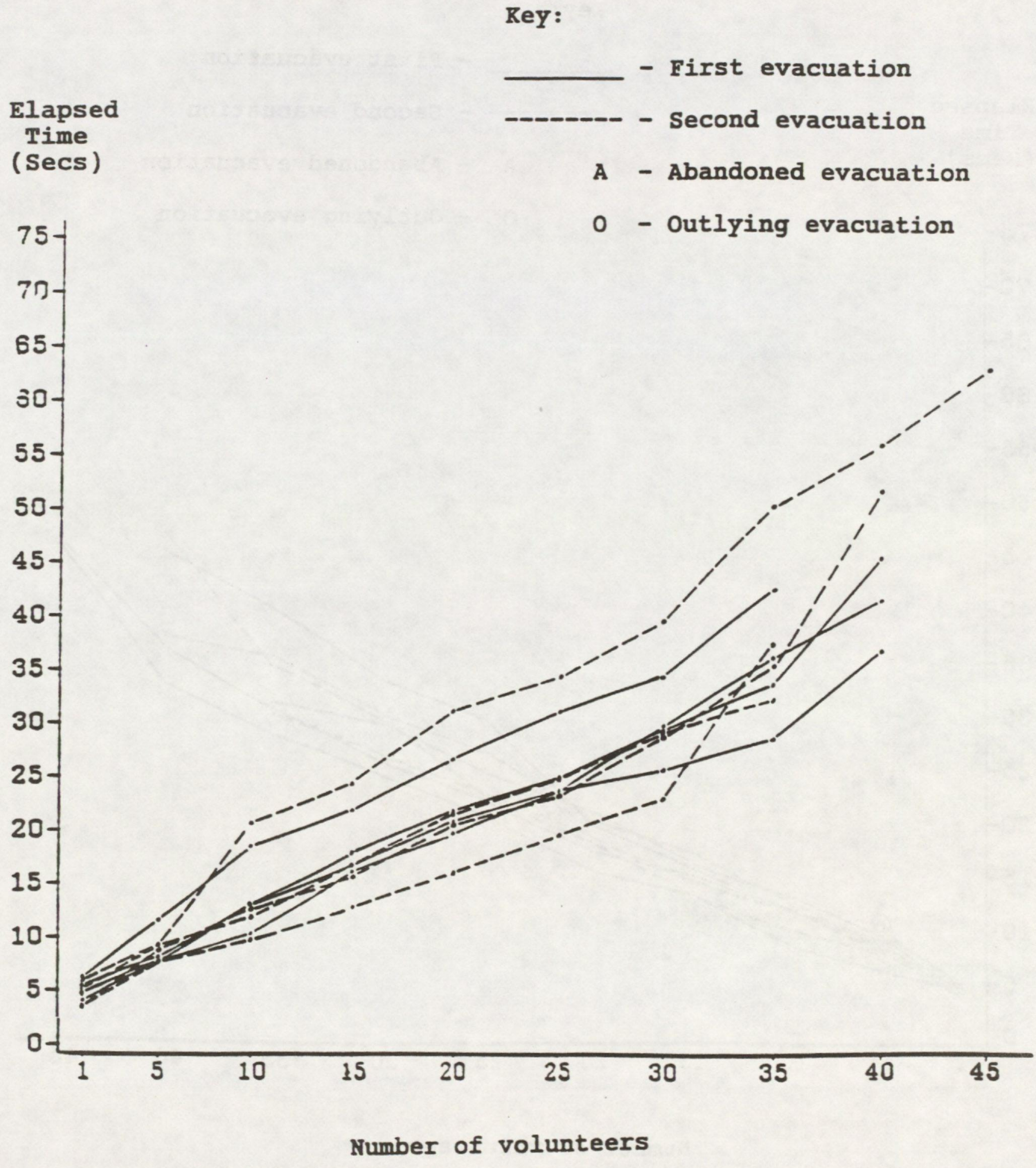

Figure F3 Plots of Individual Evacuations – 36" bulkhead aperture

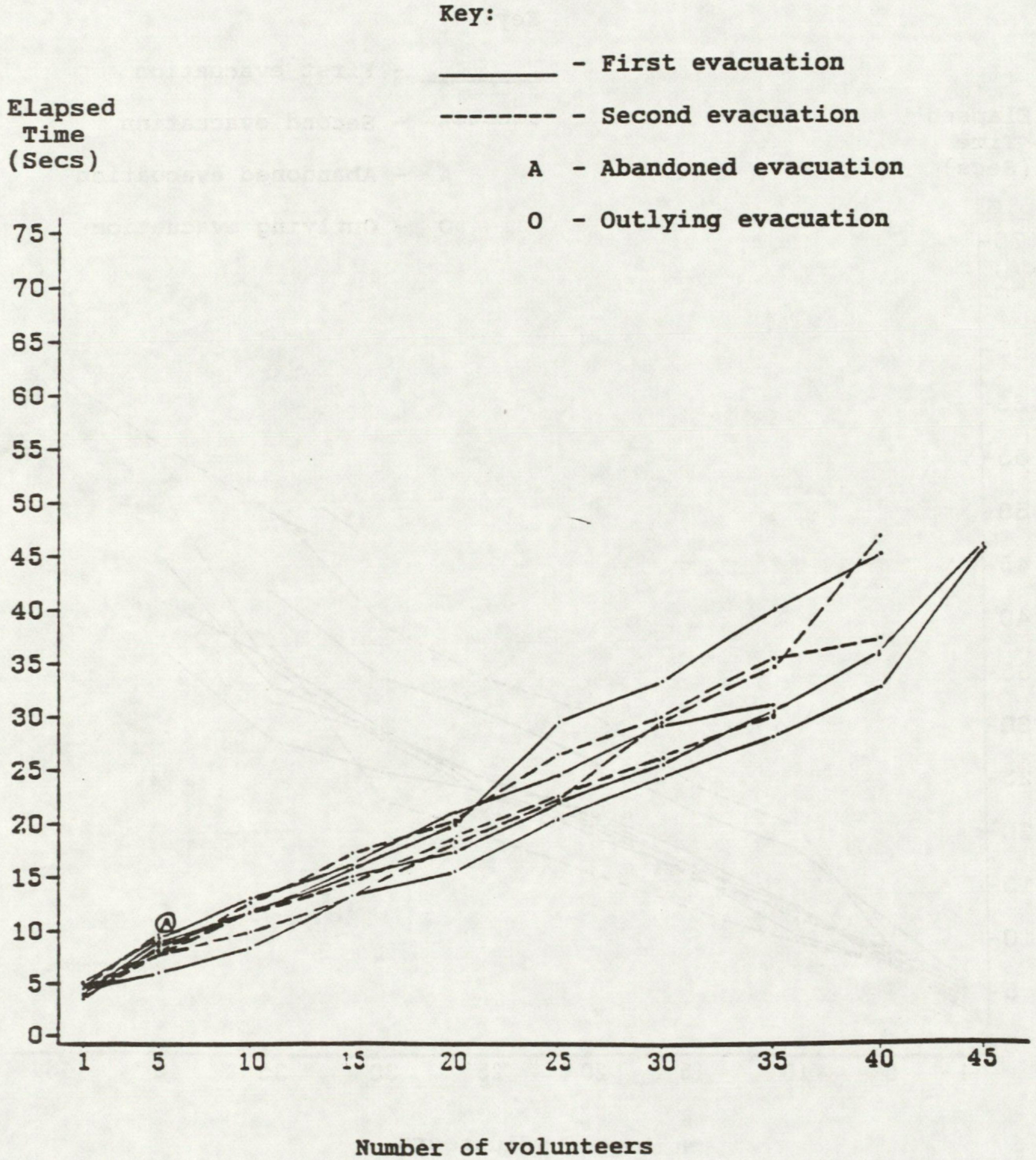

Figure F4 Plots of Individual Evacuations – Port Galley Unit Removed

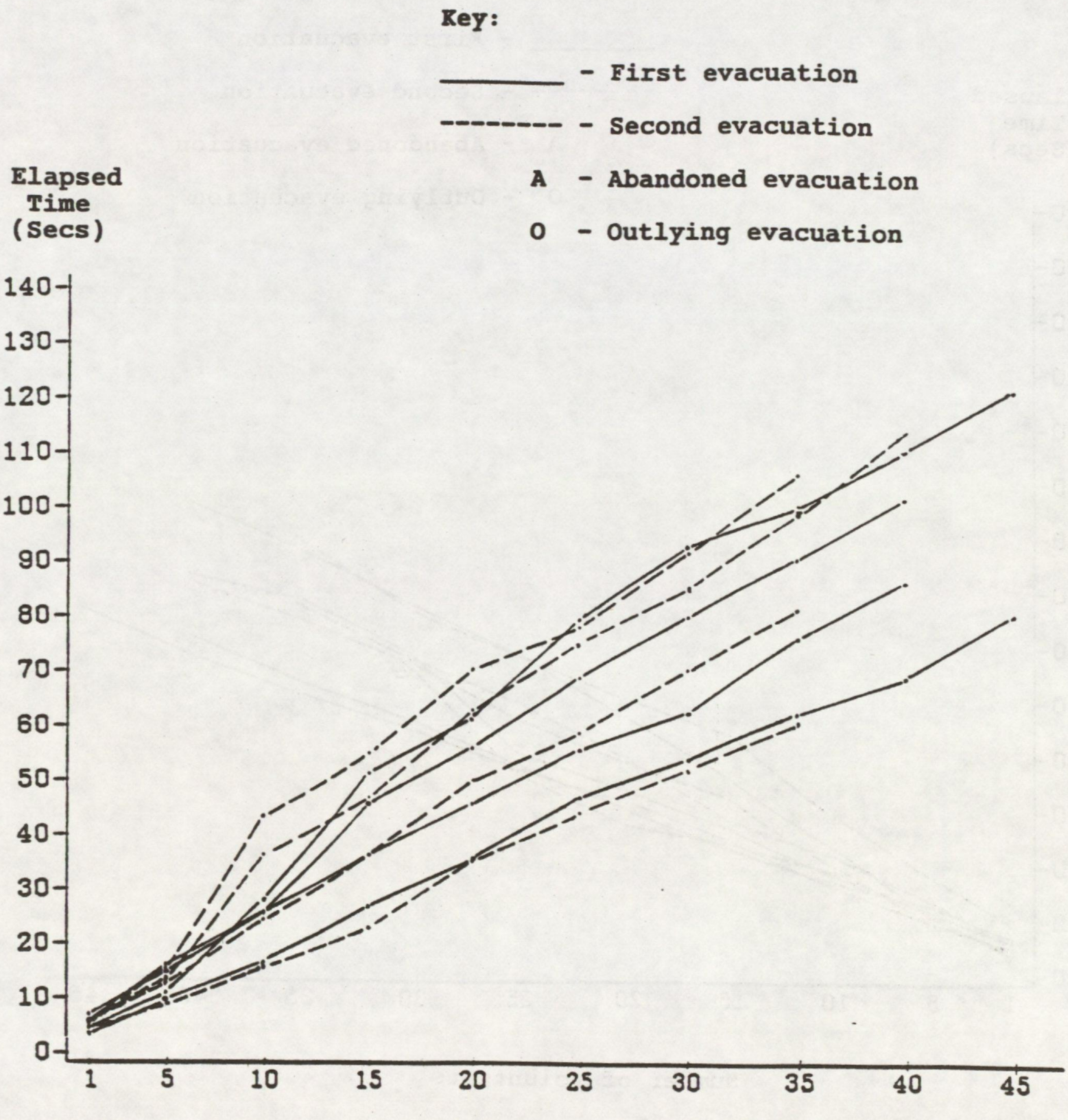

Figure F5 Plots of Individual Evacuations – 6" Vertical Projection between Seats Adjacent to Type III Exit (Outboard Seat Removed)

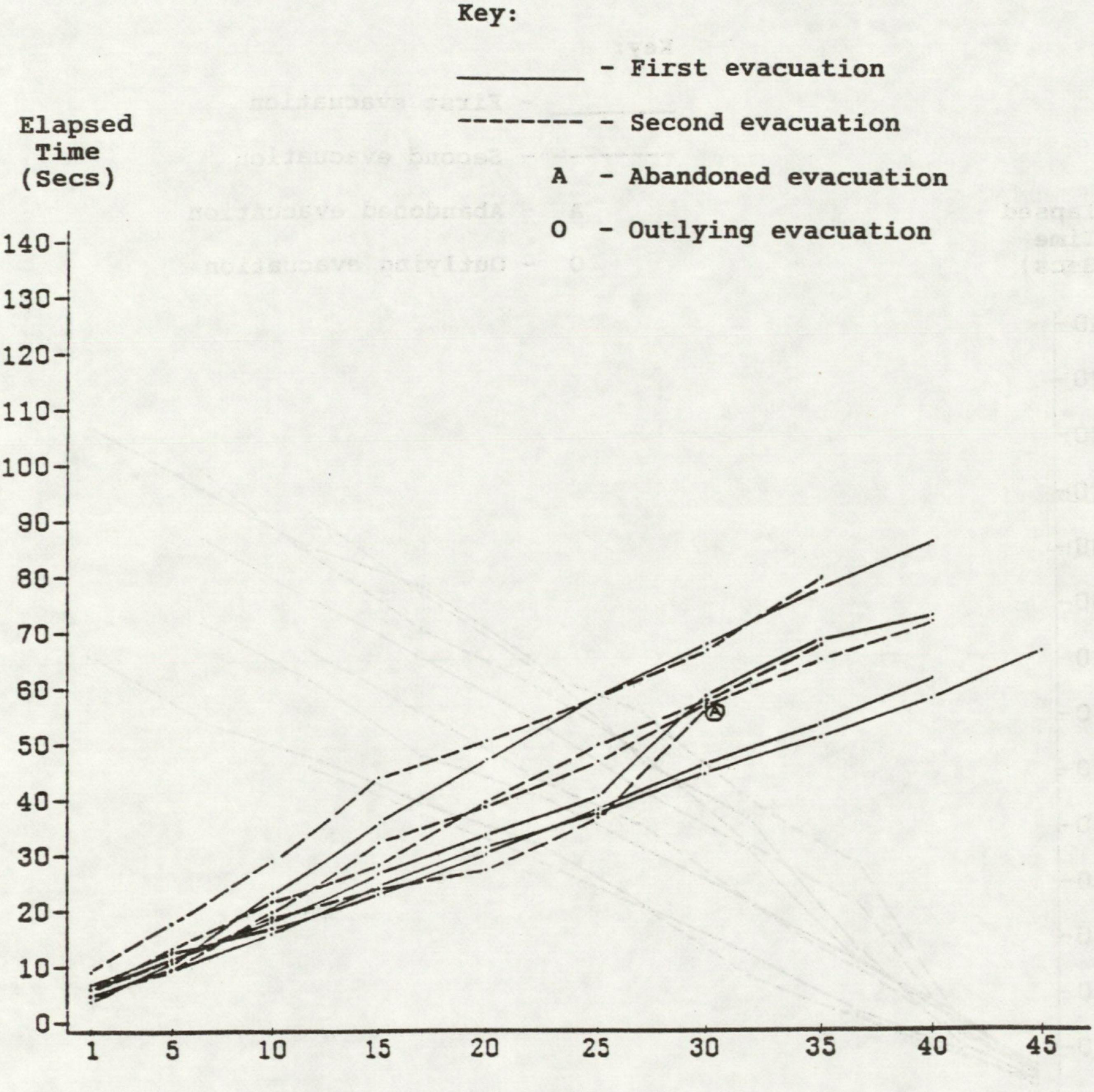

Figure F6 Plots of Individual Evacuations – 13" Vertical Projection between Seats Adjacent to Type III Exit

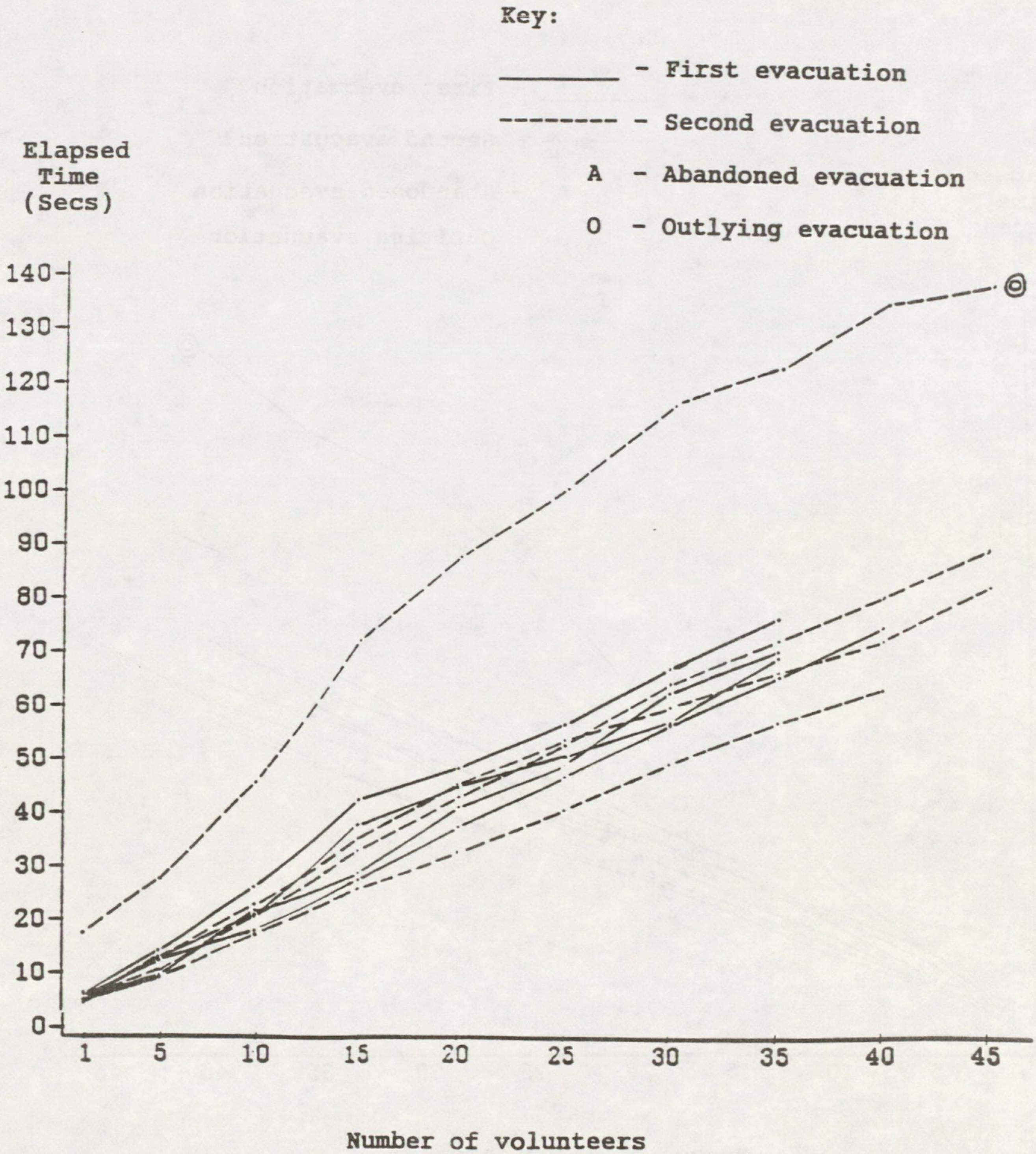

Figure F7 **Plots of Individual Evacuations – 18" Vertical Projection between Seats Adjacent to Type III Exit**

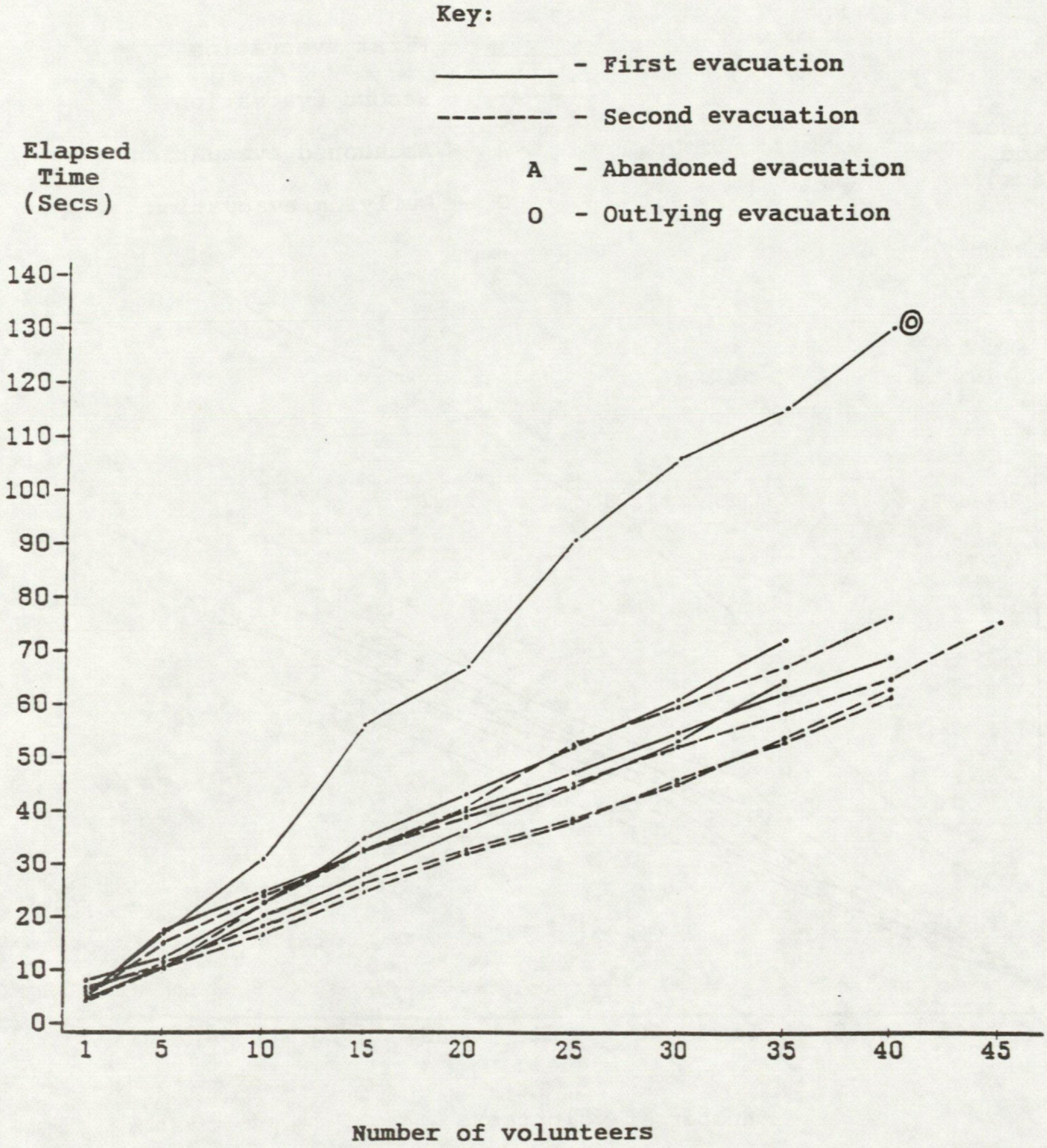

Figure F8 Plots of Individual Evacuations – 34" Vertical Projection between Seats Adjacent to Type III Exit

2-WAY ANALYSIS OF VARIANCE TABLES FOR BULKHEAD AND OVERWING EVACUATIONS

Table G.1 (below) shows the full details of the 2-way ANOVA performed to investigate the effects of seating configuration and competitive behaviour on the evacuation times for the first 30 individuals to escape through the bulkhead (see Section 3.5.1).

Table G.1 2-Way ANOVA Summary Table for Bulkhead Evacuations

Source of Variation:	*Sum of Squares*	*Deg. Free.*	*Mean Square*	*F-Ratio*	*Signif. of F*
Main Effects:	1012.38	4	253.10	11.93	0.000
Configuration	75.94	3	25.31	1.19	0.330
Competition	937.69	1	937.69	44.20	0.000
2-Way Interaction:					
Configuration/ Competition	629.09	3	234.50	11.05	0.000
Residual:	594.08	28	21.22		
TOTAL	2235.55	35	63.87		

The table reveals that the competitive element was significant beyond the 0.001 level in determining the time for the 30th person to evacuate through the bulkhead. The particular bulkhead configuration in use did not produce a significant effect, although the presence of competition was found to have a significant interaction with the configuration.

Table G.2 (below) shows the full details of the 2-way ANOVA performed to investigate the effects of seating configuration and competitive behaviour on the evacuation times for the first 30 individuals to escape through the Type III (overwing) exit (see Section 3.5.2).

Table G.2 2-Way ANOVA Summary Table for Overwing Evacuations

Source of Variation:	*Sum of Squares*	*Deg. Free.*	*Mean Square*	*F-Ratio*	*Signif. of F*
Main Effects:	1605.82	4	401.46	3.75	0.014
Configuration	1491.34	3	497.11	4.64	0.009
Competition	101.92	1	101.92	0.95	0.337
2-Way Interaction:					
Configuration/ Competition	267.17	3	89.57	2.50	0.487
Residual:	3215.20	30	107.17		
TOTAL	5088.19	37	137.52		

The table shows that the vertical projection between seat rows adjacent to the Type III exit had a significant effect (at the 0.01 level) upon the evacuation rates of the first 30 people, although the presence or absence of competitive behaviour was shown to have no significant effect upon evacuation times.