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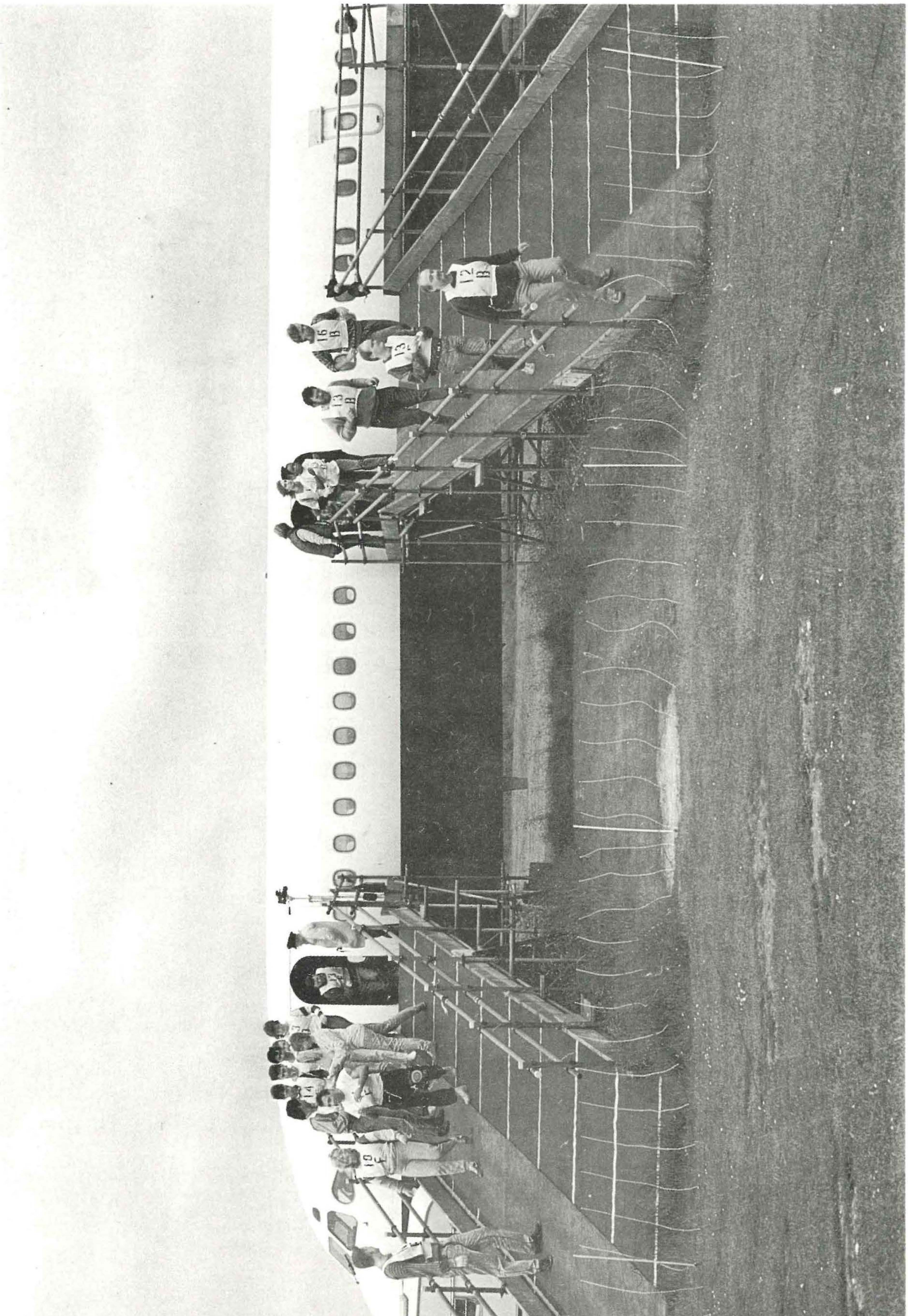

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Aircraft evacuations: the effect of passenger motivation and cabin configuration adjacent to the exit

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ABSTRACT

In 1987 the United Kingdom Civil Aviation Authority, commissioned 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 involving access to the emergency exits, on the rate at which passengers could evacuate an aircraft. The configurations evaluated involved a range of widths for the passageway through a 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 accidents.

Volunteers were recruited from the public in groups of approximately 60, to perform a series of emergency evacuations. A total of 2,262 volunteers took part in the evacuations from a Trident aircraft parked on the airfield at Cranfield.

The results suggested that the blockages known to occur in some emergency evacuations, can be significantly reduced when the passageway through a bulkhead is greater than 30 inches. 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 a Type III overwing exit in an emergency. Blockages were also found to occur in evacuations involving a three inch vertical projection between the seats (pre AN79). The six inch vertical projection with the outboard seat removed (an AN79 alternate) 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 either side of the exit would involve a vertical seat projection of between 13" and 25". A Technical Report (Ref 1) is available in which a full description of the methodology and results obtained from the programme of competitive evacuations is included.

CONTENTS

1 INTRODUCTION

In August 1987, the United Kingdom Civil Aviation Authority (CAA) commissioned the Applied Psychology Unit in the College of Aeronautics at Cranfield Institute of Technology to conduct a programme of research into passenger behaviour in aircraft emergency evacuations.

At the initiation of the investigation the CAA indicated that their requirement was for an experimental programme in which the behaviour of passengers competing to evacuate an aircraft would provide information relating to the following areas:

(a) The influence of increasing the width of the passageway through the floor to ceiling bulkhead leading to floor level Type I exits, on the time taken for passengers to evacuate the aircraft.

(b) 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 in an emergency.

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. In one of the alternates, it was specified that the vertical projection between the seat rows should not be less than 13". In the other alternate, a minimum vertical projection of 6" between the seat rows was specified. However, this configuration required the removal of the outboard seat beside the exit. (Ref 2)

Information from aircraft accidents had indicated that there had been instances of blockages of passengers at both the entrance to the galley and in the overwing Type III exit during some emergency evacuations. It was therefore hoped that the data from the research programme would also enable the CAA to explore:

(i) the extent to which the individual behaviour of some of the passengers contributes to the finding that in some accidents, problems occur which were not apparent during the evacuation demonstration conducted for the certification of the aircraft;

(ii) the reason why in some aircraft emergencies there appear to be certain seats in the cabin which are relatively near to exits, but from which passengers seem to find it difficult to evacuate the aircraft.

An experimental programme was planned in which volunteers from the public completed a series of evacuations from a stationary aircraft parked on the Cranfield Airfield. In these evacuations a range of seating configurations adjacent to the Type III overwing exit and range of aisle widths through the bulkhead at the entrance to the galley beside the Type I exit, were assessed.

Two independent series of evacuation trials were conducted which included tests of all of the configurations under consideration. In the first test series, a system of bonus payments was introduced in order to increase the individual motivation of the volunteers to get out of the aircraft as quickly as possible. In the second test series all of the volunteers were simply told to evacuate the aircraft as quickly as possible and no bonus payments were made. The bonus payments were introduced in order to simulate experimentally the competition which is known to occur between people trapped in a confined space fighting for their lives. The second test series (in which no incentive payments were made) was conducted in order that comparisons could be made between the evacuation rates for the configurations being evaluated in the first test series and the evacuations conducted by the airframe manufacturers at the time of aircraft certification.

It was anticipated that with the data from the experimental programme of evacuations, it would be possible to determine whether there was an optimum aisle width through the bulkhead leading to the Type I exit, or an optimum seating configuration adjacent to the Type III exit.

2 METHOD

2.1 Research Design

The primary objective of the research programme was to investigate the effect on passenger behaviour and flow rates, during simulated emergency evacuations of:

(a) changes to the width of the aisle through the bulkhead leading to the floor level exits;

(b) changes to the configuration of the seat rows which form the access to the overwing Type III exits.

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

(a) *Evacuations through the bulkhead*

The following configurations were assessed:

(i) The international minimum, a width between the galley units of 20 inches (51cm)
(ii) A bulkhead which is typically seen on aircraft, a width between the galley units of 24 inches (61cm)
(iii) A width between the galley units of 27 inches (68cm)
(iv) A width between the galley units of 30 inches (76cm)
(v) A width between the galley units of 36 inches (91cm)
(vi) Port galley totally removed.

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 important 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 bulkhead, a member of cabin staff was positioned in the vestibule area forward of the bulkhead in order to direct passengers to the exits. (See Appendix C)

In order 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 through 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 the chute. (See Appendix C)

(b) *Evacuations through the Type III Overwing Exit*

The following configurations were assessed:

(i) The minimum configuration complying with CAA standards prior to Airworthiness Notice No. 79, which are also the FAA minimum standards, with a seat pitch of 29 inches (73cm) and a vertical projection between the seat rows of 3 inches (7.6cm). The outboard seats in the rows bounding the exit were modified to allow minimal recline and break-forward movement.

In conditions (ii) to (vii), the movement of the backs of the seats in the rows bounding the routes to both the port and starboard, Type III exits were restricted. The limited recline and break-forward of seats, ensured that the configurations were in accordance with the specifications of Airworthiness Notice No. 79. The configurations are illustrated in Appendix B.

(ii) A configuration in which the access to the exit between the seat rows was 3 inches (7.6cm) with a corresponding seat pitch of 29" (73cm).

(iii) The CAA standard in Airworthiness Notice No. 79 paragraph 4.1.2 (Ref 2) 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 inches (81.2cm), with the vertical projection between the seat rows being 6 inches (15.2cm).

(iv) The CAA standard, specified in Airworthiness Notice No. 79, paragraph 4.1.1 (Ref 2), in which 'All forward or aft facing seats are arranged such that there is a single access route between seat rows from 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 seat rows vertically projected, shall not be less than half the exit hatch width including any trim, or 10 inches, 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 inches (99cm), with the vertical projection between the seat rows being 13 inches (33cm).

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

(vi) A configuration in which the seat pitch between the seat row fore and aft of the exit was 51 inches (129.5cm). The resultant vertical projection between the seat rows was 25 inches (63.5cm).

(vii) 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 inches (86.3cm).

In all of the evaluations of the seating configurations bounding the Type III exit, the egress took place through the port overwing exit (see Appendix C). Although it had initially been suggested that there might be differences between the ease of egress through the port and starboard exits, data which had been collected by the FAA indicated that laterality of exits did not affect the rate of evacuation (Ref 3). The FAA report indicated that an interaction was obtained between the method of opening the Type III exit and the seat configuration on egress rate. To remove this interaction, the method of opening the exit was held constant throughout the trials. This was achieved by a member of the research team being employed to open the exit, and hand it to a trained observer on the wing.

2.2 Equipment

Several modifications were made to the structure of the Trident Three aircraft in order to make it a suitable test vehicle.

The port galley unit was removed, and wooden sections were constructed which allowed the six aisle widths under consideration to be produced.

The overwing hatch on the Trident was modified to bring its height to the minimum standard (43 inches). A lower handle was fitted to the inside of the door 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 six of the seven 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 (condition iii) 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. This was done to prevent the risk of injury to volunteers caused by part of the seat being broken by people falling between the support webbing in their attempts to egress.

A feeling of crowding within the aircraft prior to the evacuation was considered to be important. For this reason the seats available for the volunteers were restricted to the aft cabin. Additionally, the seven rows at the rear of this section of the aircraft were boarded off. 'Passengers' were therefore seated between rows 8 and 19. Research personnel reduced the available number of seats to 65. Consequently, with the anticipated 60 subjects the cabin was filled almost to capacity, simulating the crowding which was desired (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 be able 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 during the evacuation. Each vest was painted with a number and the number on the vest of a volunteer indicated the seat to which they had been allocated for that evacuation.

2.3 Procedure

The experimental programme comprised two separate series of evacuations involving volunteer members of the public. The first series included making bonus payments to the first half of the volunteers to evacuate the aircraft (competitive evacuations). In the second series no bonus payments were made and the procedure for the volunteers was the same as in an aircraft certification test (non-competitive evacuations). The procedure for each of the test series will be described separately.

2.3.1 *Procedure for the Competitive Evacuations*

Volunteers were recruited in groups of approximately sixty 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 through the bulkhead and evacuated from the aircraft through either of the two port Type I exits. In the other two evacuations all of the volunteers evacuated through the port Type III overwing exit. The configurations were all tested on a minimum of eight occasions, with the exception of the configuration (b)(ii) above. This was considered to be of secondary importance and was tested on four occasions.

The test programme involved 28 separate test days of four evacuations. In order to account for the effects of fatigue and practice the order in which the configurations under review were tested, was systematically varied using a counterbalanced design based on a latin square. Although the volunteers were told that they would be required to take part in some evacuations from the aircraft, they were not given any information about the configurations under review, or the order in which the evacuations would be performed.

The volunteers were members of the public. They were recruited by local advertising and were told that they would be paid a £10 attendance fee after they had completed 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 would be paid to the first half of the volunteers to pass through the exits which were used on each evacuation.

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 incentive. 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 trials, (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 any volunteer.

In order to introduce as much realism as possible, not only did the evacuations take place from a real 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 liaising with the cabin staff. The shut down period was predetermined for each evacuation, being either seven or 25 seconds. The variation ensured that the subjects could not anticipate the precise time at which the call to evacuate would be given. On the command 'Undo your seatbelts and get out', the appropriate exits were opened by research personnel and the 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 on a scale of 1 to 10 of the difficulty of their evacuation. Additional questions were included on the questionnaire completed after the fourth evacuation asking volunteers for information about whether they had adopted or changed their strategy for egress during the course of the evacuations. Demographic information relating to each volunteer's age, sex, 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. At the end of the test programme the volunteers were invited to return to Cranfield to attend a lecture about the work in which they had participated. This feedback to volunteers proved to be very popular and was a useful source of volunteers for other investigations.

2.3.2 *Procedure for the non-competitive evacuations*

Volunteers were recruited in groups of approximately sixty to take part in one experimental session which comprised two evacuations from the Trident aircraft. In one of the evacuations all of the volunteers passed through the bulkhead and evacuated from the aircraft through either of the two Type I exits. In the other evacuation, all of the volunteers evacuated through the port Type III overwing exit.

The six bulkhead configurations at the entrance to the galley unit and the overwing seating configurations (ii)–(vii) which were tested in the competitive evacuations, were each tested on two occasions. The test programme involved 12 separate test days of two evacuations. 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. As in the competitive evacuations, the volunteers were told that they would be required to take part in some evacuations from the aircraft, but they were not given any information about the configuration under review, or the order in which the evacuations would be performed. On arriving at Cranfield they were told that they would be paid a £10 attendance fee after they had completed the two evacuations. The volunteers were instructed that their task was to evacuate the aircraft as quickly as possible once the exit(s) had been opened by the Cranfield staff.

3 RESULTS

The results from the competitive and non-competitive evacuations are treated in separate sections. The third section includes a comparison of the results from the two methods.

3.1 Competitive Evacuations

3.1.1 *Trial Programme*

In the test series of competitive trials the final data base included information from 110 evacuations, of which 56 were through the bulkhead and 54 were through the overwing exit. Deteriorating weather conditions, poor quality video recording and damage to seating during preceding evacuations caused four evacuations to be omitted from the programme. Five evacuations were abandoned because blockages of people in the overwing exit caused the safety officer to consider it to be dangerous to continue. Two evacuations through the bulkhead were terminated when a volunteer fell and would have been trampled upon if the evacuation had continued. Thus data was not obtained from ten of the planned evacuations. Over the trial series 1558 volunteers took part with an average of 55 participants on each test day. The mean age of the participants was 28.8 years and 71% were male.

The seating in the cabin was designed so that all volunteers would have an equal chance of receiving the bonus payments on two out of the four trials in which they took part. In practice, individual differences in behaviour meant that this did not occur. Table 1 indicates the frequency with which volunteers received the bonus payments.

Table 1 Age and sex of volunteers achieving bonus payments

No of bonuses	*% of volunteers*	*% of males*	*Mean age (yrs)*
0	12.2	56.7	29.0
1	17.2	67.2	29.8
2	37.3	73.5	29.0
3	24.6	76.6	28.4
4	8.7	82.1	27.3

It is interesting to observe from the figures for the percentages of volunteers receiving bonuses, that in fact only 37.3% received two bonus payments. A total of 41% received either one or three bonuses. Only 8.7% of volunteers managed to obtain a bonus on all of the evacuations and 12.2% were unable to obtain bonuses on any of the four evacuations in which they took part. Since 71% of the volunteers taking part in the evacuations were male the data indicated that they tended to be more successful than females in achieving bonus payments. The age of a volunteer seemed to have little influence on their chances of being in the first half out of the aircraft.

3.1.2 *Evacuations through the bulkhead*

(i) Passenger Flow Rates

Passenger flow rates through the exits were obtained from the video recordings. The evacuation times for each of the volunteers to pass through one of the exits were taken from the call to evacuate the aircraft rather than from the elapsed time from the first individual to reach the exit. Statistical analysis indicated that there was no significant difference between the results from the two methods. The evacuation times have been compared for the first thirty to pass through the exits used. These times were used as the criteria for determining the evacuation flow rate for each of the configurations tested. Since the bonus payments were only available to the first half of the volunteers to reach the exits, (approximately thirty), it was assumed that many of the volunteers reaching the exits in the latter half of the group had realised that they would not receive a payment and had therefore stopped competing. For this reason their data was not included in the analysis.

Table 2 Mean evacuation time for the thirtieth individual (time in seconds)

Bulkhead Aperture		*Evacuation*					
		1st		*2nd*		*Overall*	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
(i)	20"	25.5	3.5	27.3	1.9	26.3	2.9
(ii)	24"	22.4	1.5	26.6	8.0	24.5	5.8
(iii)	27"	22.4	6.0	24.0	9.0	23.2	7.1
(iv)	30"	19.4	1.1	17.6	2.2	18.4	1.9
(v)	36"	19.0	3.8	15.9	1.8	17.2	3.1
(vi)	PGR	15.0	1.5	14.4	1.6	14.7	1.4

SD = Standard deviation associated with the mean
PGR = Port galley removed

As the means suggest, statistical treatment of the data indicated that as the aperture in the bulkhead was increased, the evacuation rate increased, leading to a reduction in the time for the first thirty individuals to evacuate the aircraft (F511 = 10.5 $p<0.001$*). This data may also be seen in Figure 1. There was no significant difference between the times for the first or second evacuations through the bulkheads which the individual groups of volunteers completed (F1,11 = 0.01NS). The individual comparisons of means indicated that there was a significant difference between the mean times when the aperture in the bulkhead was 27" or less, and the mean times when this aperture was 30" or greater (see Appendix D Table 1). The raw data from the evacuations may be found in Appendix E.

* The F ratio is obtained by performing the technique of Analysis of Variance in order to establish whether any statistically significant differences exist between the data from a number of conditions. Whether the F ratio is sufficiently large to achieve significance will be influenced by the variability in the data and also by the number of conditions and replications of the test. In the text, the value of the F is followed by NS if the result is not significant or a p value indicating the probability of a reliable result.

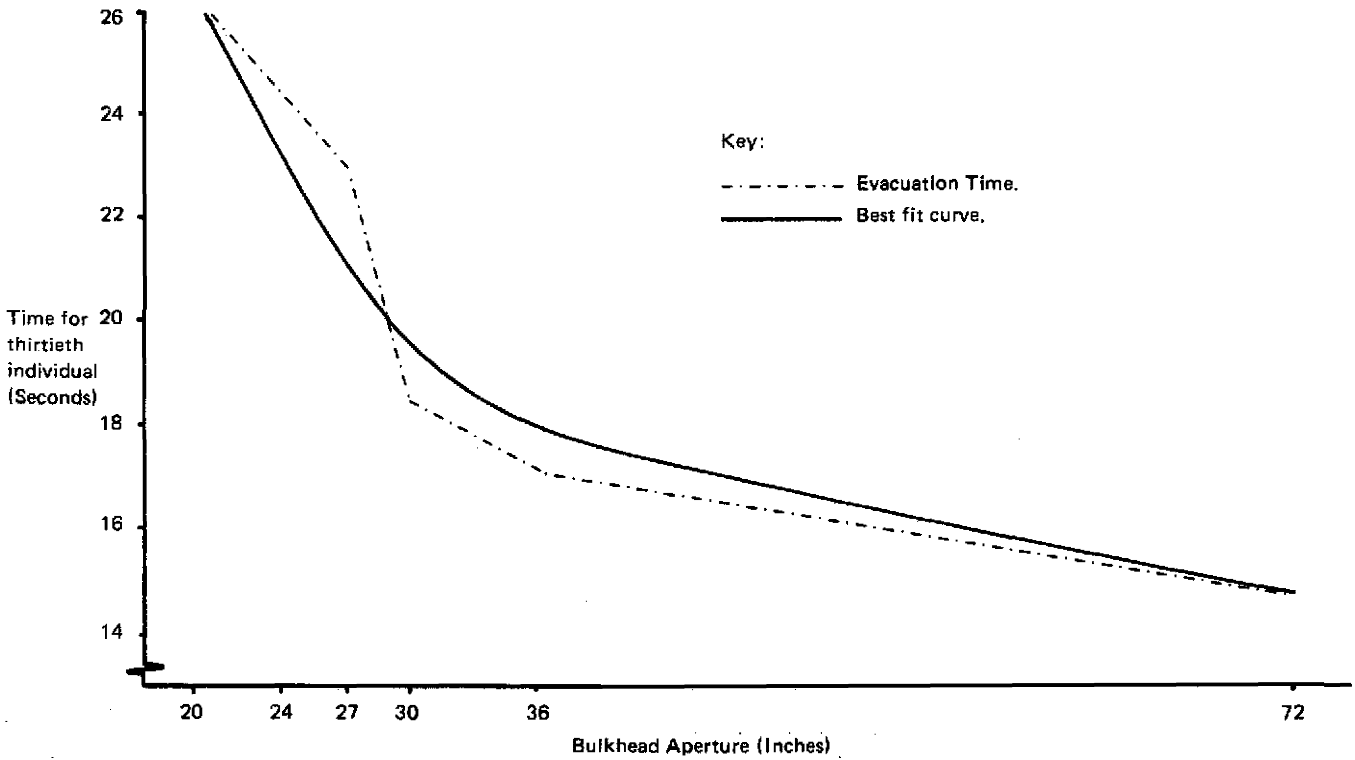


Figure 1 Mean times for competitive evacuations through the bulkhead

(ii) The impact of seating position

Volunteers were seated in rows 8 to 19 in the aircraft, with each row consisting of 6 seats (A to F) (see Appendix C). The analysis which was conducted to assess the impact of seating position included the evacuation times from all of the volunteers through the differing bulkhead configurations.

The mean evacuation times for volunteers from each seat row and location are shown in Tables 3 and 4 below:

Table 3 Mean evacuation time from each row of seats

Number of rows from bulkhead	*Actual row*	*Mean time (in secs)*
0	8	6.3
1	9	9.4
2	10	12.9
3	11	15.4
4	12	17.5
5	13	19.4
6	14	20.8
7	15	24.4
8	16	26.1
9	17	27.7
10	18	28.1
11	19	29.8

Table 4 Mean evacuation time from each seat position (time in seconds)

F	E	D	Aisle	C	B	A
21.2	20.3	19.2		17.8	18.6	19.7

The means from Table 3 suggest that as the distance from the exit was increased the time to evacuate the aircraft was significantly increased ($F_{11,49} = 165$ $p<0.0001$).

A comparison between the means for each seat letter indicated that although differentials existed between the outboard, mid and inboard locations ($F_{5,49} = 2.6$ $p<0.05$), the comparable seats positioned on the port and starboard sides of the aircraft were not shown to differ.

A mean evacuation time from each seat for each of the configurations tested, is presented graphically in the technical report (Ref 1).

(iii) Other factors found to influence the evacuation time

These included the route taken to the exit, ($F_{4,2716} = 5.14$ $p<0.001$), with those who went over seats to the bulkhead, rather than using the aisle, taking longer to evacuate the aircraft.

Not surprisingly those individuals who claimed to have been hindered in their access to and progression along the aisle were shown to be later out of the aircraft than those whose progress had not been impaired. ($T_{,2863} = -13.03$ $p<0.001$)

There were significantly more reported instances of volunteers being obstructed in their route to the bulkhead when the gap was 20″ than in any of the other configurations tested. (Appendix D, Table 2.)

Age was shown to influence the position an individual attained in the evacuation ($F_{4,2846} = 4.4$ $p<0.01$) with those who were under 25 achieving a greater success than those who were over 30.

Males were superior to females ($T_{,2846} = -6.13$ $p<0.0001$). The number of times an individual had flown was not found to be associated with an individuals position in the evacuation.

The existence of a plan of how to reach the exits was not shown to significantly improve the chance of a volunteer being out of the aircraft in the first half of the evacuation ($T_{,1276} = 0.20$ NS).

A full description of these results together with the other information obtained from the questionnaires may be found in the technical report (Ref 1).

3.1.3 *Evacuations through the Overwing Type III Exit*

(i) Passenger flow rates

As in the analysis of the evacuation times through the bulkhead, the evacuation times for the first thirty volunteers to pass through the exit have been compared for the range of configurations tested.

Table 5 Mean evacuation time for the thirtieth individual (time in seconds)

Vertical projection		*Evacuation*					
		1st		*2nd*		*Overall*	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
(i)	3"	83.8	11.2	84.0	0.0	83.9	9.7
(ii)	3"	61.9	4.6	81.0	17.0	71.4	15.0
(iii)	6" (OBR)	55.1	11.6	48.6	1.4	53.2	10.0
(iv)	13"	54.6	13.4	57.5	6.3	55.9	10.3
(v)	18"	49.1	6.5	58.5	7.7	53.7	8.2
(vi)	25"	54.9	14.3	54.9	10.0	54.9	11.5
(vii)	34"	57.2	5.7	67.3	7.2	62.3	8.1

SD = The standard deviation associated with the mean.
OBR = Outboard Seat Removed.

Note:
In conditions (ii) to (vii) – all the seats in the rows bounding access to the exit had limited recline and break-forward but, in condition (i) the movement of only outboard seat backs was restricted.

Blockages led to the abandonment of certain of the evacuations through configurations (i) and (iii). As a result the data for the second evacuation conducted on each test day are based on a sample of one for condition (i) and a sample of 2 for condition (iii).

As the means suggest, the statistical treatment of the data indicated that the seating configuration had a significant effect on the mean evacuation times ($F6,1 = 7.0$ $p<0.001$). Comparisons for the first and second evacuation times were not significantly different ($F6,1 = 0.9$ NS).

Individual comparison of means indicated that the time for the first thirty volunteers to egress through the configuration involving a 3" vertical projection (ie pre Airworthiness Notice No. 79), was significantly longer than the evacuation times for all of the other configurations (see Appendix D Table 3). The raw data from these evacuations may be found in Appendix F.

The influence of an increase to the vertical projection between the seats is shown graphically in Figure 2. The data from the configuration with the 6" vertical seat projection (condition (iii)) has not been included in this figure. In this condition the removal of the outboard seat meant that rather than being a single aisle with a 6" vertical projection adjacent to the exit which would be comparable with the other configurations tested there were two aisles with 6" vertical projections leading to the exits.

(ii) The impact of seating position

This analysis involved the evacuation times from all of the volunteers through the differing seating configurations. The mean evacuation times for each seat row and location are shown in tables 6 and 7 below.

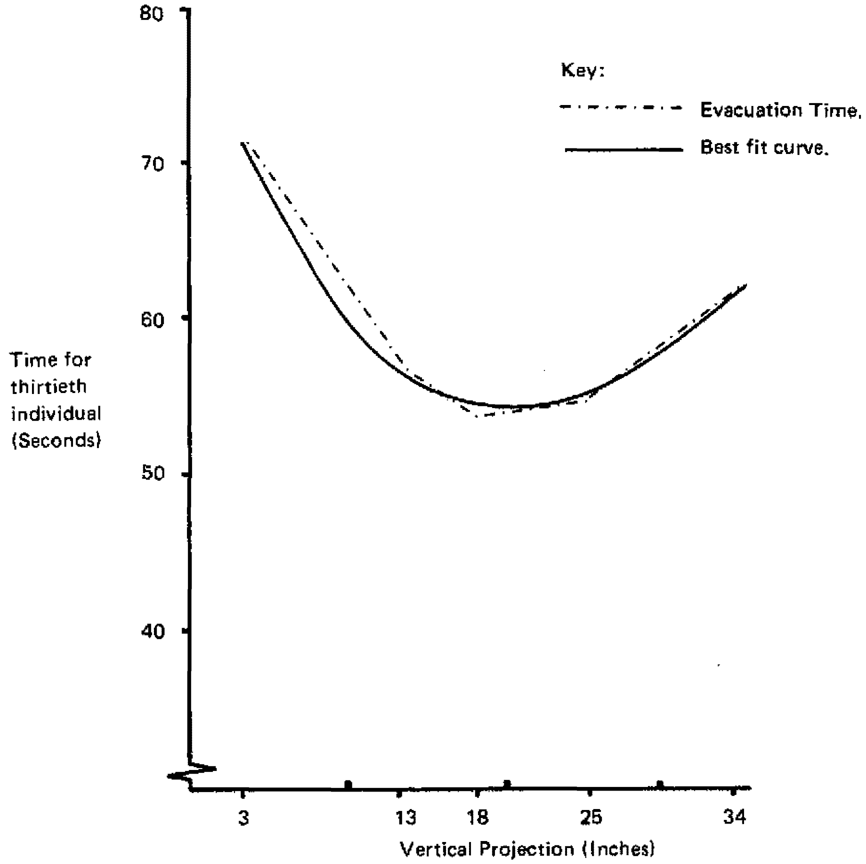


Figure 2 Mean times for competitive evacuations through the overwing exit

Table 6 Mean evacuation time for each row of seats

Number of rows from overwing exit		*Actual row*	*Mean time (in secs)*
6	Aft	8	82.4
5		9	71.6
4		10	66.0
3		11	57.4
2		12	47.7
1		13	37.1
0		14	18.1
1	Forward	15	38.4
2		16	46.8
3		17	56.1
4		18	58.0
5		19	68.9

Table 7 Mean evacuation times for each seat locality (time in seconds)

F	*E*	*D*	*Aisle*	*C*	*B*	*A*
66.4	57.8	49.2		48.4	56.5	58.9

Although a difference was found between the number of rows from the exit ($F1,48 = 42.7$ $p<0.001$) and between seats on the port or starboard side of the aircraft, ($F5,48 = 6.2$ $p<0.001$), no differences were found between volunteers seated forward of the exit and those who were positioned in comparable rows aft of the exit. A comparison of the means for each seat letter indicated that differentials existed between the outboard, mid and inboard locations with the outboard seat on the side opposite to that of the exit which was used (seat F) being at the greatest disadvantage. (Appendix D, Table 4.)

A mean evacuation time from each seat for each of the configurations tested is presented graphically in the technical report (Ref 1).

(iii) Other factors found to influence evacuation times

Other factors included the route taken to the exit with those individuals who did not have to go over seats and were able to use the aisle, having significantly shorter evacuations times ($F5,2056 = 42.5$ $p<0.001$).

Not surprisingly, statistical analysis revealed that those individuals who reported being hindered in their attempt to evacuate, came out later in the evacuation ($T,2679 = -10.2$ $p<0.0001$).

As was found in the evacuations through the bulkhead, age was shown to influence the position an individual attained in the evacuation ($F4,2846 = 3.61$ $p<0.01$) with those over thirty five being significantly slower out of the aircraft. Similarly, males were found to be superior in their ability to evacuate the aircraft ($T,2667 = -9{,}03$, $p<0.0001$).

There were significantly more reports of volunteers being obstructed on their route to the exit caused by conditions (i) (Pre Airworthiness Notice No. 79 with 3″ vertical seat projection) and (vii) (vertical seat projection 34″ equivalent to removing one row of seats beside the exit). (See Appendix D, Table 5.)

The existence of a plan of how to reach the exits, was shown to significantly increase the chance of a volunteer being out of the aircraft in the first half of the evacuation ($T,1374 = 3.75$ $p<0.0001$).

A full description of these results together with the other information obtained from the questionnaires may be found in the technical report (Ref 1).

3.2 Non-competitive evacuations

3.2.1 *Trial programme*

In the test series of evacuations not involving bonus payments, the final data base included information from 24 evacuations. Twelve evacuations were through the bulkhead (2 evacuations were conducted for each of the 6 configurations tested) and twelve evacuations were conducted through the Type III overwing exit (2 evacuations for each of the 6 configurations tested). Over the series of trials 704 volunteers took part. The volunteers were aged between

20 and 50 and 63% were male. All of the planned evacuations were successfully completed as it did not become necessary to halt any of the evacuations as a result of blockages, damage to the equipment or concern for the safety of volunteers.

As in the competitive evacuations, passenger flow rates through the exits were obtained from the video recordings with the evacuation time for each volunteer being taken from the call to evacuate the aircraft rather than from the elapsed time from the first individual to reach the exit.

3.2.2 *Evacuations through the bulkhead*

Comparisons between the mean evacuation times for the six configurations tested were conducted for the first thirty individuals through the exits. This was in order that the analysis would be comparable with that carried out for the competitive evacuations.

Table 8 Mean evacuation times for the thirtieth individual (time in seconds)

Bulkhead aperture	*Mean*	*SD*
20"	25.1	2.0
24"	21.8	1.4
27"	23.7	2.7
30"	23.4	0.0
36"	21.4	3.4
PGR	17.6	0.5

PGR = Port galley removed

At first sight, the means suggest that increasing the width of the aperture through the bulkhead leads to a small reduction in the evacuation times. However, statistically there was no significant difference between the mean evacuation times for the first thirty to evacuate the aircraft ($F_{5,11} = 3.2$ NS) through the six configurations, however this result may have been due to the fact that only two evacuations were conducted through each configuration.

3.2.3 *Evacuations through the Overwing Type III Exit*

Table 9 Mean evacuation times for the thirtieth individual (time in seconds)

Vertical projection	*Mean*	*SD*
3"	53.2	1.8
6" (OBR)	39.6	2.5
13"	39.9	3.3
18"	37.2	0.2
25"	40.8	2.7
34"	35.3	0.6

OBR = Outboard seat removed

As the means suggest statistical treatment of the data indicated a significant difference between the mean evacuation rates for the various configurations ($F_{5,11} = 16.84$ $p<0.01$).

Individual comparisons of means indicated that the seating configuration involving a 3″ vertical projection gave rise to significantly increased evacuation times when compared to any of the other configurations (see Appendix D, Table 6).

3.3 Comparison between the competitive and non-competitive evacuations

3.3.1 *Comparison between the times for the evacuations through the bulkhead*

Table 10 Competitive and non-competitive mean evacuation times for the thirtieth person to exit over the six bulkhead conditions

	Competitive trials		*Non-competitive trials*	
Bulkhead aperture	*Mean*	*SD*	*Mean*	*SD*
20″	26.3	2.9	25.1	2.0
24″	24.5	5.8	21.8	1.4
27″	23.2	7.1	23.7	2.7
30″	18.4	1.9	23.4	0.0
36″	17.2	3.1	21.4	3.4
PGR	14.7	1.4	17.6	0.5

PGR = Port galley removed

The mean times show that for the 20″ and 24″ bulkhead apertures the times for thirty people to exit were a little faster in the non-competitive trials. For the remaining widths, the times were faster in the competitive trials. Statistical analysis indicated that there was an overall difference between the means for the six configurations ($F5.1 = 11.87$ $p<0.01$). The total of 12 non- competitive evacuations as opposed to 56 competitive evacuations meant that no significant difference was found between the means for the competitive and non-competitive evacuations ($F5,1 = 0.2$ NS).

The comparative data is represented graphically in Figure 3.

3.3.2 *Comparison between the times for the evacuations through the Overwing Type III Exit*

Table 11 Competitive and non-competitive mean evacuation times for the thirtieth person to exit over the six overwing conditions

Vertical projection	*Competitive trials*		*Non-competitive trials*	
	Mean	*SD*	*Mean*	*SD*
3″	71.4	15.0	53.2	1.8
6″ (OBR)	53.2	10.0	39.6	2.5
13″	55.9	10.3	39.9	3.3
18″	53.7	8.2	37.2	0.2
25″	54.9	11.5	40.8	2.7
34″	62.3	8.1	35.3	0.6

OBR = Outboard seat removed

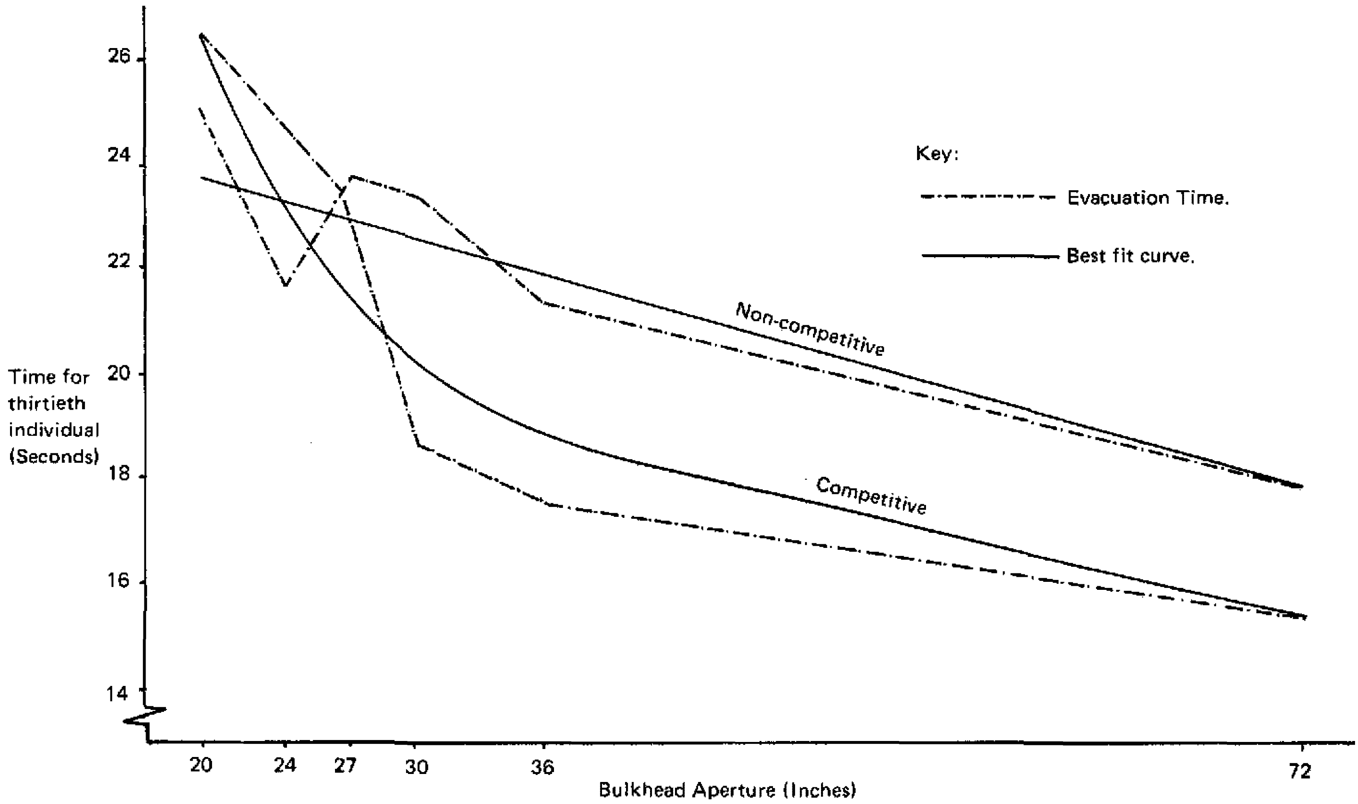


Figure 3 Mean times for competitive and non-competitive evacuations through the bulkhead

As can be seen from the means, the times to evacuate thirty passengers were slower in the competitive trials for all of the configurations tested ($F5,1 = 37.99$ $p<0.001$). In Figure 4 the influence of an increase to the vertical projection between the seats is shown graphically. As in Figure 2, the data from the configuration with the 6″ vertical projection (condition (iii)) has not been included in this figure. The removal of the outboard seat meant that rather than there being a single aisle with a 6″ vertical projection adjacent to the exit which would be comparable to the other conditions, there were two aisles with 6″ vertical projections leading to the exit.

There was also an overall significant difference between the means for the six configurations ($F5,1 = 9.28$ $p<0.001$).

4 DISCUSSION

4.1 Evacuations through the bulkhead

The results from the evacuations which were conducted involving competition between volunteers for bonus payments clearly indicated that as the width of the aperture in the bulkhead was increased, passengers were able to evacuate the aircraft more quickly. During these evacuations, there was a sudden rush towards the front of the cabin once the call to evacuate the aircraft had been made. This frequently lead to temporary blockages caused by people struggling to get through the gap in the bulkhead ahead of those beside them. The smaller the aperture in the bulkhead, the more pronounced and more frequently the blockages

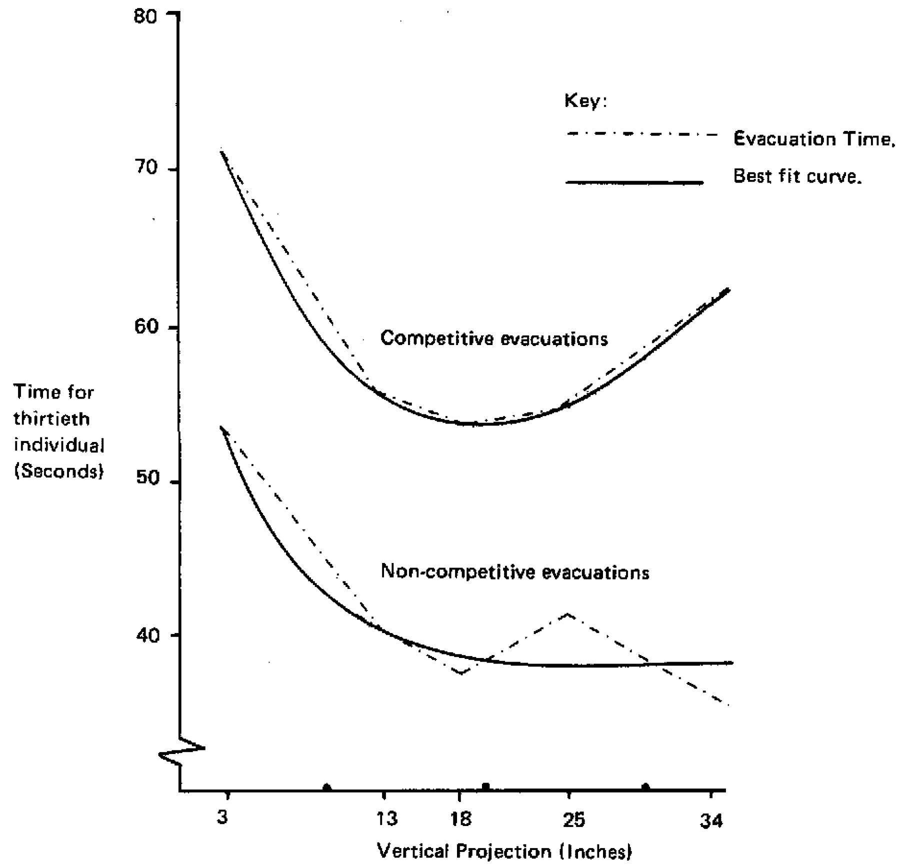


Figure 4 Mean times for competitive and non-competitive evacuations through the overwing exit

seemed to occur. The blockages and people struggling against each other contributed to the slower evacuation times found in the results. The fact that the evacuation times for the 20", 24" and 27" apertures were significantly slower than for the 30" and 36" and the port galley unit removed conditions, suggests that consideration could be given to a minimum width of 30" for a passageway through a bulkhead.

The most rapid evacuation occurred when the port galley unit had been removed. This configuration had the disadvantage that the member of cabin staff responsible for opening the aft Type I exit, had no bulkhead to protect her from the sudden rush of people following the call to evacuate the aircraft. As a result she frequently experienced difficulty opening the exit and on a number of occasions she was pushed out of the aircraft by the surge of passengers. In an emergency, cabin staff are not only responsible for the opening of the exits to be used, but they must also ensure that the chutes are inflated. They are also expected to direct and if necessary assist passengers. If the member of cabin staff is evicted from the aircraft by the rush of passengers, the resulting evacuation may become disorganised and less efficient, resulting in an increased probability of injuries and fatalities.

In the competitive evacuations the behaviour of volunteers travelling through the cabin towards the bulkhead was observed to show marked similarity to the behaviour which has been reported by survivors from some aircraft accidents after the conditions in the cabin have become extreme. There were instances of people getting arms and legs trapped between or under seats, occasionally individuals were pushed onto the floor between rows of seats or were trapped by their seat backs being pushed down on top of them by others coming over the seat quickly from behind. There were instances of torn clothing, broken spectacles and watch straps and shoes lost.

Reports of aircraft accidents have indicated that fatalities have been found in passageways through bulkheads. On a number of occasions, volunteers fell or were pushed in the competitive evacuations. If the evacuations had not been halted immediately they would have been trampled unseen by the later volunteers in their rush to evacuate the aircraft. Since there were fewer blockages when the aperture in the bulkhead was increased there was less danger of the volunteers falling and being injured.

In the configurations in which the aperture in the bulkhead was narrow, the member of cabin staff located in this area found that, in addition to directing volunteers to the exits, an important part of her task was to assist people who had become trapped against the bulkhead by the pressure of others pushing from behind. On a number of occasions it was necessary for the member of cabin staff to catch hold of passengers who had started to fall, in order to enable them to stay on their feet and keep moving towards the exit.

In the non-competitive evacuations, the differences between the times for the first thirty passengers to evacuate in the six configurations tested, did not reach statistical significance. Nevertheless the results did show the same general trend as the results from the competitive evacuations, in that the evacuation times were reduced as the aperture in the bulkhead was increased (see Figure 3). One exception was the 24" configuration which produced a faster evacuation time than would have been predicted from the overall trend.

The behaviour in the non-competitive evacuations was far less extreme than that witnessed in the competitive evacuations. Although the volunteers were given exactly the same verbal instructions in the cabin, and the behaviour of the cabin staff remained unchanged, there were no instances of passengers running across seats or people becoming trapped. The evacuation proceeded in a rapid but essentially orderly manner, with the behaviour of the passengers being similar to that witnessed during both evacuation certification demonstrations, precautionary evacuations and during some accidents. As a consequence, there were no real instances of blockages of people in the passageway through the bulkhead, although when the aperture was narrow some volunteers experienced difficulty squeezing through and then quickly turning left to the exit.

In the competitive evacuations, the effect of the bonus payments was to increase the motivation of the volunteers to get out of the aircraft as quickly as possible. The reason that the evacuation times for the narrower bulkhead configurations were slower in the competitive evacuations, than in the non- competitive evacuations (see Figure 3) was due to the blockages and struggling caused by some passengers trying to get through the bulkhead ahead of other people. This did not occur in the non-competitive evacuations where volunteers worked collaboratively to allow everyone through the narrow gap as quickly as possible, thus no blockages occurred.

By contrast, in the evacuations through the wider bulkhead configurations, blockages did not tend to occur as there was sufficient space for people to pass through the bulkhead whilst trying to get ahead of the others around them. In these circumstances, the effect of the bonus payments was to increase the effort which individual volunteers made to get out of the aircraft and therefore the times for the competitive evacuations were faster than for the non- competitive evacuations. In other words, it is only when the configuration in the aircraft will lead to the flow of people being restricted during the evacuation process, that the competitive element of behaviour, known to occur in emergencies will be a problem. Not surprisingly, one of the important findings is that as long as there is sufficient space through which people can evacuate, increasing the motivation to escape, will increase the speed at which evacuation is completed.

4.2 Evacuations through the Overwing Type III Exit

As in the results obtained from the evacuations through the bulkhead, in the competitive evacuations through the overwing exit, there was a sudden rush towards the exit once the call to evacuate had been made and the operator had started to open the exit. Volunteers seated near the front of the cabin were frequently observed to initially rush forward as soon as the call to evacuate had been made, as they could not at first see that it was the overwing exit which was being opened. The member of cabin staff seated behind the bulkhead beside the Type I exit was not visible until she had left her seat and moved through the bulkhead into the aisle. She was then able to direct the volunteers back in the direction of the overwing exit. In other respects the behaviour by volunteers in the cabin in the competitive evacuations was essentially similar to that observed in competitive evacuations through the bulkhead.

In the competitive evacuations when the configuration of the seating adjacent to the overwing exit involved a vertical projection of 3", and the movement of the backs of the outboard seats only was restrained (condition (i)) there was a continuous series of people temporarily trapped in the exit aperture. This was caused by groups of passengers pushing and all trying to get out at the same time. On three occasions the blockages became so severe that the safety officer had to halt the evacuation. It was apparent from the video data how easily this exit could become blocked with passengers in an aircraft accident. A comparison of the data from the evacuations through the two configurations which involved a vertical projection between the seat rows of 3", clearly indicated the importance of restricting the movement of the backs of all of the seats in rows adjacent to the exit. When the movement of the backs of these seats was restricted (condition (ii)), the evacuation flow rate was significantly faster than when only the movement of the back of the outboard seat was restricted (condition (i)). Furthermore, in the evacuations in which the movement of all of the backs of the seats in the row was restricted, and the vertical seat projection was 3" (condition (ii)), there were no instances of abandoned evacuations as a result of blockages in the exit aperture.

In the configuration in which the outboard seat was removed and the vertical seat projection was 6", two of the eight evacuations were halted when the exit became blocked. The evacuation flow rates for this configuration varied widely. The seat configuration caused passengers to arrive at the exit in two streams which met in the space vacated by the removal of the outboard seat. If one stream became dominant, the passengers from this stream would egress with the injection of the occasional passenger from the other stream. In this instance the evacuation was rapid and the space created by the removal of the outboard seat was of considerable benefit. If, however, there was continuous competition at the exit between individual passengers from the two streams, this reduced the speed of the evacuation and on two occasions lead to a complete blockage at the exit.

As the distance between the seat rows was increased, the tendency for blockages to occur in the doorframe was reduced. The results of the evacuation flow rates indicated, that as the vertical projection between the seats was increased from 3" to 25" the speed of the evacuation of the first thirty volunteers was increased. However, when the vertical projection between the seats was increased from 25" to 34", the evacuation time became longer. A 34" vertical projection is equivalent to the removal of a whole row of seats. Once the vertical projection exceeds 25" it would appear that the channel which is made between the seat rows allows more people into the area than can get through the exit at once. Thus the blockages tend to recur and this in turn causes the evacuation to take a longer period of time. It was interesting to note that the volunteers reported more instances of being obstructed on their route to the exit in the 3" and 34" vertical seat projection configurations than in the other four configurations tested.

In the non-competitive evacuations the volunteers were able to evacuate the aircraft more quickly than in the competitive evacuations in all of the seating configurations. This finding is illustrated in Figure 4. However, unlike the evacuations through the bulkhead, there were marked differences between the evacuation times as a function of the configuration. These differences occurred because as the distance between the rows of seats beside the exit were reduced it became physically more difficult for volunteers to pass between the rows of seats and step over the side of the fuselage onto the wing. Since volunteers were not competing but working collaboratively, an increase in the distance between the seats lead to a shorter evacuation time (see Figure 4).

The two members of staff responsible for the opening of the overwing exit were given special training prior to the evacuations. This enabled them to open the hatch in almost exactly the same time in all of the evacuations, regardless of the seating configuration beside the exit. This was done in order to remove this variable from being a compounding factor in the data. In the course of the evacuations they discovered, that in spite of their training, the seating configuration beside the exit influenced the ease with which they were able to open the hatch. In the competitive evacuations, the rush of people towards the exit caused particular problems when the seat row at the exit had the outboard seat removed. In this configuration volunteers crowded into the space obtained by the removal of the outboard seat, making it extremely difficult for the operator to withdraw the hatch into the cabin, turn it on one side and then push it out onto the wing. This difficulty was not experienced to the same extent in any of the other configurations.

The times obtained from both the competitive and non-competitive evacuations clearly indicate that the two seating configurations introduced by the CAA in Airworthiness Notice 79 have significantly increased the rate at which passengers can be expected to evacuate through a Type III overwing exit. As Figure 4 illustrates, the evacuation times in both the competitive and non-competitive evacuations for the 13", 18" and 25" vertical seat projections are not significantly different, although an 18" vertical projection would appear to be the optimum.

In an emergency, the passenger seated beside the overwing exit will be required to open the hatch. Their instruction will be the information which they will have obtained from the placards on the seat backs in front of them. A further investigation involving volunteers from the public opening this exit whilst being pushed by other people, would be required in order to explore the influence of the seating configuration on the efficiency of opening and disposing of the hatch.

4.3 Methodological implications

The video data and reports from volunteers indicated that the system of bonus payments successfully motivated volunteers to compete against each other in order to evacuate the aircraft. It is suggested therefore that the method can be used in order to produce as realistic a simulation of emergency escape behaviour as safety and ethical principles will permit. At the end of each day of competitive evacuations many of the volunteers stated that they had been pleased to take part and would be willing to do so again. They also stated that they had learnt a great deal about how to get out of an aircraft in an emergency but that they had found the rush of people a frightening experience.

The video and questionnaire data from the evacuations have also provided an insight into the dynamics of behaviour within the cabin which have been reported in an actual emergency. A group of survivors from an aircraft accident which had involved smoke and fire, viewed the videos of the evacuations. They reported that in the accident in which they were involved, immediately the doors had been opened the evacuation proceeded in an orderly manner with the behaviour of passengers being similar to that observed in the non-competitive evacuations. However, in the latter part of the evacuation once the conditions in the cabin became life threatening, the behaviour of passengers changed and became similar to that seen in the competitive evacuations.

In the competitive evacuations aisles and exits were blocked by the sheer numbers of people trying to egress, volunteers walked over others, some searched for friends and family before making any attempt to escape. Some participants managed to by-pass others and come from the back to the front of the aircraft, occasionally volunteers near operational exits did not achieve the bonus payments and a percentage of volunteers had problems undoing their seat belts. Within the trials, the instances of panic were negligible whilst there was a notable number of volunteers who were unable to move, that is behaviourally inactive, a phenomenon which is seen in accident situations.

Individuals are known to vary in their mental and physical abilities to respond to emergency evacuations. It was interesting to discover that this also occurred in the competitive evacuations. The seating of volunteers was designed in such a way that if everyone had come out in an orderly manner, each volunteer would have obtained a bonus on two out of four evacuations. In practice only 37.3% obtained two bonuses. Some volunteers managed to obtain bonuses on all four evacuations (8.7%) whilst others were never able to get out in the first half (12.2%). Approximately 42% obtained either one (17.2%) or three (24.6%) bonuses.

Information from aircraft accident reports suggest that males who are young and fit have the best chance of survival and that in general men are more likely to survive than women. This finding was replicated in the competitive evacuations with men being more likely than women to be in the first half of the evacuation. Although all of the volunteers had to declare themselves medically fit and were from a restricted age range, the data indicated that the younger volunteers tended to be more likely to be among the first half to evacuate the aircraft. The sample of volunteers did not represent a cross- section of the flying public in that they were self-selected, under fifty, fit and healthy. It must therefore be recognised that in an accident, the evacuation times are likely to be considerably longer and the problems greater than in this reported programme of simulated evacuations.

5 CONCLUSIONS

1. The experimental programme successfully met the objective to produce a series of simulated emergency evacuations in order to explore the influence of (a) increasing the width of the aperture in the bulkhead at the entrance to the galley vestibule leading to the Type I exits and (b) increasing the distance between seat rows next to the Type III overwing exit.

2. The results from the programme of evacuations involving competition between passengers suggested that increasing the width of the aperture through the bulkhead will lead

to an increase in the speed at which passengers can evacuate the aircraft in an emergency. The fact that the evacuation times for the 20", 24" and 27" apertures were significantly slower than those for the 30" and 36" configurations, suggest that consideration could be given to a minimum width of 30" for a passageway through a bulkhead.

3 The results from the evacuations through the Type III overwing exit, indicated that changes to the distances between the seat rows either side of the exit will influence the speed of the evacuation.

4 The configuration flown by UK and other operators prior to the publication of Airworthiness Notice No. 79 was shown to reduce the evacuation rate and to cause serious blockages.

5 The configuration in which a seat row is completely removed was found to produce slower evacuation flow rates than those with a vertical projection between the seat rows ranging from 13" to 25".

6 The two alternate minimum requirements specified for the seating configuration beside the overwing exit in Airworthiness Notice No. 79, were shown to have significantly increased the rate at which passengers can evacuate an aircraft in a simulated emergency.

7 The CAA minimum (in AN 79) in which the outboard seat was removed, gave rise to a rapid evacuation flow rate. However not only did this configuration have a tendency to give rise to blockages, but the opening and disposing of the exit was found to be more difficult in this configuration.

8 Further investigations are recommended to investigate the influence of (i) the seating configuration on the ease of the operating the exit and (ii) the positioning of the hatch in the cabin on the evacuation rate.

9 The results from a comparison of the video data from the competitive and non-competitive evacuations indicated that the non-competitive evacuations provided an effective simulation of passenger behaviour in precautionary evacuations, and in aircraft evacuations when the physical conditions in the cabin have not deteriorated.

10 The introduction of incentive payments to volunteers, successfully induced a simulation of the behaviour reported to occur among passengers, when conditions in the cabin are perceived to be life threatening.

11 The use of incentive payments to produce a competitive evacuation has been shown to have the potential to provide both the behavioural and statistical data required for the assessment of design options or safety procedures for use in emergency evacuations which maximise the degree of realism. Nevertheless the technique should be used sparingly since it can be potentially hazardous for volunteers.

CONTRIBUTORS TO THE RESEARCH

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

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

3 Ms C Marrison, from the Applied Psychology Unit, was responsible for the majority of the implementation of the evacuation programme and analysis of the experimental data. The competitive evacuations occasionally involved some personal risk.

4 Ms A Evans, from the Applied Psychology Unit, provided assistance with the collection and analysis of data.

5 Mr F Taylor of the Aviation Safety Centre, was responsible for the management of the changes to the structure of the cabin and the aircraft seating. His role as the overwing exit operator was on occasions difficult and threatening.

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

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.

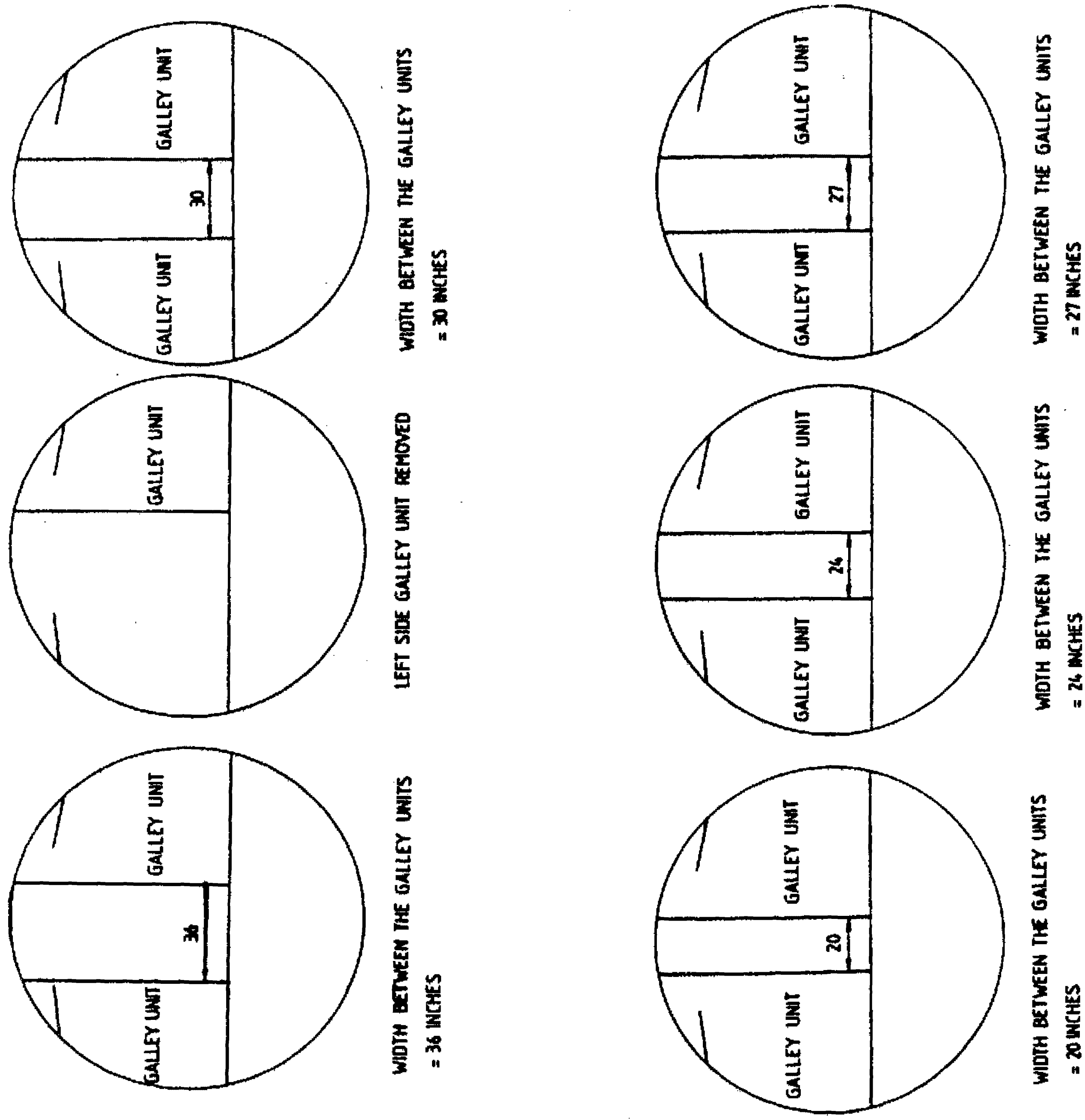
6 REFERENCES

1 '*The Effect on Aircraft Evacuation of Competitive Passenger Behaviour Giver Specified Constraints*' Marrison C and Muir H C, Technical Report, Cranfield Institute of Technology, 1989.

2 Airworthiness Notice No. 79, '*Access to and Opening of Type III and Type IV Emergency Exits*' published by the Civil Aviation Authority, 1986.

3 '*The Effect of Proximal Seating Configuration on Door Removal Time and Flow Rates Through Type III Emergency Exits*', Rasmussen P G and Chittum C B. Memorandum No. AAM-119-86-8 Federal Aviation Administration 1986.

APPENDIX A


GALLEY UNIT
GALLEY UNIT
36
WIDTH BETWEEN THE GALLEY UNITS
= 36 INCHES
GALLEY UNIT
LEFT SIDE GALLEY UNIT REMOVED
GALLEY UNIT
GALLEY UNIT
30
WIDTH BETWEEN THE GALLEY UNITS
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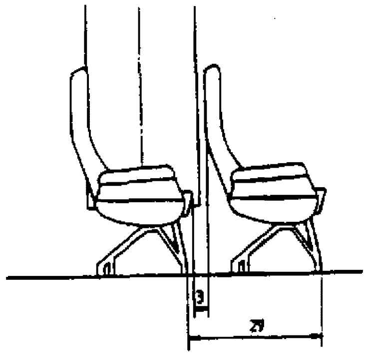
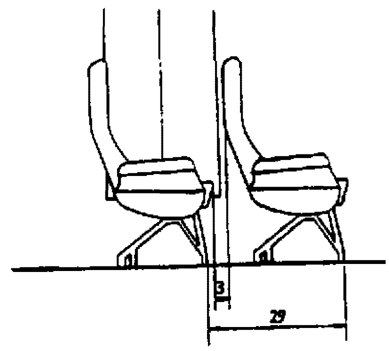
24
WIDTH BETWEEN THE GALLEY UNITS
= 24 INCHES
GALLEY UNIT
GALLEY UNIT
27
WIDTH BETWEEN THE GALLEY UNITS
= 27 INCHES

APPENDIX B

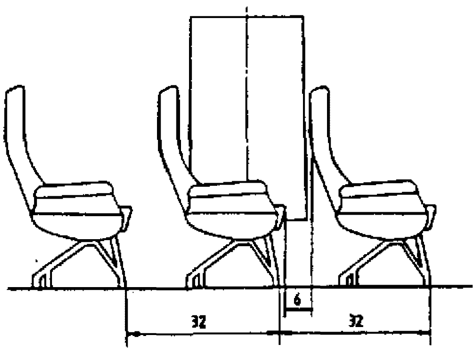
For configurations (ii) to (vii) the seat backs remain in a fixed position



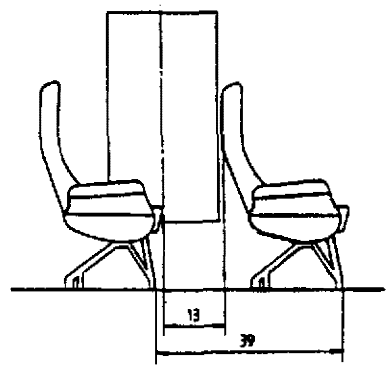
Configuration (i) SEAT PITCH – 29 INCHES
VERTICAL PROJECTION – 3 INCHES



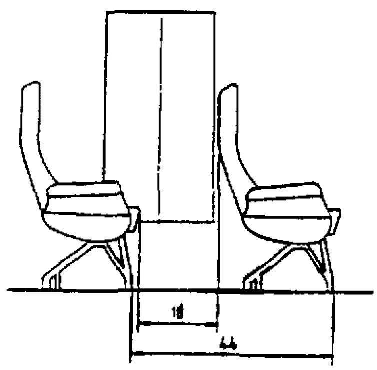
Configuration (ii) SEAT PITCH – 29 INCHES
VERTICAL PROJECTION – 3 INCHES



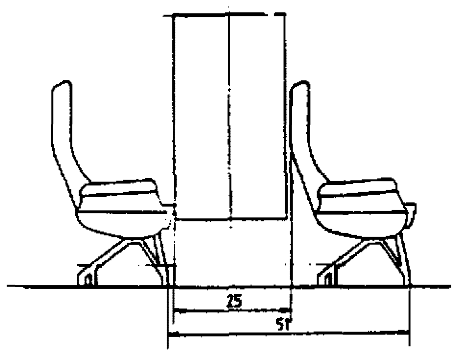
Configuration (iii) SEAT PITCH – 32 INCHES
VERTICAL PROJECTION – 6 INCHES
EQUIVALENT TO AN 79 REQUIREMENTS
WITH OUTBOARD SEAT REMOVED



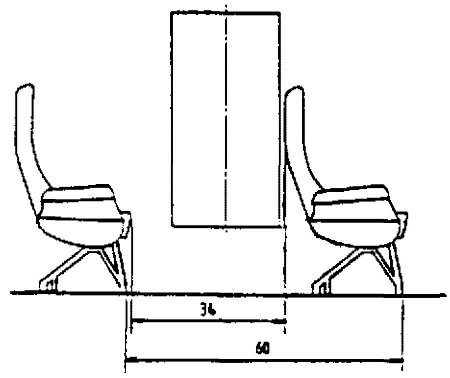
Configuration (iv) SEAT PITCH – 39 INCHES
VERTICAL PROJECTION – 13 INCHES
EQUIVALENT TO AN 79 REQUIREMENTS



Configuration (v) SEAT PITCH – 44 INCHES
VERTICAL PROJECTION – 18 INCHES

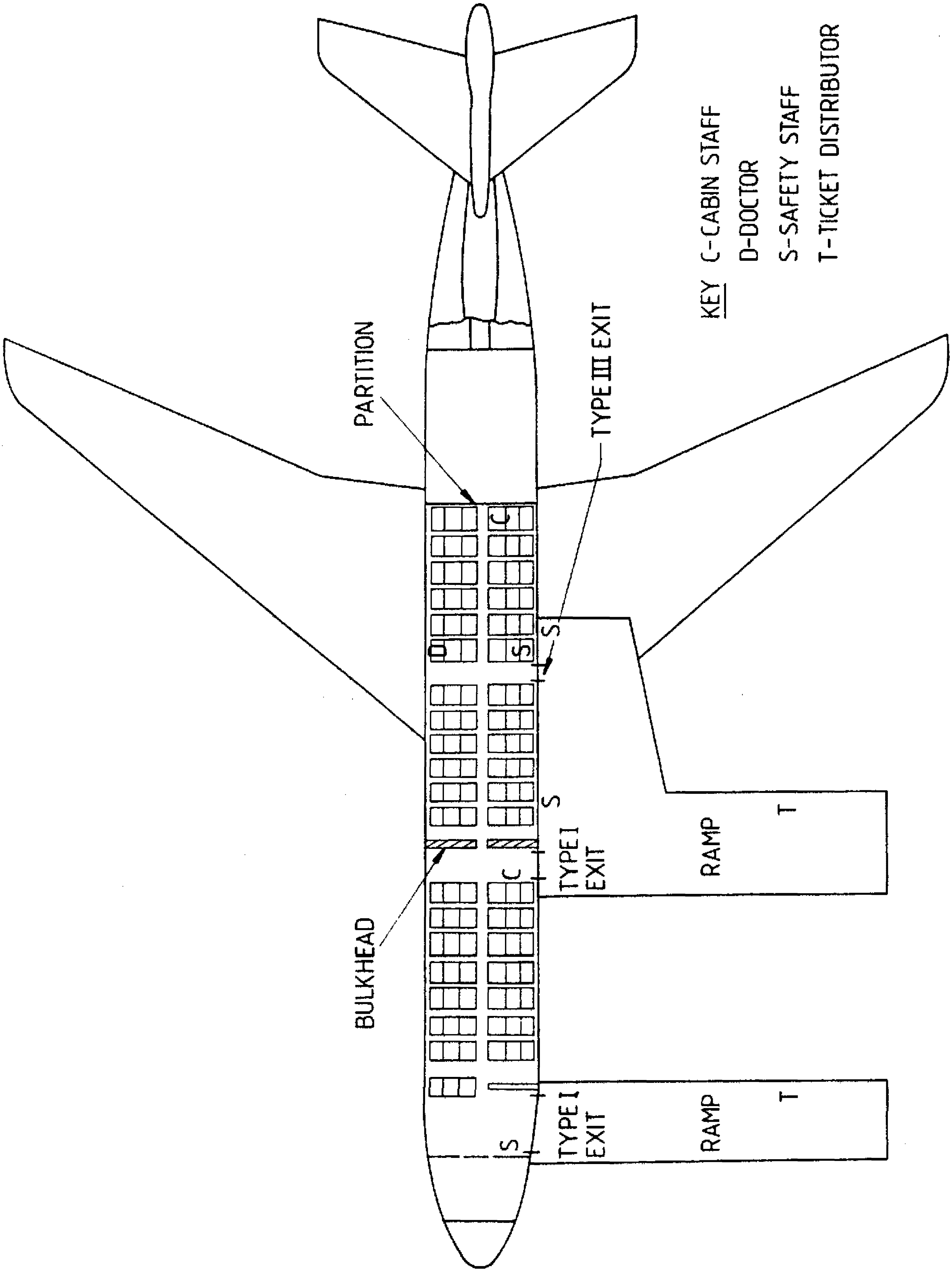


Configuration (vi) SEAT PITCH – 51 INCHES
VERTICAL PROJECTION – 25 INCHES



Configuration (vii) SEAT PITCH – 60 INCHES
VERTICAL PROJECTION – 34 INCHES

APPENDIX C



PARTITION
TYPE III EXIT
KEY C-CABIN STAFF
D-DOCTOR
S-SAFETY STAFF
T-TICKET DISTRIBUTOR
C
D
S
S
S
C
S
TYPE I EXIT
TYPE I EXIT
RAMP
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BULKHEAD

APPENDIX D

Table 1 Competitive evacuations through the bulkhead
Post-hoc comparisons at the 0.05 level (Newman-Keuls)

Bulkhead aperture	*PGR*	*36″*	*30″*	*27″*	*24″*	*20″*
PGR						
36″						
30″						
27″	*	*	*			
24″	*	*	*			
20″	*	*	*			

Notes
* denotes pairs of groups significantly different at the 0.05 level
PGR = Port galley removed
OBR = Outboard seat removed

Table 2 Competitive evacuations through the bulkhead and reports of obstructions
Post-hoc comparisons at the 0.05 level (Newman-Keuls)

Bulkhead aperture	*PGR*	*36″*	*30″*	*27″*	*24″*	*20″*
PGR						
36″						
30″						
27″						
24″						
20″	*	*	*	*		

Table 3 Competitive evacuations through the overwing Type III exit
Post-hoc comparisons at the 0.05 level (Newman-Keuls)

Vertical projection		*(iii)*	*(v)*	*(vi)*	*(iv)*	*(vii)*	*(ii)*	*(i)*
		6″ (OBR)	18″	25″	13″	34″	3″	3″
(iii)	6″ (OBR)							
(v)	18″							
(vi)	25″							
(iv)	13″							
(vii)	34″							
(ii)	3″							
(i)	3″	*	*	*	*	*	*	

Table 4 Competitive evacuations through the overwing Type III exit: influence of seat position on ease of egress

Post-hoc comparisons at the 0.05 level (Newman-Keuls)

Seat letter	*C*	*D*	*B*	*E*	*A*	*F*
C						
D						
B	*	*				
E	*	*				
A	*	*				
F	*	*	*	*	*	

Table 5 Competitive evacuations through the overwing Type III exit: reports of obstructions

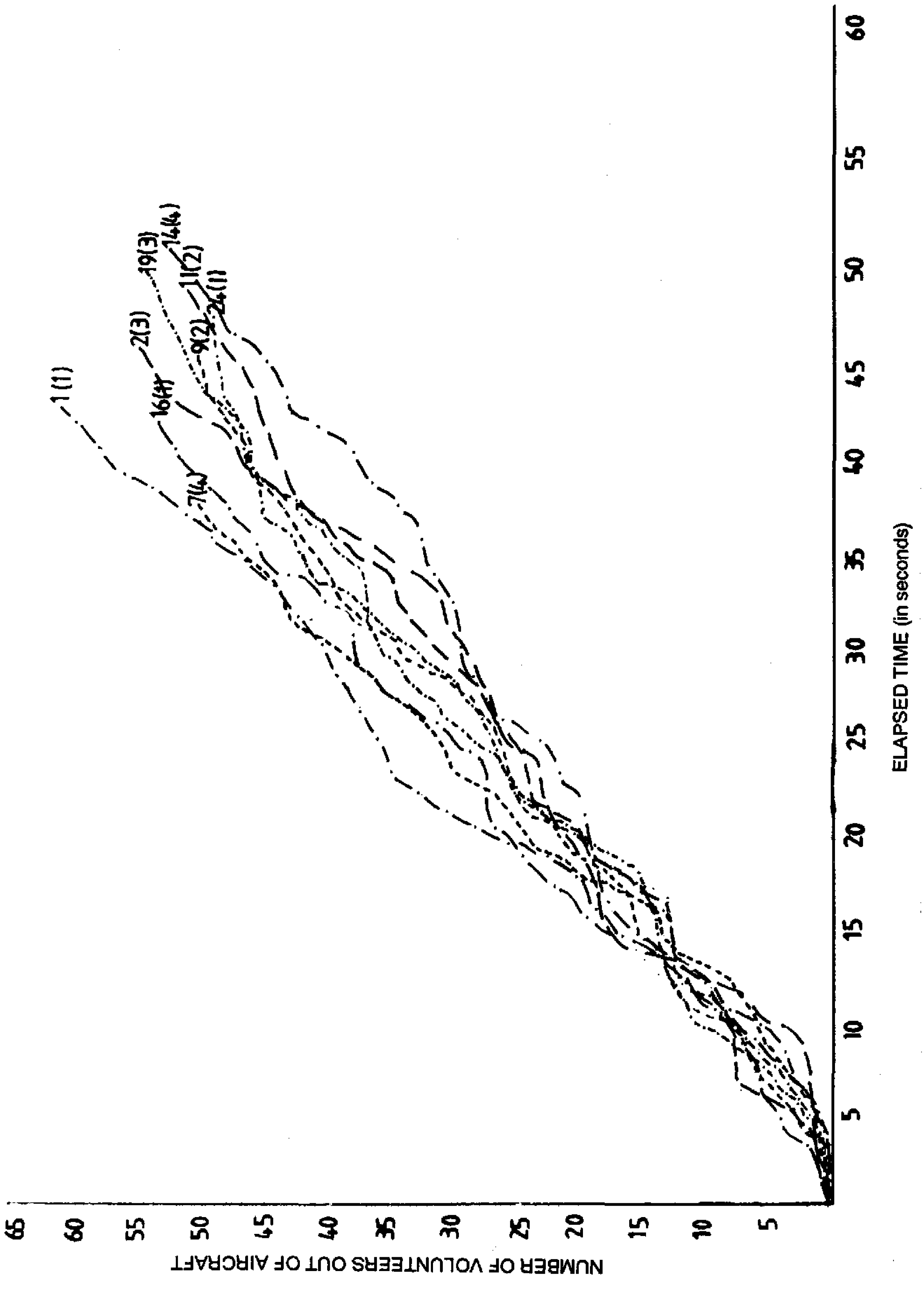
Post-hoc comparisons at the 0.05 level (Newman-Keuls)

Vertical projection		*(vi)*	*(v)*	*(iv)*	*(iii)*	*(ii)*	*(vii)*	*(i)*
		25″	18″	13″	6″ (OBR)	3″	34″	3″
(vi)	25″							3″
(v)	18″							
(iv)	13″							
(iii)	6″ (OBR)							
(ii)	3″							
(vii)	34″	*	*	*	*	*		
(i)	3″	*	*	*	*	*		

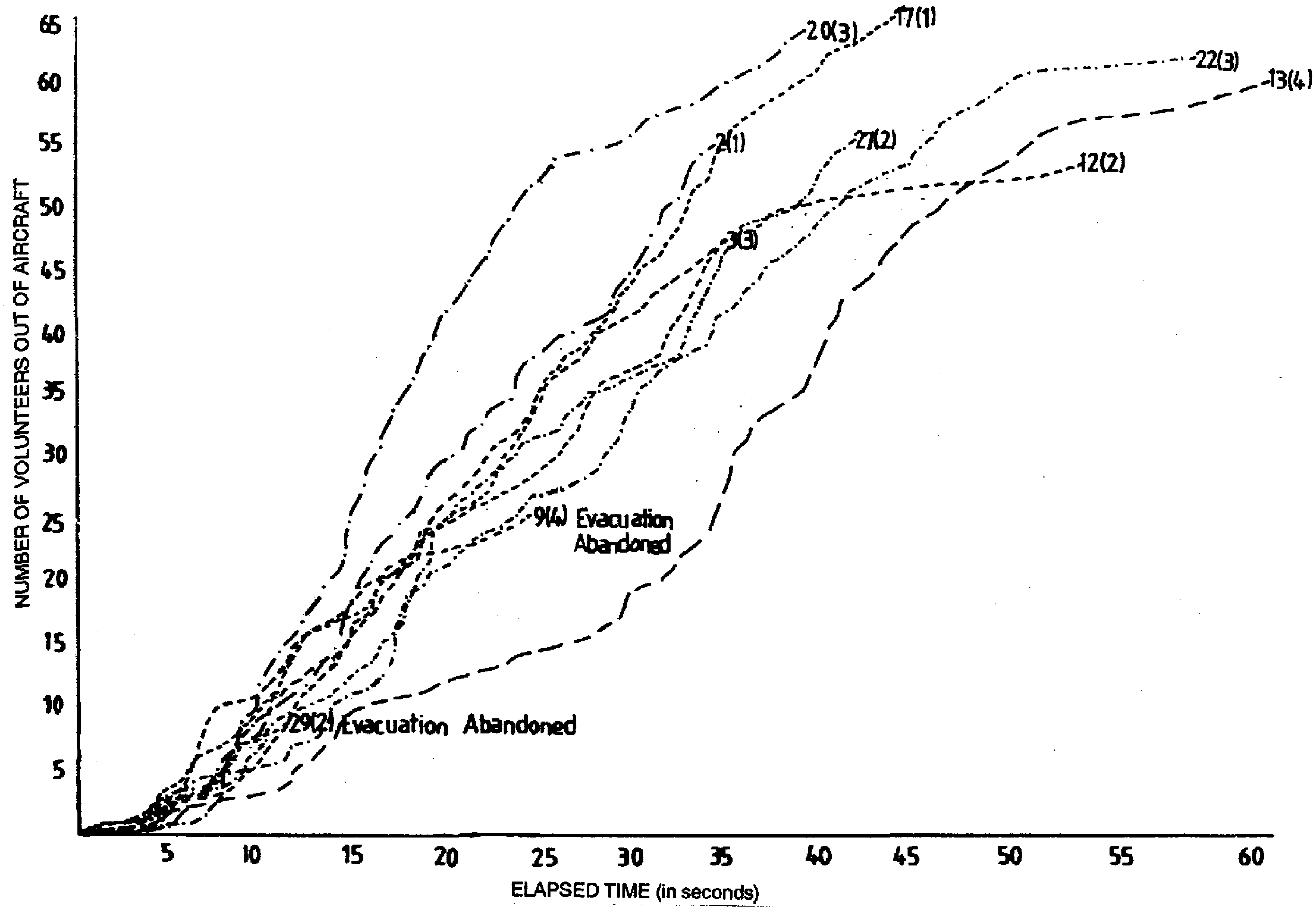
Table 6 Evacuations through the overwing Type III exit: summary of analyses of variance of comparisons between competitive and non-competitive evacuations

Vertical projection	*Significant difference*
3″ (pre AN 79)	Yes
6″ (OBR)	No
13″	Yes
18″	No
25″	No
34″	Yes

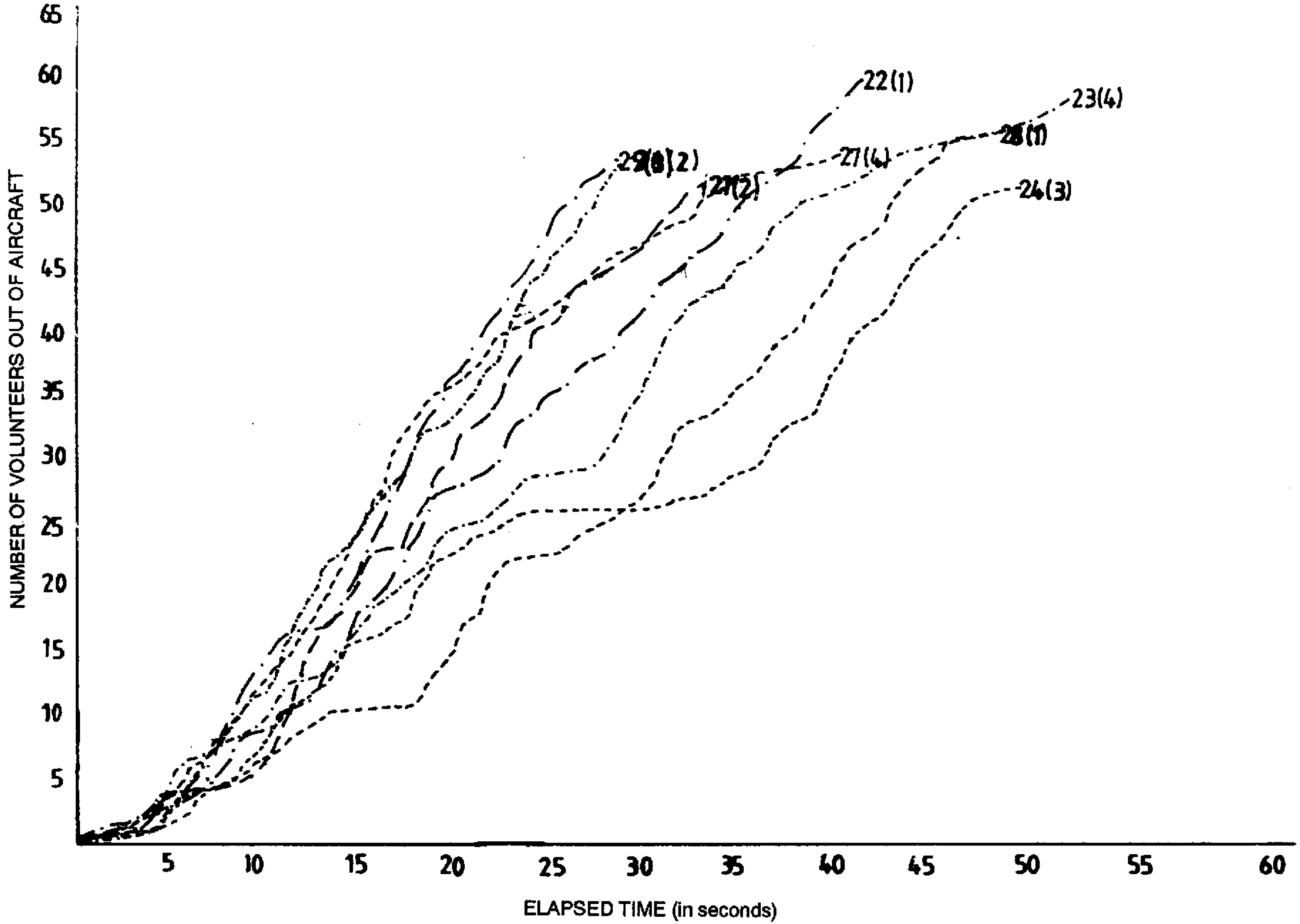
APPENDIX E



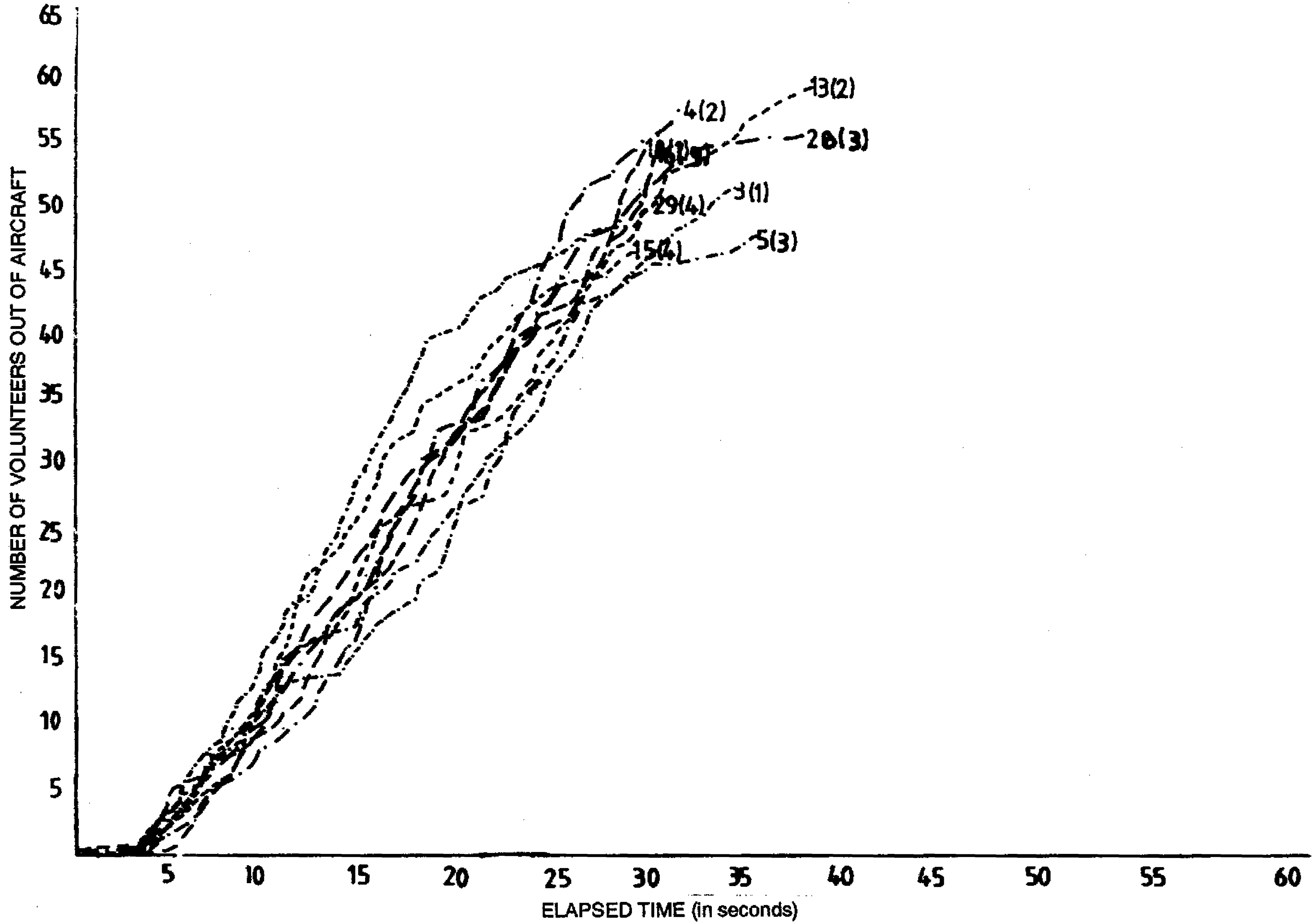
Graphical representation of evacuation flow through a 20" bulkhead aperture – all evacuations



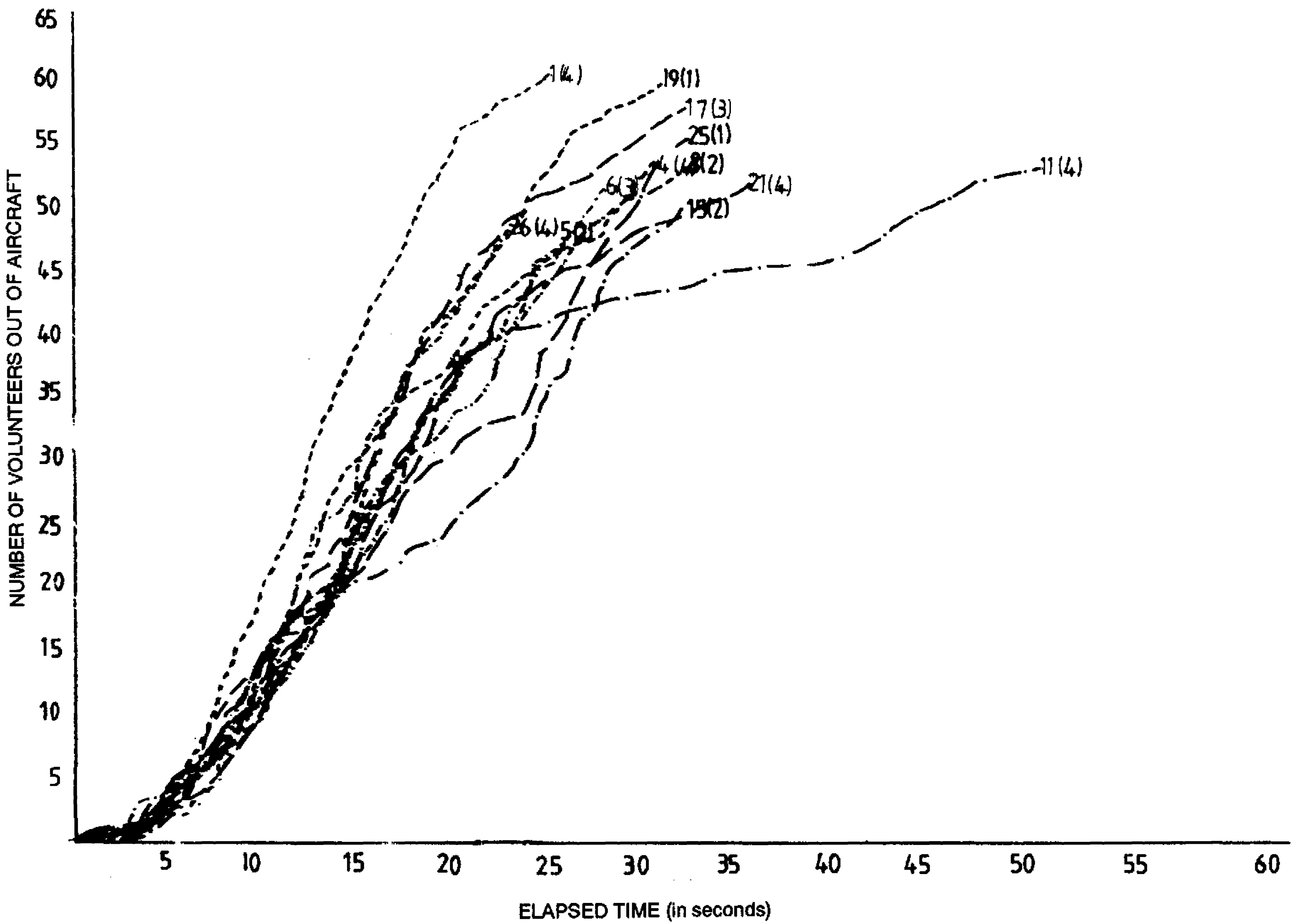
Graphical representation of evacuation flow through a 24" bulkhead aperture – all evacuations



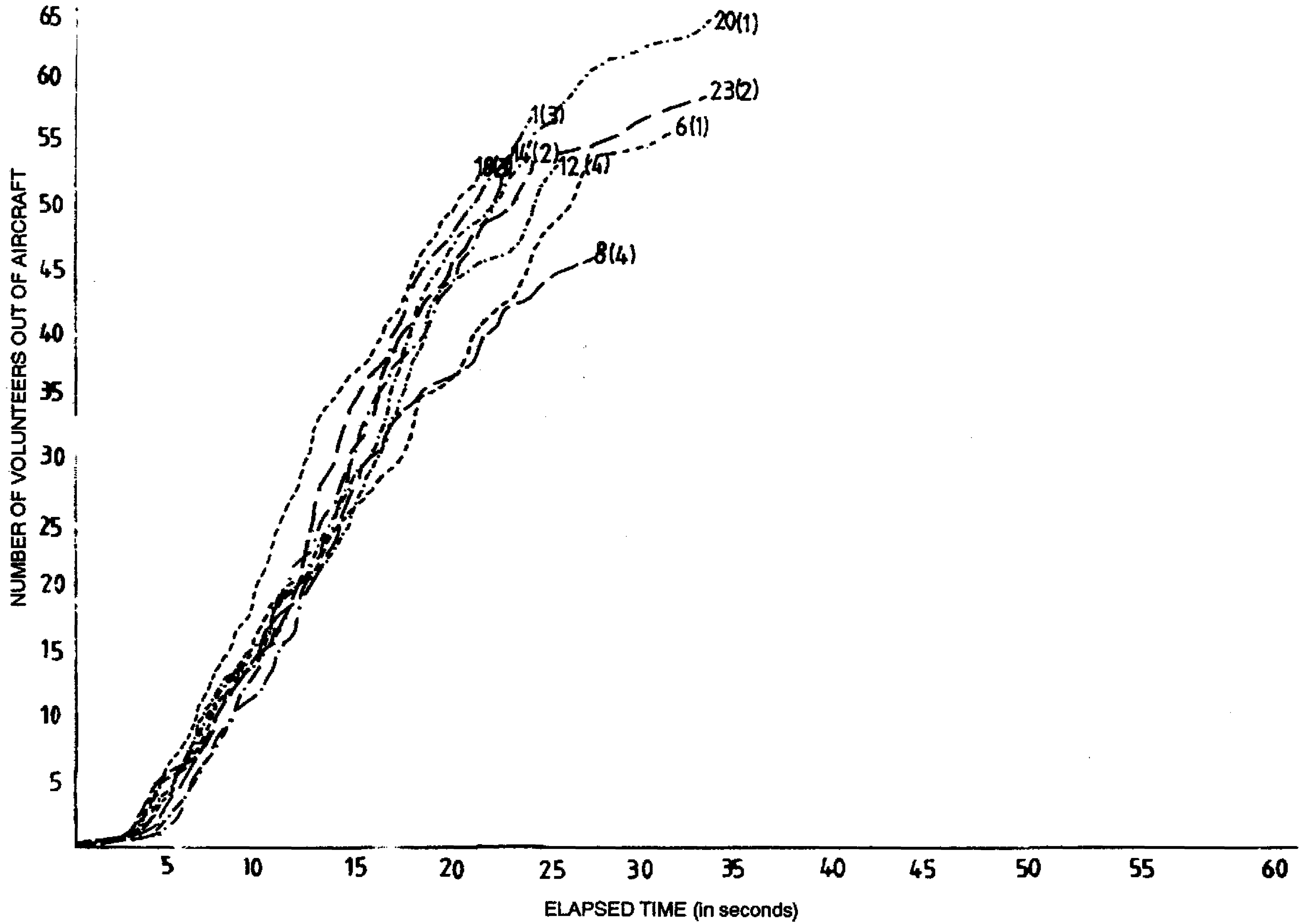
Graphical representation of evacuation flow through a 27″ bulkhead aperture – all evacuations



Graphical representation of evacuation flow through a 30″ bulkhead aperture – all evacuations

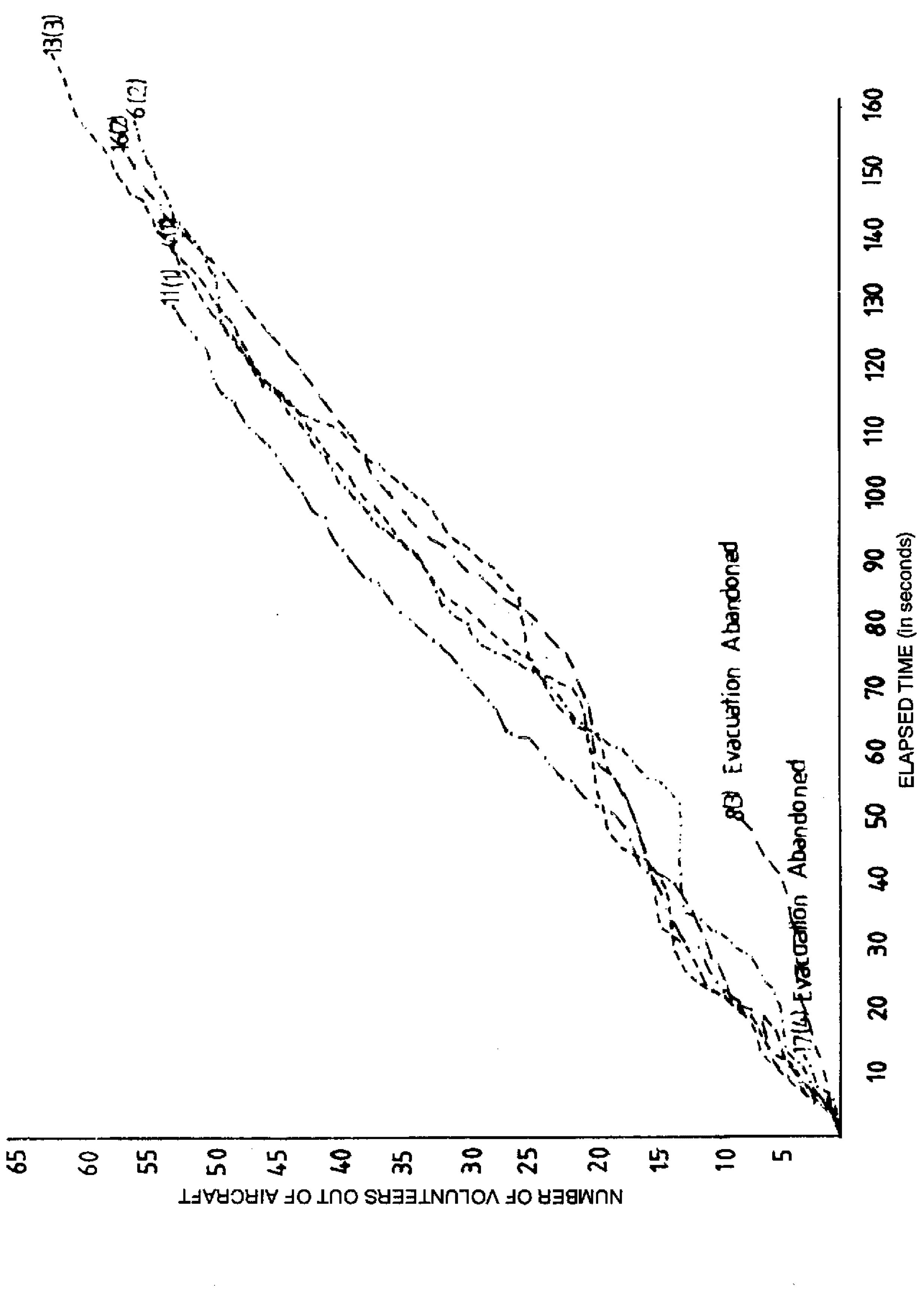


Graphical representation of evacuation flow through a 36″ bulkhead aperture – all evacuations

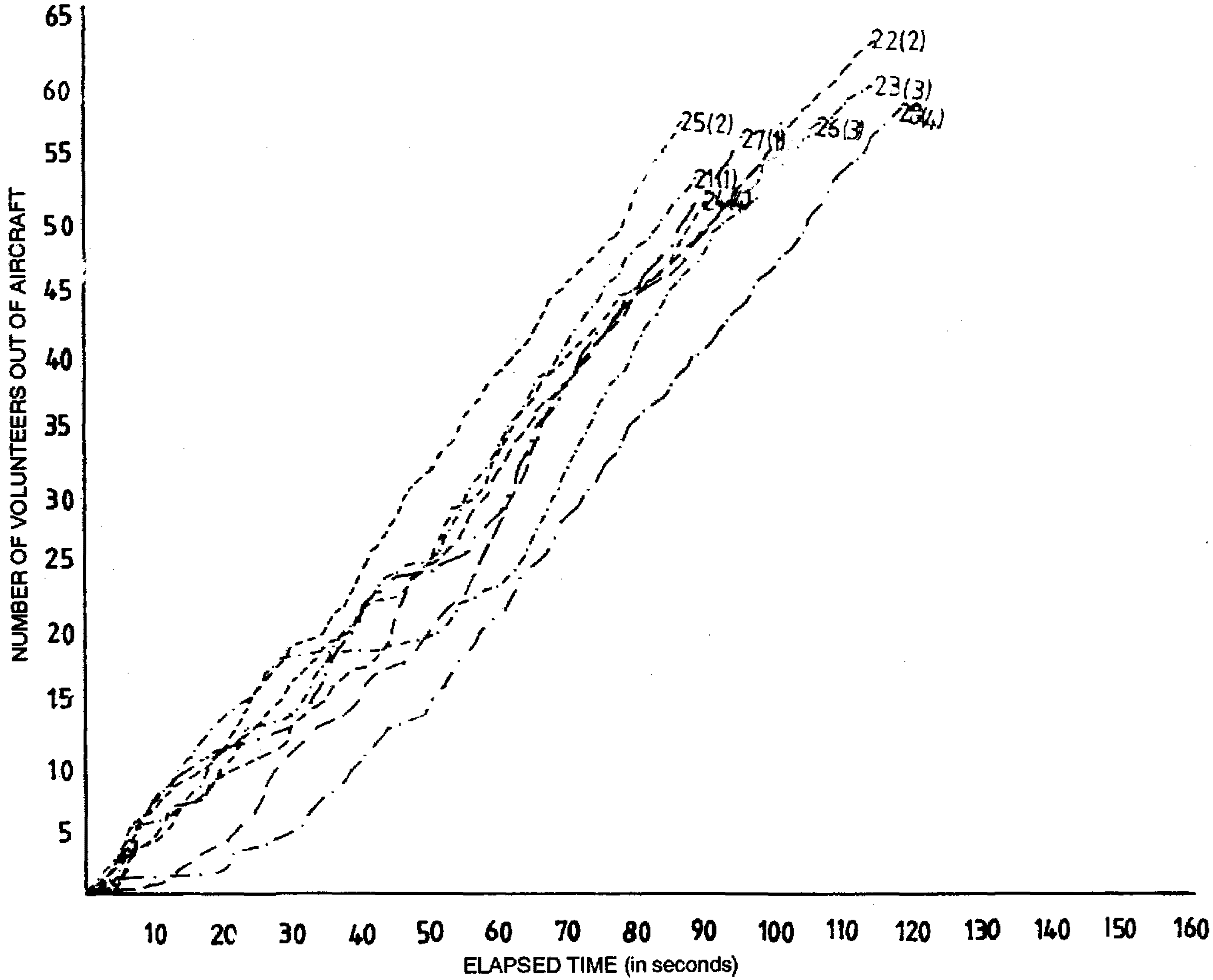


Graphical representation of evacuation when the port galley unit was removed – all evacuations

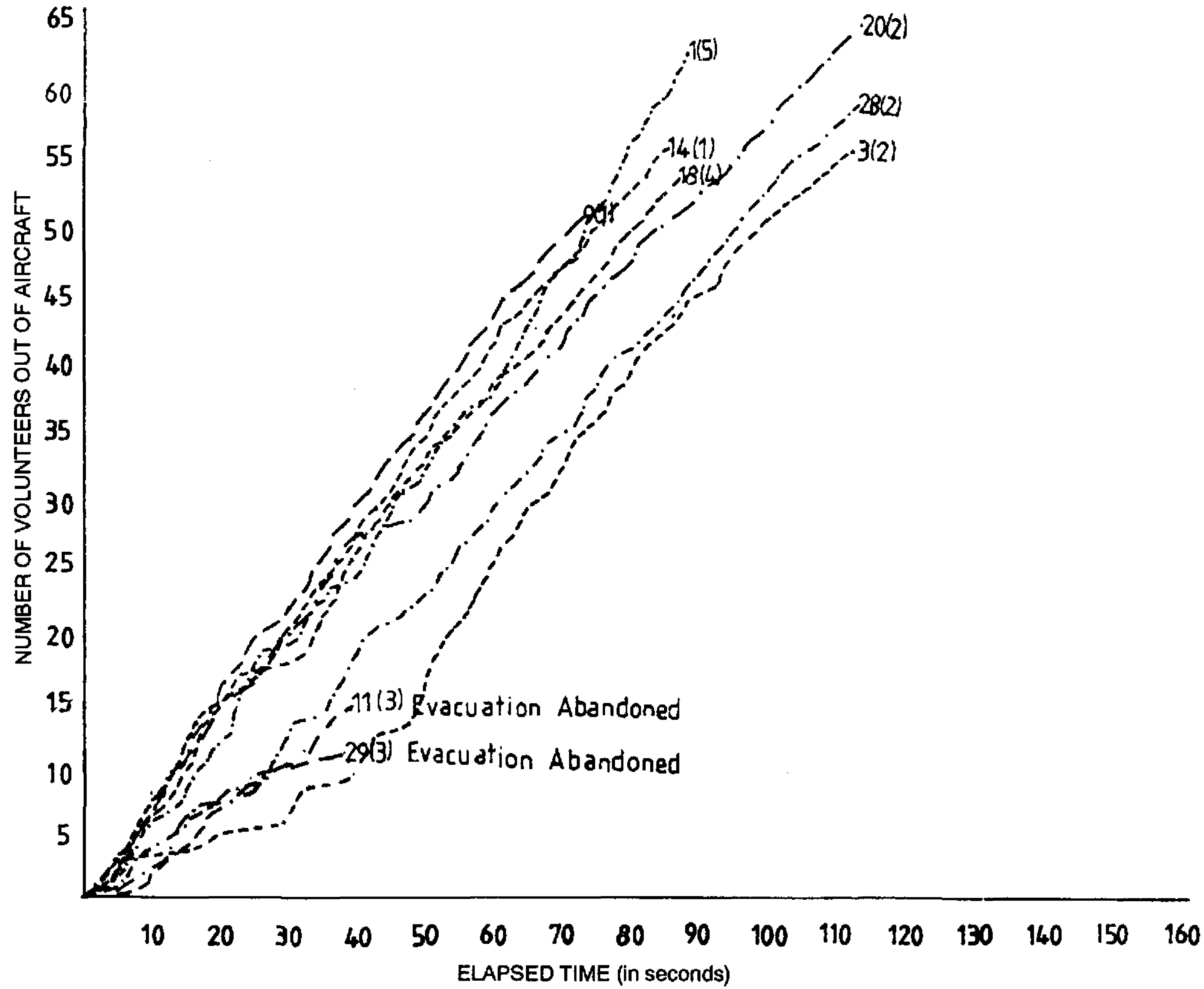
APPENDIX F



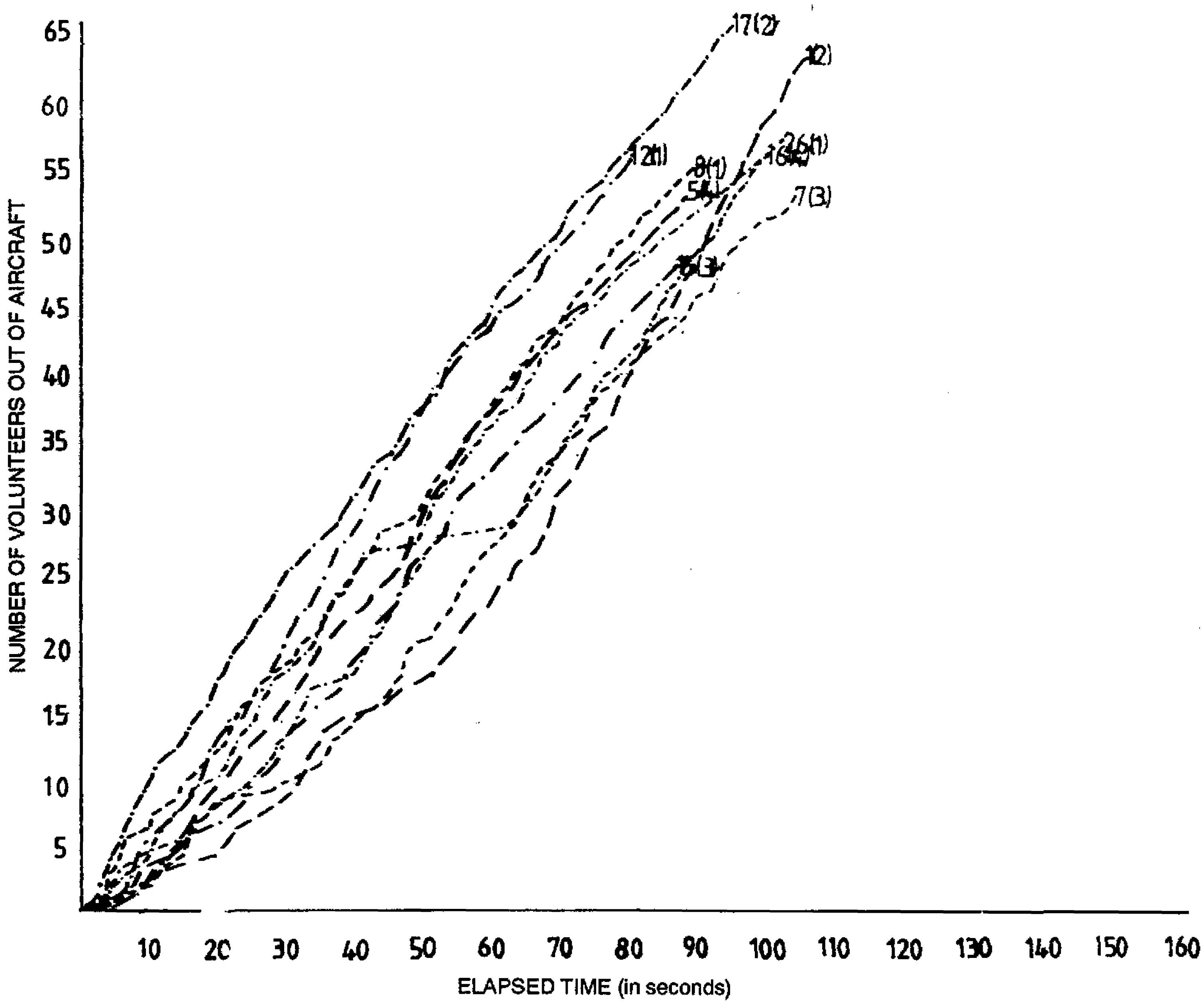
Graphical representation of evacuation flow through a Type III Exit with a vertical projection of 3" (pre AN 79) – all evacuations



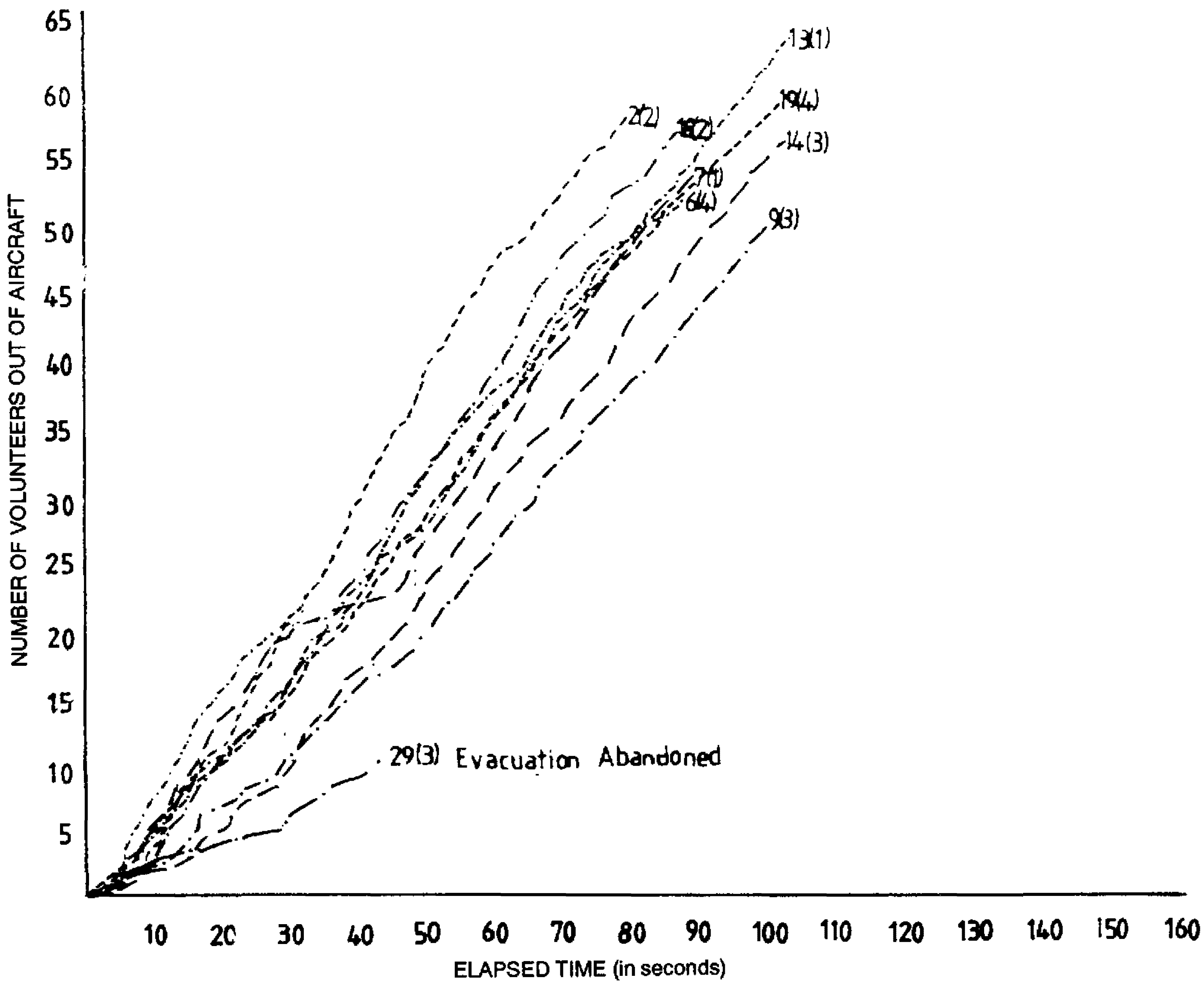
Graphical representation of evacuation flow through a Type III Exit with a vertical projection of 3" – all evacuations



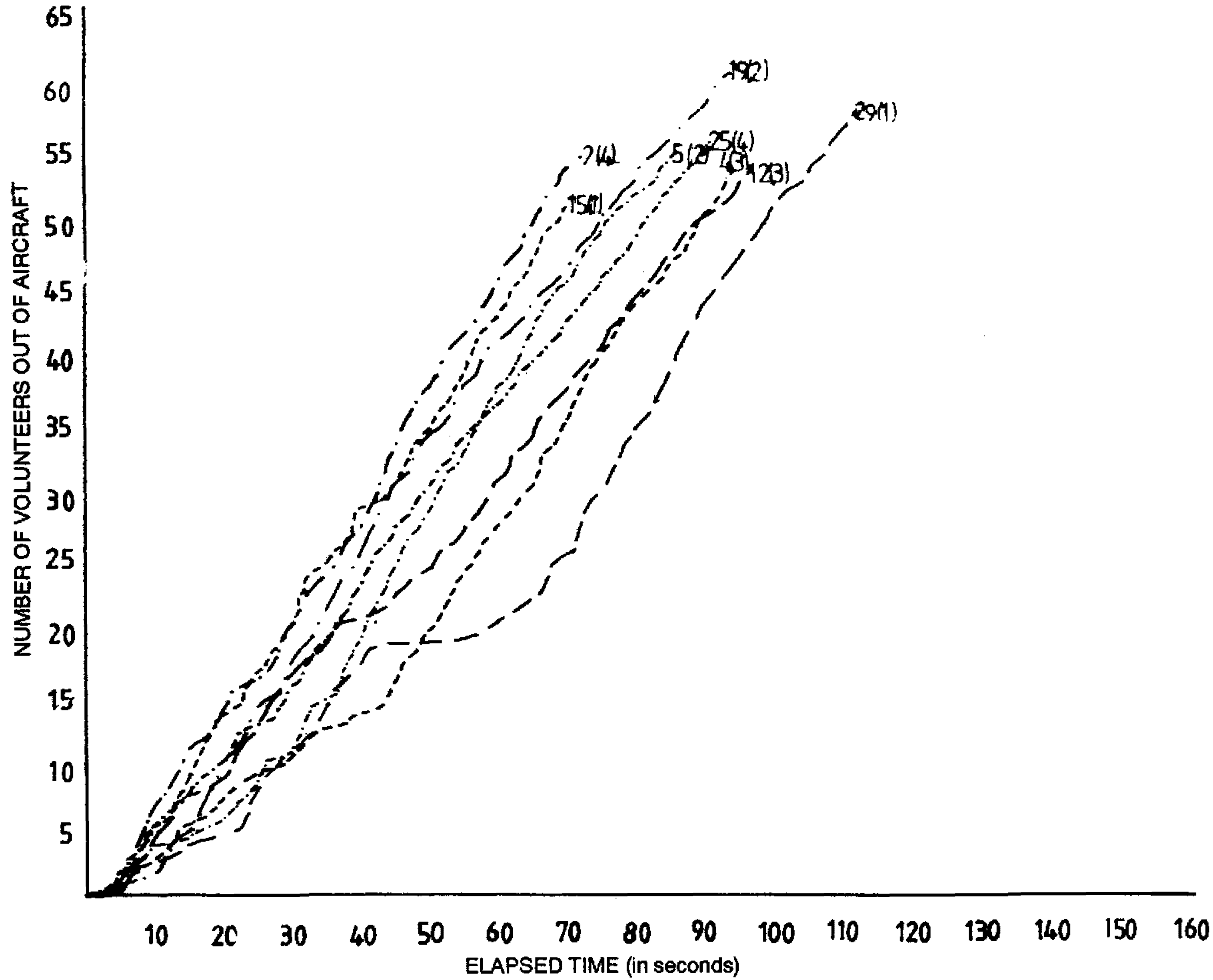
Graphical representation of evacuation flow through a Type III Exit with the outboard seat removed and a vertical projection of 6″ – all evacuations



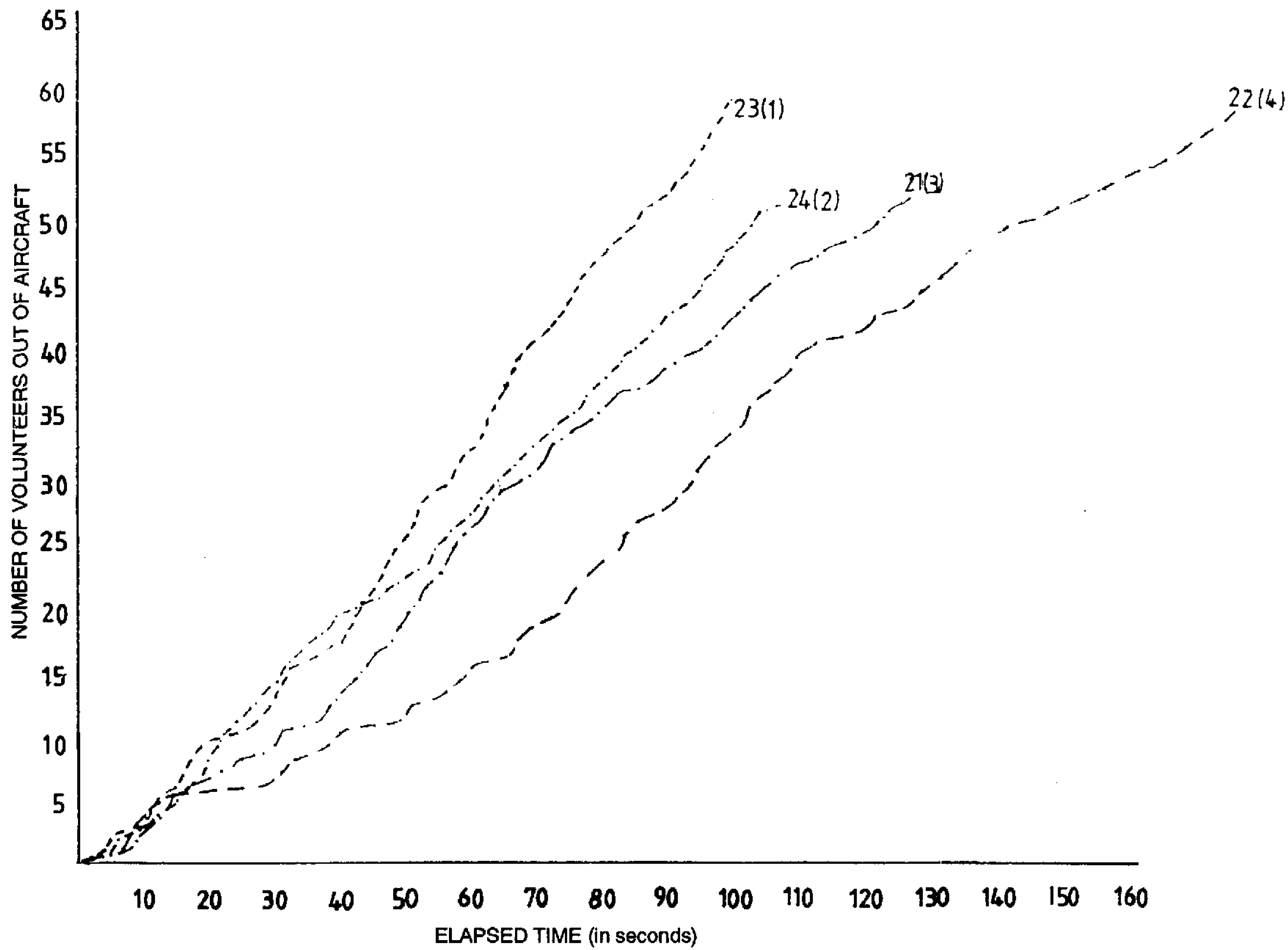
Graphical representation of evacuation flow through a Type III Exit with a vertical projection of 13″ – all evacuations



Graphical representation of evacuation flow through a Type III Exit with a vertical projection of 18" – all evacuations



Graphical representation of evacuation flow through a Type III Exit with a vertical projection of 25" – all evacuations



Graphical representation of evacuation flow through a Type III Exit with a vertical projection of 34" – all evacuations