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Abstract

Water spray systems have been proposed as a means of reducing the effects of a fire occurring in an aircraft cabin. The research described in this report was commissioned by the Civil Aviation Authority to investigate the human factors aspects of such systems and their potential effects upon evacuation rates and other issues such as visibility and audibility within the cabin.

In total, eight full-scale aircraft evacuations were conducted using a 707 airframe located at the Fire Research Station at Cardington. Each evacuation involved a group of around forty-five adults who performed one evacuation only. Four groups evacuated in dry conditions, the remaining four evacuated in the water spray. Video cameras were positioned both inside the aircraft cabin and on the platform outside to provide objective measures of evacuation performance. Subjective accounts were also obtained using post-evacuation questionnaires.

The results revealed that the evacuation times for the two conditions were virtually identical, the lack of a statistically significant difference suggesting that the presence of the water spray did not affect evacuation rates. Similarly, subjective visibility ratings within the cabin were not found to differ between the conditions. However, the audibility of the evacuation commands given by the cabin attendants was rated as significantly worse in conditions in which the water spray was in use. As volunteers appeared to be considerably more motivated to evacuate in the 'wet' conditions, it was hypothesized that the differences in audibility ratings may have been a consequence of the possibility that these volunteers had less spare attentional capacity to take note of more peripheral sources of information such as the commands given by the cabin attendants.

The majority of volunteers reported that the water spray had not affected their evacuation, with the majority of the remainder claiming that their vision had been adversely affected. In addition, it was found that volunteers wearing glasses had more visibility problems within the cabin during 'wet' evacuations (although this did not affect their evacuation performance) but the water did not appear to affect those wearing contact lenses. Finally, no problems resulting from the floor surface and other cabin furnishings becoming wet were identified.

A video record of this work is available from the CAA Library.

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1 INTRODUCTION

1.1 Background

The primary function of a cabin water spray system is not to attempt to extinguish a fire but rather to control the temperature within the cabin, hence delaying the onset of fire penetration and, ultimately, 'flashover'. This would allow a survivable atmosphere to be maintained within the cabin for a longer period of time and therefore enhance the survival chances of the passengers and crew. Indeed, there is now evidence (Refs 1, 2, 3 and 4) to suggest that such systems would be successful in combating the effects of a cabin fire, particularly in its early stages. In many cases, such as the accident involving the British Airtours 737 at Manchester International Airport in August 1985, it is possible that an extra few minutes of available evacuation time could have had a dramatic effect upon survival. In this case, the majority of the 55 fatalities were found to be due to smoke inhalation and the Air Accidents Investigation Branch concluded in their report of the accident (Ref 5) that water spray systems:

'... should be developed as a matter of urgency and introduced at the earliest opportunity on all commercial passenger carrying aircraft.'

However, although it now appears that the use of such systems would be useful in delaying the impact of a cabin fire, there has been no research regarding the human factors implications of on-board water spray systems. For example, any serious impairment to vision or hearing could have the potential to put escaping passengers at even greater risk. In addition , it is possible that the clothes soaked by a continuous water spray could reduce passengers' mobility and therefore delay evacuation rates. Finally, wet cabin floors and fittings may also become hazardous in such circumstances, particularly if the aircraft does not come to rest on level ground.

In order to address these concerns, the United Kingdom Civil Aviation Authority commissioned the Applied Psychology Unit at Cranfield Institute of Technology to conduct an experimental programme to study the effect of cabin water spray systems upon evacuation rates.

In addition, the Institute of Sound and Vibration Research (ISVR) was commissioned by the CAA to study the acoustic environment during the evacuation tests and the results and discussion from this analysis are included as Appendices D and E of this report.

1.2 Aims and objectives of the research

The principal aims and objectives of the research programme can be summarised as follows:

(a) to determine the effect of a cabin water spray system upon the evacuation rates and behaviour of members of the public;

(b) to determine the effect of a cabin water spray system upon the subjective perceptions of visibility and audibility within the cabin;

(c) to determine the impact of a cabin water spray system upon any other aspects of passenger safety and survivability;

(d) to measure the acoustic environment during the evacuations.

2 METHOD

In order to study the human factors implications of aircraft cabin water spray systems, it was decided to perform a number of aircraft evacuation exercises similar to those previously undertaken by the Applied Psychology Unit (Refs 6, 7 and 8). However, on this occasion, the aircraft cabin used was situated at the Fire Research Station at Cardington. This 707 fuselage had previously been used to assess the effectiveness of a water spray system on pooled fuel fires (Ref 4) and was modified according to the requirements of the research described in this report. As with the previous evacuation trials noted above, the simulated scenario in this exercise was a cabin evacuation following an abandoned take-off as a result of a fire. Due to limitations regarding the cabin design, only one floor level exit (the forward Type I) could be used for the evacuations. Although this scenario may not be representative of a true evacuation situation, it is argued that this is a minor problem given the consistency between the two experimental conditions (see below).

2.1 Research design

The basic design consisted of two groups: one control group, in which the evacuation exercise was performed in dry conditions; and one experimental group, in which the exercise was carried out in identical circumstances with the addition of the water spray system. Ideally, a repeated measures design, in which each group performed one 'dry' and one 'wet' evacuation, would have been implemented. However, the need to counterbalance the design to eliminate the influence of practice effects would have meant that half of the groups would have had to perform a 'dry' evacuation followed by a 'wet' evacuation with the remaining groups performing the two evacuations in the reverse order. Unfortunately, it was not possible to dry out the aircraft following a 'wet' test in sufficient time to allow the same group to perform a 'dry' run. In practice, the drying-out took around two or three days and it would have been unacceptable to ask the volunteers to return several days later to perform the second test as the influence of intermediary factors could not have been controlled. Additionally, it is unlikely that a full complement of volunteers could be guaranteed to report for the second test.

Under these circumstances, it was decided to opt for an independent groups design with each group performing a single evacuation and remaining unaware as to which group they had been assigned. As a total of eight groups of volunteers had been budgeted for, this did mean that each experimental condition only contained four cases. Although this number is too small to make extrapolations concerning the population from the samples obtained, it is sufficient for the exploratory nature of the research.

The 45 seats used for the evacuations were identical for each evacuation and were chosen to give an even spread of volunteers throughout the cabin (see Appendix A for locations). Specific seats were randomly assigned to individuals so as to reduce any biases that may have occurred had volunteers been allowed to choose their own seat positions.

2.2 Volunteers

Volunteers were recruited in groups of 45 to enable the front portion of the cabin to be filled almost to capacity, thereby giving an effect of crowding. Recruitment was accomplished via advertisements containing full details of the trials placed in the locality and included as inserts in local newspapers. Volunteers who had taken part in previous test programmes were also contacted. For insurance purposes, it was required that volunteers were aged between 20 and 50 and that all were sufficiently fit to participate in a potentially strenuous evacuation. All were required to sign a medical declaration form before being allowed to participate (see Appendix B).

All potential volunteers were offered a choice of trial dates and every effort was made to ensure that, whenever possible, the majority of volunteers were able to take part in their preferred evacuation. However, checks were made to ensure that the constitution of each group (ie in terms of sex and age distributions) was as consistent as possible. Volunteers were requested that they make their own way to Cardington and directions were sent along with booking confirmation details. Additionally, they were asked to bring a complete change of clothing should the water spray be operated during the evacuation.

2.3 Equipment

2.3.1 *Aircraft cabin*

The aircraft cabin used for the evacuations was a Boeing 707, located at Cardington FRS. As a result of its extensive use in fire tests, only the forward section of the cabin was deemed suitable for use (see Appendix A). The cabin was fitted with conventional interior trim, including simulated overhead storage compartments and front and rear bulkheads. Due to the design of the aircraft shell, it was also necessary to construct an exit aisle between the front bulkhead and the small vestibule area adjacent to the forward Type I exit. Twenty 707 triple seat rows were installed, conforming to a CAA Airworthiness Notice No. 64 (Ref 9).

Although regular carpeting was used in the main portion of the cabin, a special non-slip surface was fitted in the exit corridor and vestibule areas. An additional safety feature was the use of an exit platform and ramp, rather than slides, leading from the front Type I exit to ground level. This was also covered with a non-slip surface. The soundtrack for the pre-flight briefing and the abandoned take-off sound effects was played on audio equipment located in a temporary office outside the aircraft fuselage and relayed via four speakers placed inside the ceiling panels within the cabin.

2.3.2 *Water spray system*

The aircraft cabin was installed with 41 spray nozzles, located in the ceiling and along the side walls in the recess underneath the overhead lockers. The heads were angled to ensure full coverage of the aircraft interior, the exact positions being determined by the FRS team at Cardington. The water pump powering the system was located outside the fuselage and provided water to the nozzles via a series of hoses, valves and pipes. The system was designed such that a pressure of 45–50 lb/in^2 (or approximately 3 bars) would produce a flow rate of around 0.8 litres/square metre/minute.

2.3.3 *Data collection*

It was considered important to obtain both objective and subjective records of each of the evacuations. Hence, both 'dry' and 'wet' evacuations were recorded on video tape and all volunteers were asked to complete two questionnaires, one before and one after the evacuation.

2.3.3.1 Video

In order that a more objective account of the evacuations was obtained, each evacuation was recorded on video tape via four video systems, all with timebase facilities. Two camera/recorder systems were located inside the cabin, one behind each of the forward and aft bulkheads (see Appendix A). Small portholes were incorporated into the bulkheads to allow activity within the cabin to be recorded on these systems. As mains electricity was unavailable in the cabin, these cameras had to be battery-powered.

2.3.3.2 Questionnaires

In addition to the information provided concerning the safety, insurance and medical aspects of the trials, volunteers were given a brief questionnaire (see Questionnaire 1 in Appendix B) to complete containing a number of personal details that it was felt may be relevant to the research objectives. As well as a number of basic demographic items, volunteers were asked to complete a checklist of the clothing they were wearing for the evacuation. This was included primarily to isolate any problems associated with particular types of clothing that use of the water spray may exacerbate.

A second questionnaire (Questionnaire 2, Appendix B), completed after the evacuation, was used to record responses to issues concerned with the evacuation itself. Of particular interest were: a subjective rating of the ease of the evacuation; factors which volunteers felt both helped and hindered their evacuation; problems associated with visibility and audibility within the cabin; and what precautions were felt to be necessary should aircraft be installed with cabin water spray systems. An additional item, concerning reported ill effects noted after the evacuation, was used to monitor any health implications for the spray systems.

2.4 Pilot test

Prior to the main series of eight evacuations, an additional group of volunteers were recruited to take part in two trial evacuations, one each of the 'dry' and 'wet' type. The purpose of these evacuations was primarily to allow the evacuation staff an opportunity for a full dress-rehearsal and to ensure that the equipment and procedure were suitable for the test requirements. The procedure was identical to that adopted for the main series of tests, other than the fact that, having completed a 'dry' evacuation, the volunteers then performed a second test, with the water spray in operation. A number of minor changes were made as a result of the pilot test, most notably the inclusion of an additional item on the second questionnaire concerning ill effects resulting from the evacuation. Furthermore, an additional external camera providing an overall view of the proceedings had been used during the pilot and it was decided to dispense with this camera after viewing the resulting video recordings. No data from the pilot test is included in this Report with the exception of some acoustic measurements in Appendices D and E.

2.5 Procedure

Upon arrival at Cardington, volunteers were asked to register and collect an FRS identity card. They were then requested to check-in for the trial with the Cranfield staff. Once their presence on a volunteer booking-in form had been confirmed, each volunteer was given a clipboard containing information sheets and questionnaires along with a numbered vest indicating their seat position. After checking each volunteer had brought a change of clothing, members of evacuation staff dressed as cabin attendants then accompanied groups of volunteers to the briefing room. Volunteers were then asked to read the information sheets, sign the medical declaration (see Appendix B) and complete the first questionnaire.

When all volunteers had arrived (or when it appeared that no others would report), the initial briefing began. This consisted of a background to the study, the nature of the evacuation exercise (including emphasis on the test's non-competitive format) and the precise task that volunteers would be expected to perform. A variety of safety precautions were highlighted, including a demonstration of the alarm used to signal an abandoned evacuation. Volunteers who wore glasses were also requested to take particular care whilst evacuating. At this point, those volunteers who had signed declaration B on the medical form (indicating that they suffered from a state which may have excluded them from the exercise) were required to see the medical officer in attendance to determine whether they would be allowed to continue.

The volunteers were then boarded by the two 'cabin attendants' in groups according to their seat positions. Once all were seated and the medical officer (seated at the rear of the cabin throughout the evacuation) was on-board, the 'cabin attendants' took their places, one at the front of the cabin and one at the rear, and the cue for the evacuation to begin was given. A member of technical staff then started the pre-recorded tape containing the pre-flight briefing and other sound effects. This briefing was based on a standard UK operators pre-flight briefing, indicating the location of the available exit, the operation of the seat belt and drawing attention to the specially-made safety cards located in each seat pocket. In addition, the presence of the water spray system was announced with the following wording, agreed by the CAA:

'The aircraft is fitted with a cabin water spray mist system. In the very unlikely event of it being required, either on take-off or on landing, a fine mist of water will be discharged into the cabin. Please remain in your seats until you are given further instruction.'

After approximately two minutes of aircraft taxi noise there followed a 15 second period of silence. During the 'wet' evacuations (ie when the water spray was used), the spray was timed to begin at the start of this period of silence. Two members of FRS staff operating the pump and valve were given 1-minute and 10-second 'warnings' then a countdown from 5 seconds by a member of technical staff taking their cue from the briefing tape. Following the silence, the call to evacuate (*'Undo your seatbelts and get out'*) was given, this being the volunteers' cue to evacuate the aircraft cabin as quickly as possible. Therefore in the 'wet' condition, volunteers sat in the spray for at least 15 seconds before being told to evacuate.

Upon leaving the aircraft, volunteers were asked to make their way down the ramps and into the briefing room area. For 'wet' evacuations, they were then allowed to change their clothing in the separate changing rooms. During this period, they were asked not to communicate with one another so as not to affect their questionnaire responses. Upon returning to the briefing room, volunteers were asked to complete the second questionnaire and were also offered a hot drink by the 'cabin attendants'. Finally the volunteers were given a de-brief and a chance to ask questions before being paid their participation fee which they collected on the way out. The volunteers were then asked to make their way to the main reception area to deposit their identity cards before leaving the site.

On each trial, two evacuations were completed – the first 'dry', the second 'wet'. Therefore, following the departure of the first group of volunteers, the research staff made preparations for the second evacuation of the day.

3 RESULTS

3.1 Demographics details

The eight evacuations involved a total of 350 volunteers, a mean of 43.75 per evacuation with a maximum of 45 and a minimum of 42. This included 198 (56.57%) males and 152 (43.43%) females. The mean age of volunteers was 31.33 years, their mean height 171.63 centimetres and mean weight 68.43 kilograms. Only 23 (6.63%) reported never having flown, whilst 58 (16.71%) claimed to have flown on over 30 occasions. The majority (81.42%) of those with flying experience reported flying mainly for leisure purposes. Finally, 180 volunteers (52.02% of those who provided a response) had experience of previous Cranfield evacuation tests and 166 (47.98%) had no such previous experience.

3.2 Evacuation rates

One of the primary objectives of the research described in this report was to ascertain what effect, if any, the use of water sprays had upon evacuation rates. Therefore, the times taken to evacuate for the four groups under conditions in which the spray was not in operation (hereafter referred to as 'dry') were compared with those for groups who were subjected to the water spray (ie 'wet'). The elapsed times were taken from the end of the call to evacuate to the moment each individual had fully cleared the aircraft cabin. The mean times for the first, fifth, tenth and each subsequent fifth person are presented for both conditions in Table 1 (over) along with times for the 42nd individual (the last position available for all eight groups). In the table, 'SD' refers to the standard deviations associated with the means whilst 'N' is the sample size. These figures are also plotted in Figure 1 (over). Additionally, a t-test was performed on the data from the 'dry' and 'wet' groups for each of these evacuation positions to determine whether the differences between the mean evacuation times of the two conditions were likely to be a result of chance factors alone. The tests statistics, showing the t statistic ('t'), degrees of freedom ('df') and probability of the result occurring by chance

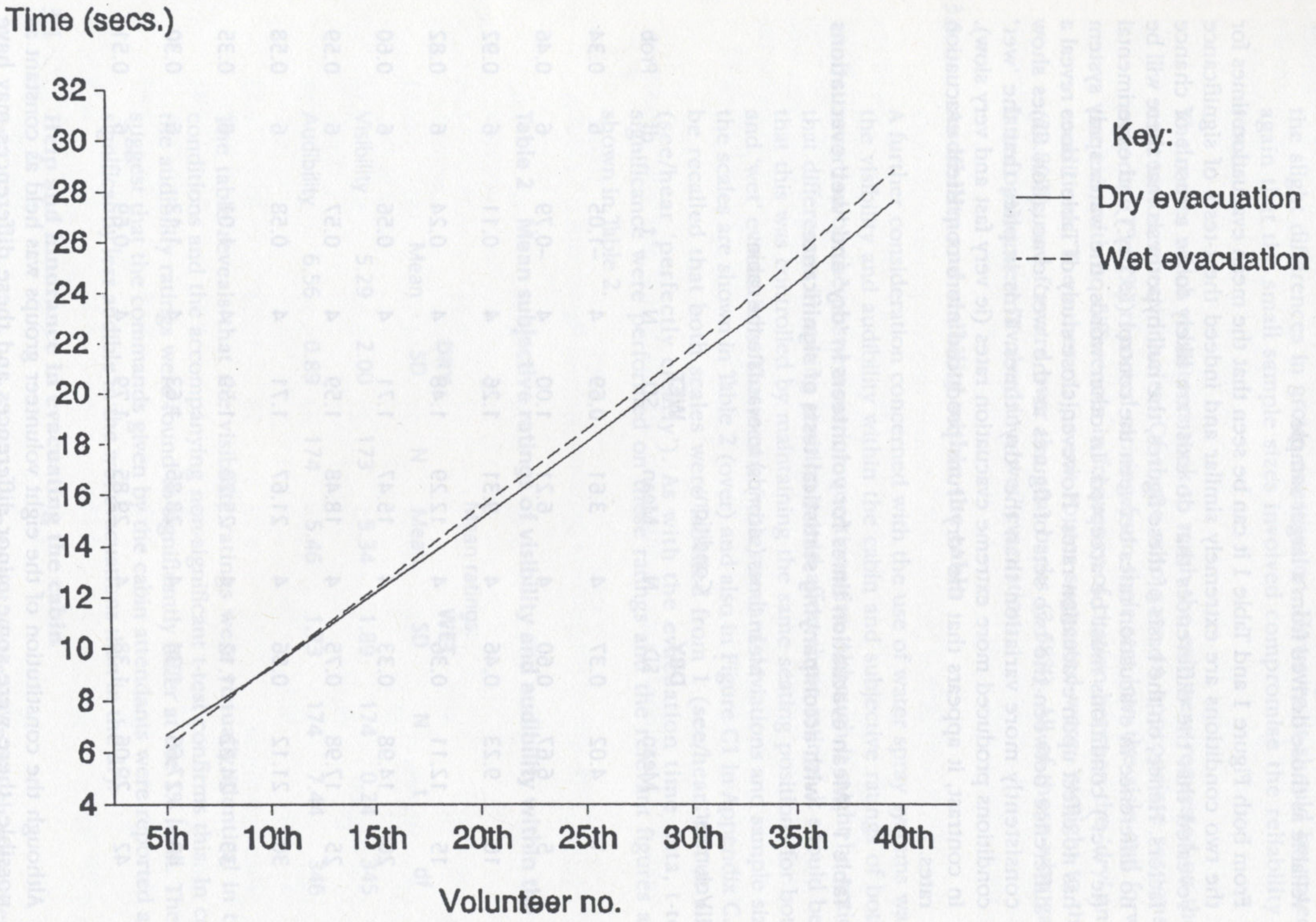

Figure 1 Graph showing evacuation rates for 'dry' and 'wet' conditions

('prob') are also presented in Table 1. For these, and all subsequent tests described in this report, the criterion for rejection of the null hypothesis (ie no significant difference between groups) was set at 5%. It should be noted, however, that the small sample sizes mean that these results will not be as statistically reliable as those derived from a larger sample.

From both Figure 1 and Table 1 it can be seen that the mean evacuation times for the two conditions are extremely similar and indeed the t-tests of significance revealed that the differences that do exist are likely to be a result of chance factors. Hence, on the basis of these figures, the null hypothesis that there will be no difference in evacuation rates between the control (ie 'dry') and experimental (ie 'wet') conditions must be accepted. In other words, the water spray system has no effect upon evacuation rates. However, close study of Table 1 does reveal a difference between the two sets of figures as the 'wet' evacuation times show consistently more variation than the 'dry' times. This implies that the 'wet' conditions produced more extreme evacuation rates (ie very fast and very slow). In contrast, it appears that the 'dry' runs produced more consistent evacuation rates.

Table 1 Mean evacuation times for volunteers in 'dry' and 'wet' evacuations with accompanying statistical tests of significance

Mean times (seconds) to evacuate the cabin:

Volunteer:	Condition: DRY Mean	DRY SD	DRY N	WET Mean	WET SD	WET N	t	df	Prob
1	4.02	0.37	4	3.61	0.69	4	−1.05	6	0.34
5	6.67	0.60	4	6.21	1.00	4	−0.79	6	0.46
10	9.23	0.46	4	9.31	1.26	4	0.11	6	0.92
15	12.11	0.36	4	12.29	1.48	4	0.24	6	0.82
20	14.98	0.33	4	15.47	1.71	4	0.56	6	0.60
25	17.98	0.75	4	18.48	1.59	4	0.57	6	0.59
30	21.12	0.86	4	21.67	1.71	4	0.58	6	0.58
35	24.22	1.12	4	25.20	1.59	4	1.01	6	0.35
40	27.66	1.34	4	28.85	1.63	4	1.13	6	0.30
42	29.06	1.38	4	29.85	1.79	4	0.69	6	0.51

Although the constitution of the eight volunteer groups was held as constant as possible, there were some minor differences and these differences may have influenced the results of the tests described above. A one-way analysis of variance test of significance was performed on the evacuation times for the 40th individual out of the cabin using the groups' mean age and sex distributions as co-variates, a technique used to nullify their influence. This produced a main effect (ie the variance due to the experimental conditions) F-ratio of 0.00 (df = 1,4) with an accompanying probability level of 1.00. This implies that what little difference there was between evacuation rates for the two groups can be accounted for by the slight differences in group constitution. However, it should be noted once again that the small sample sizes involved compromise the reliability of the results.

The routes which volunteers took to reach the exit were requested on the post-evacuation questionnaire. Of those who gave an appropriate response, the majority (73.62%) reported moving from their seat into the aisle and forward to the exit, with no differences in frequency of citation between the 'dry' and 'wet' conditions. The other major exit routes suggested were: 'straight to the exit' (22.80%); and forward over the seat backs (3.58%). All of those who gave the latter option were involved in a 'wet' evacuation.

3.3 Audibility and visibility within the cabin

A further consideration concerned with the use of water spray systems was upon the visibility and audibility within the cabin and subjective ratings of both were recorded on the post-evacuation questionnaire. Although it might be anticipated that differences in seating position would affect these ratings, it should be noted that this was controlled by maintaining the same seating positions for both 'dry' and 'wet' evacuations. The means (with standard deviations and sample sizes) for the scales are shown in Table 2 (over) and also in Figure C1 in Appendix C. It may be recalled that both scales were labelled from 1 (see/hear 'not at all') to 7 (see/hear 'perfectly clearly'). As with the evacuation time data, t-tests of significance were performed on these ratings and the relevant figures are also shown in Table 2.

Table 2 Mean subjective ratings of visibility and audibility within the cabin

	Mean ratings:								
	DRY			WET					
	Mean	SD	N	Mean	SD	N	t	df	Prob
Visibility	5.29	2.00	173	5.34	1.89	174	0.24	345	0.81
Audibility	6.56	0.89	174	5.46	1.73	174	7.44	346	0.00

The table reveals that the visibility ratings were virtually identical in the two conditions and the accompanying non-significant t-test confirms this. In contrast, the audibility ratings were found to significantly differ at the 1% level. The means suggest that the commands given by the cabin attendants were reported as being significantly less audible in the wet evacuations than in the dry.

3.4 Help and hindrance in evacuating the cabin

The post-evacuation questionnaire included scales upon which volunteers were asked to rate the degree to which each of five factors had either helped or hindered their evacuation, the scale ranging from 1 ('hindered considerably') to 5 ('helped considerably') with the mid-point labelled 'had no effect'. Overall, the cabin seats (mean rating = 2.68, SD = 1.01), other parts of the cabin interior (mean = 2.84, SD = 0.64) and other 'passengers' (mean = 2.24, SD = 1.03) were rated as being a hindrance. Instructions given by the cabin attendants were generally felt to be the most help (mean = 4.24, SD = 0.78) and the floor surface was considered a minor overall help (mean = 3.13, SD = 0.51). These means are all represented graphically in Figure C2 in Appendix C. Tests were performed to determine whether the presence of water in the cabin had any influence upon ratings of these factors. The majority of these t-tests produced non-significant results at the 5% level, although the instructions given by the cabin attendants were found to be significantly more help in the 'dry' evacuations than in the 'wet' ('dry' mean = 4.42, SD = 0.75; 'wet' mean = 4.07, SD = 0.77; t = 4.27, df = 346, prob = 0.000).

The second questionnaire also included open-ended items in which respondents were asked to note other factors influencing their evacuation.

3.4.1 *Additional factors helping evacuation*

Table 3 (below) lists the most-frequently cited factors aiding evacuation of the aircraft in both 'dry' and 'wet' conditions, with an additional column for the whole sample. It should be noted that, as up to two responses were coded for each individual, the column totals sum to a figure greater than the 350 volunteers who took part in the evacuations. However, the accompanying percentages express the proportion of all respondents (172 'dry' and 171 'wet') who cited each category.

Table 3 Additional factors helping evacuations in 'dry' and 'wet' conditions

	DRY		WET		TOTAL	
Category:	N	%	N	%	N	%
Nothing	6	3.49	4	2.34	10	2.92
Instructions	21	12.21	17	9.94	38	11.08
Cabin attendants	81	47.09	71	41.52	152	44.31
Seat location	23	13.37	29	16.96	52	15.16
Pax	43	25.00	44	25.73	87	25.36
Self/own initiative	12	6.98	18	10.53	30	8.75
Seats	7	4.07	15	8.77	22	6.41
Floor surface	4	2.33	1	0.58	5	1.46
Clear access	9	5.23	4	2.34	13	3.79
Others	7	4.07	10	5.85	17	4.96
TOTAL	213	–	213	–	426	–

Table 3 shows that the most commonly-cited aid to evacuation was the cabin attendants, a response provided by almost half of all respondents, although they appeared to be a help to more people in the 'dry' condition. There appears to have been some degree of affiliative behaviour present during the both 'dry' and 'wet' evacuations, as other passengers were noted as having aided over a quarter of volunteers in both conditions. The evidence suggests that instructions given (ie initial volunteer briefing and pre-flight briefing) and the floor surface were more help to volunteers in the 'dry' evacuations whilst a higher proportion of volunteers evacuating in 'wet' conditions reported being helped by their own initiative and the aircraft seats. Otherwise, there appear to be few differences between the two conditions.

3.4.2 *Hindrance*

Additionally, respondents were asked to note factors that had hindered their evacuation. Table 4 (below) lists the most common suggestions for 'dry', 'wet' and all evacuations. Once again, up to two suggestions per respondent were included.

Over 40% of respondents claimed that nothing had hindered their evacuation, with a slightly high proportion of these being in the 'dry' condition. Other passengers were cited by a quarter of volunteers, with 'lack of space' (mainly due to seat pitch and aisle width) and seats also noted by a relatively high proportion of respondents. Table 4 shows some more pronounced differences between 'dry' and 'wet' conditions than noted in the previous section. Lack of space was seen to be more of a problem in the dry condition, whilst the seats, restricted vision and delayed response were cited by more volunteers in evacuations with the water spray in operation. However, it should be noted that the latter two responses were cited by merely 2.29% and 1.71% of 'wet' volunteers respectively.

Table 4 Additional factors hindering evacuations in 'dry' and 'wet' conditions

	DRY		**WET**		**TOTAL**	
Category:	N	%	N	%	N	%
Nothing	6	3.49	4	2.34	10	2.92
Lack of space	39	22.41	20	11.43	59	16.91
Seats	18	10.34	34	19.43	52	14.90
Pax	45	25.86	43	24.57	88	25.21
Seat location	5	2.87	2	1.14	7	2.01
Instructions	3	1.72	6	3.43	9	2.58
Restricted vision	0	–	4	2.29	4	1.15
Delayed response	0	–	3	1.71	3	0.86
Floor surface	1	0.57	1	0.57	2	0.57
Others	2	1.15	10	5.71	12	3.44
TOTAL	191	–	194	–	385	–

3.5 **Perceived effect of water spray upon escape**

In order to determine what effect, if any, volunteers felt the water spray had upon their evacuations, an open-ended question pertaining to this was included on the questionnaire for completion by the 'wet' volunteers only. Surprisingly, over three-quarters (134 or 77.01%) claimed that the spray had no effect whatsoever (see Figure C3 in Appendix C). Of the remainder, over half (22 or 12.64% of all 'wet' volunteers) felt that their vision had been affected with 5 of these claiming that their glasses had steamed over and a further 4 felt this was because they kept their heads down during the evacuation. Despite this figure, the video recordings reveal that considerably more than 4 volunteers (in fact, most during the 'wet' trials) evacuated in this latter manner. Only one further effect of the spray was listed by over 5% of volunteers, this being an increased incentive to evacuate quickly, cited by 9 (5.17%) of them. A small number (4 or 2.30%) reported some coughing or breathing difficulty affecting their evacuation and the same proportion reported finding the water 'distracting'. Finally, 2 (1.15%) people claimed that the water prevented them from hearing instructions clearly and 2 more that the water was 'comforting'.

3.6 **Suggested precautions**

When asked to suggest any precautions against the use of a water spray system that airlines should adopt, most volunteers (244 or 70.72% of those who gave some response) did not propose anything, with virtually equal proportions in 'dry' and 'wet' conditions. The most common suggestion was the use of non-slip floor surfaces, which was advocated by 35 (10.14%) volunteers, although a far higher proportion of these took part in 'dry' evacuations (13.45% against 6.90% for 'wet' evacuations). Additionally, twice as many 'dry' as 'wet' (10 or 5.85% against 5 or 2.87% respectively) volunteers felt that the intensity of the spray should be of an acceptable level. Figure C4 in Appendix C displays these figures for all evacuations.

In contrast, more volunteers in 'wet' trials suggested providing passengers with more information about the sprays (ie by including details in the pre-flight briefing etc), proposed by 10.92% of these respondents but by only 5.26% of those participating in 'dry' evacuations. Other notable suggestions included: special measures for wearers of glasses (proposed by 3.48% of all volunteers); assurance that visibility within the cabin would remain acceptable (2.32%); passengers should be provided with some form of physical protection from the water (2.32%); and finally that passengers should be given extra protection from exposure should an aircraft crash-land in an excessively cold climate (0.87%).

3.7 **Ill effects reported**

It was felt that, due to the nature of the water spray, any ill effects reported by the volunteers should be recorded and consequently the post-evacuation questionnaire contained such an item. Over 90% of all volunteers (90.20%: 91.38% in the 'dry' and 89.02% in the 'wet') did not report any symptoms at all. In the 'wet' evacuations, the most common symptom was coughing, reported by 5 (2.87%) volunteers, followed by some form of minor breathing difficulty, as claimed by 3 (1.72%) of these 'wet' respondents. The remaining symptoms receiving more than a single citation were: caustic smell or taste (1.72%); mild headache (1.15%); increased arousal (1.15%) and hitting cabin fittings (1.15%).

The last two symptoms were the most frequently-cited by volunteers in the 'dry' condition. In this latter condition, 'increased arousal' was reported by 7 (4.02%) volunteers, whilst a further 6 (3.45%) claimed to have very slight injuries as a result of hitting cabin fixtures.

3.8 Influence of water upon wearers of glasses and contact lenses

Of the 350 volunteers who took part in the evacuations, 57 (16.29%) wore glasses and 40 (11.43%) wore contact lenses. Although it has already been noted that the water spray had no effect on reported visibility levels overall (see Section 3.3), it was hypothesized that wearers of glasses and contact lenses may have experienced particular problems in the water spray evacuations. Therefore, volunteers with no form of eyewear were compared with those wearing glasses and contact lenses on the scales assessing perceived ease of evacuation and comfort levels for the 'wet' condition only. However, neither analysis of variance test produced a result significant at the 5% level and it must be concluded that eyewear had no effect upon evacuation ease and comfort levels. These groups were also tested for differences on the audibility and visibility scales included in the questionnaire and, not surprisingly, no significant difference was found between audition ratings. However, a significant difference was obtained for the ANOVA (analysis of variance) testing for differences in visibility ratings, producing an F-ratio of 3.25 (df = 2,171) which was found to be significant at the 5% level (prob = 0.041). The means suggest that contact lens wearers and those with no form of eye wear achieved roughly equal mean scores (5.29 and 5.54 respectively, see Figure C5 in Appendix C), whilst those wearing glasses had most difficulty with vision in the cabin (with a mean score of 4.59).

A further comparison was made between the scores on a 'performance index' achieved by volunteers in these three groups. This index was calculated by subtracting each volunteer's actual evacuation position (ie order out of the cabin) from their 'expected' position, determined by their seat location and based upon evacuations times from similar previous trials (Refs 6, 7 and 8). Although this is an admittedly crude guide, it is argued that it serves its purpose in distinguishing between 'good' (producing a positive score) and 'bad' (ie those with a negative score) performances. However, in this case, the resulting ANOVA test was non-significant and therefore there is no evidence to suggest that either wearers of glasses or contact lenses performed differently from those with no form of eyewear.

Finally, comparisons were also made on responses to the open-ended items included on the second questionnaire. Generally, the responses of volunteers wearing glasses were found to be distinct from those with no eyewear and contact lens wearers, who differed little in their responses. Glasses wearers were found to be more likely to report being slowed down by visibility problems, although the numbers involved are small. Fewer people with glasses claimed that the water had not affected their escape (17 or 53.13% for wearers of glasses against 103 or 82.40% and 14 or 82.35% for those without eyewear and contact lens wearers respectively) and were also more likely to claim that their vision had been affected by the water spray (37.50% of wearers of glasses against 5.60% of no-eyewear volunteers and 11.76% of contact lens wearers). Although no differences in reported ill effects were discernable, the groups did differ in some of the precautions against the spray suggested, particularly with reference to special treatment or instructions for wearers of glasses with 12.5% of those wearing glasses suggesting this option in comparison to 0.8% of no-eyewear volunteers and no contact lens wearers. Additionally, almost half (46.88%) of the former group suggested some form of precaution, whilst only 26.40% and 17.65% of the latter two groups respectively suggested at least one form of precaution.

3.9 Potential problems with the cabin floor surface

Although Table 4 revealed that two volunteers felt that a slippery floor surface had hindered their evacuation, both were referring to the surface of the exit platform outside the cabin. Technically, these respondents did not answer the question correctly and this does not, therefore, fall within the objectives of the research. In Section 3.4, it was noted that, when rated in terms of its contribution to the evacuations, the floor surface emerged as having virtually no effect, although it was rated as a slight overall 'help'. However, it was felt that volunteers wearing alternative types of footwear may have experienced different problems whilst evacuating and a one-way analysis of variance was carried out upon the help-or-hindrance ratings of wearers of each of the three types of footwear categorised. Volunteers wearing heeled shoes or boots were found to rate the floor surface as a slight overall hindrance (mean = 2.94) and those wearing flat shoes/boots or training shoes a slight overall help (mean = 3.14 for both groups). However, the result of the analysis of variance carried out on these means was found to be non-significant ($F_{(2,346)} = 1.17$, prob = 0.310) and it must be concluded that footwear-type had no influence upon the perceived effect of the floor surface upon evacuations.

3.10 Influence of clothing upon perceptions of comfort, ease of evacuation and performance

Volunteers' clothing was recorded on the pre-evacuation questionnaire and it was decided to test for any differences on the perceived comfort and ease of evacuation scales in addition to the 'performance index' as reported in the previous section when evacuating in 'wet' conditions. Therefore, analyses of variance were performed on each scale, comparing the different types of clothing in each category as listed on the questionnaire (ie one test for ease of evacuation by shoe-type, one for comfort by type of trousers worn etc). No significant differences were found on the ease of evacuation comparisons and all bar one of the perceived comfort comparisons. The single exception revealed that wearers of pullovers or sweatshirts (mean rating = 4.95), who were found to report being significantly (t = 2.73, df = 174, prob = 0.007) more uncomfortable in the water spray than those not wearing such clothing (mean = 5.76). Similarly, only one of the comparisons of performance scores, that on alternative shoe types, produced a significant difference at the 5% level ($F_{(2,347)} = 3.59$, prob = 0.029). Those wearing flat shoes or boots had a mean performance score of –0.81, those with heeled shoes or boots a score of 1.38 and those wearing trainers 0.51, suggesting that the best performances were achieved by those in heeled shoes or boots.

4 DISCUSSION

4.1 Methodological considerations

In general, the methodology adopted for these evacuation tests was able to address the basic research aims and objectives as outlined in Section 1.2. The volunteers represented a cross-section of age groups and airline passenger experience and a reasonably equal distribution of males and females was obtained.

However, it should be noted that the findings reported are only relevant to the specific scenario investigated and it is possible that the situation may be different under alternative circumstances, such as one in which more than one exit were available. Additionally, given that each condition was tested on only four occasions, the samples obtained may not be fully representative of the population. Therefore, it is recommended that any interpretation of the results should take these points into account.

4.2 Evacuation rates

The primary objective of this research was to assess the influence of a cabin water spray system upon evacuation rates. The fact that no significant differences between evacuation rates for groups in 'dry' and those in 'wet' conditions implies that the particular water spray system used does not influence ability to escape from the aircraft cabin used. Indeed, there was little variation in times over the eight evacuations, suggesting that factors other than the water spray may have been chiefly responsible for the evacuation rates achieved. Perhaps the main contributor to evacuation rates was the aisle bottleneck which developed very shortly after the initiation of each evacuation, caused by the restrictive access to the exit aisle and forward exit. The internal cameras revealed that the bottleneck in the aisle usually developed after the first few volunteers had escaped.

Although the evacuation rates in the two conditions were not found to significantly differ, it is worth noting that the 'wet' evacuations displayed more variable evacuation rates (see Table 1), indicating that this condition produced more extreme (ie relatively fast and slow) times than the more consistent 'dry' tests. In fact, the times for the individual evacuations revealed that one 'wet' evacuation was exceptionally fast, whilst the remaining three were the slowest of all. Some volunteers reported that the water spray motivated them to evacuate more quickly and it may be possible that this extremely fast group contained a high proportion of these people. In fact, this group was subsequently found to contain the highest proportion of volunteers who had flown and who had taken part in previous Cranfield tests.

In spite of the fact that a relatively small proportion of volunteers reported this enhanced level of motivation to escape, the internal views of the evacuations suggest that volunteers were certainly trying harder during the 'wet' trials. This is supported by the fact that the only volunteers choosing to evacuate over seat backs did so in the 'wet' and that more pushing was reported in these trials. However, the bottleneck at the forward bulkhead vestibule area will have prevented most people adopting either of these evacuation patterns from making any significant progress. Nevertheless, this may explain why the 'wet' evacuations were found to be faster for the first few individuals, who would probably have managed to exit from the aircraft before the bottleneck effect developed. Once these appeared, any advantage resulting from increased motivation to escape will have been nullified. Indeed, as more pushing was evident in these trials, this may have contributed to the slightly slower times obtained for the 'wet' trials for those evacuating beyond the 10th individual as it is likely that this form of behaviour would only aggravate the situation at the bulkhead.

Although there is some evidence to suggest that use of the water spray may have enhanced volunteer motivation, there is none to indicate that use of the water spray system had any detrimental effect upon evacuation rates under the test circumstances explored in the research described here. This was supported by the fact that no volunteer reported the water as adversely affecting their evacuation as such and the video evidence from inside the cabin reveals that the water spray was not of sufficient intensity as to cause distress to any of the volunteers.

4.3 Potential problems with visibility due to the operation of the water spray

Subjective ratings of visibility within the cabin were not found to differ between the 'dry' and 'wet' conditions and the majority of these ratings remained at the 'see perfectly clearly' end of the continuum, implying that the water spray did not affect subjective visibility within the cabin. However, it may be argued that, for the specific scenario investigated, visibility may not have had much impact upon evacuation rates given that all volunteers were aware that only a single exit was available and had had this indicated during the pre-flight briefing. Consequently, if visibility problems did not have a marked effect upon escape route identification, it is possible that volunteers may have under-estimated any visibility problems present. In a real-life evacuation situation, visual information may be considerably more crucial to a successful evacuation.

Despite this, it was found that those volunteers wearing glasses did appear to have more visibility problems in wet conditions than either those with no form of eyewear or those wearing contact lenses. Although this impaired visibility did not affect these volunteers' evacuation performance, over half claimed that they had been affected in some way, most commonly that their glasses had steamed over. Whilst this did not appear to be much of a problem in these circumstances, possibly for the same reason outlined in the previous paragraph, it is again possible that in a more ambiguous scenario, ie one in which visual information plays a vital role in exit route identification, these people may be at a serious disadvantage. However, this is purely speculative and further research would be necessary to fully address this issue.

Alternatively, there are other situations in which wearers of glasses may not be at such a disadvantage. For example, in a smoke-filled cabin, visibility would be considerably reduced for everyone and consequently eyewear type would not be likely to affect the evacuation potential of any passengers. Unfortunately, there is no evidence to suggest what effect a combination of a cabin water spray system and smoke would have upon evacuating passengers and so any conclusions regarding this potential visibility problem must also remain speculative.

Finally, many wearers of glasses felt that they should be given some form of preferential treatment regarding instructions concerning the water spray and seating locations. However, in the scenario investigated, these volunteers were not found to perform any worse than other volunteers and on this evidence, it is suggested that such precautions would not be necessary. Furthermore, it should be noted that the practical implications of implementing such measures are likely to be considerable.

4.4 Potential problems with audibility due to the operation of the water spray

Unlike ratings of visibility within the cabin, the volunteers' subjective ratings of the audibility of the cabin attendants during the evacuations was found to be influenced by the presence of the water spray. This appears to imply that the noise produced by the spray system was sufficient to affect the audibility of those commands, a finding supported by the fact that cabin attendants were rated as being significantly less of a help during the 'wet' evacuations. However, evidence from other sources suggests that this may not be the sole cause of such a difference. For example, a parallel study of the noise levels within the cabin performed by the Institute of Sound and Vibration Research at the University of Southampton (see Appendix D) revealed that the noise produced by the spray system itself was extremely low and is unlikely to have influenced the audibility of the cabin attendants.

It has already been noted that volunteers appeared to possess greater motivation to evacuate quickly in the 'wet' trials and it follows that they will have considerably more focused upon the central task of escaping from the aircraft than in the 'dry' evacuations. If this is so, the reported lack of audibility of the cabin attendants may be a reflection of the possibility that the 'wet' volunteers were less able to attend to other sources of information, such as the cabin attendants. This ties in with Kahneman's theory of selective attention (Ref 10), which suggests that individuals possess a limited pool of attention which they may, under 'normal' circumstances, distribute to a number of parallel sources of information. However, when the workload required for one particular source (in this case, evacuating from the aircraft as quickly as possible) becomes predominant (ie more important than the remainder), it requires more 'attention space' and consequently there is less available for other (now peripheral) sources of information. If the evacuation commands given by the cabin attendants can be classed as the latter, it may be that the 'wet' volunteers simply did not notice them rather than the water sprays obscuring their content.

Further evidence for this can be gained from the fact that more volunteers in the 'dry' evacuations felt that lack of space within the cabin (eg seat pitch, aisle width etc) adversely affected their evacuation than in the wet. The cabin configuration was held constant throughout the test programme and it hypothesised that in the dry, volunteers not as motivated to escape had more spare 'attention space' in which to notice factors such as the lack of space within the cabin whereas those more motivated to evacuate simply did not have 'space' to register this. It should also be noted that in previous evacuation tests of a competitive nature (eg Ref 6) in which it might be expected that volunteers were subject to similar attention resource restrictions, it was often reported that the sound effects played during the evacuation had not been noticed. Although this attentional theory is somewhat speculative, it should be noted that, if the commands given by the cabin attendants had been significantly dampened by the water spray, it might be anticipated that many more than 2 volunteers would have suggested this as an effect of the water spray (see Section 3.5).

4.5 Other issues

The other aspect of the use of water spray systems that could potentially have implications for evacuating aircraft was the effect of floor surfaces and cabin furnishings becoming wet. However, ratings of the helping or hindering effect of the floor surface were not found to differ between conditions and no volunteers reported slipping inside the cabin. Similarly, no problems with other items of cabin furnishings were noted. In fact, the seats were rated as being more of a help in the 'wet' than in the 'dry', although this may be at least partly due to the fact that volunteers only helped their progress by climbing over seat backs in the former condition. In contrast, the seats were also rated as a hindrance by almost twice as many volunteers in the 'wet' than in the 'dry'. However, this difference is more likely to be due to a single incident during a 'wet' evacuation in which a seat-cushion became dislodged and partially blocked access to the exit for a short while.

Analysis of potential problems encountered by volunteers wearing different types of clothing produced few statistically significant results and the practical importance of such findings must be questioned. Indeed, even though volunteers wearing a pullover or sweatshirt during the evacuation reported a greater degree of discomfort, their actual performance was not found to be impaired and it is argued that this does not constitute sufficient cause for concern over the use of water spray systems.

Additionally, the finding indicating that those wearing heeled shoes or boots performed significantly better than others is not as anomalous as may at first appear. One of the initial information sheets sent out to volunteers stressed that high-heels should not be worn for the evacuations. Therefore, 'heels' may have been interpreted in many different ways, supported by the fact that almost half of those selecting this category of footwear were male, and it is unlikely that this result is anything more than a spurious one.

Finally, it was recommended, particularly by those who had had direct experience of the spray, that more information concerning the spray should be provided. This implies that volunteers' expectations of the system were often not met and this is supported by the fact that many claimed the spray was not as intense as they had anticipated. It may be, therefore, that passengers worried about the intensity of a spray system would be comforted by greater detail concerning its intensity. However, it is hard to imagine how this information would be accurately conveyed during a pre-flight briefing.

4.6 **Conclusions**

1 The results from the test programme suggest that, for the specific scenario investigated, the use of cabin water spray systems would not be likely to cause any significant adverse consequences for emergency evacuation of the aircraft.

2 The presence of the water spray was not found to have any effect upon rates of evacuation from the aircraft.

3 Subjective reports of visibility within the cabin were not found to be affected by the water spray.

4 Volunteers reported that the evacuation commands given by cabin attendants were significantly less audible when the spray was used. It was argued that this may have been due to differences in allocation of attentional resources rather than to the spray itself.

5 The 'cabin attendants' were reported as being the single most useful aid to evacuation.

6 Over three-quarters of the volunteers reported that the water spray had not affected their evacuation, whilst over half of the remainder claimed that their vision had been adversely affected.

7 Wearers of glasses were found to report having more visibility problems in the 'wet' evacuations than those wearing contact lenses or no eyewear.

8 No potential problems with the floor surface or cabin fittings becoming wet were identified.

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Appendix A

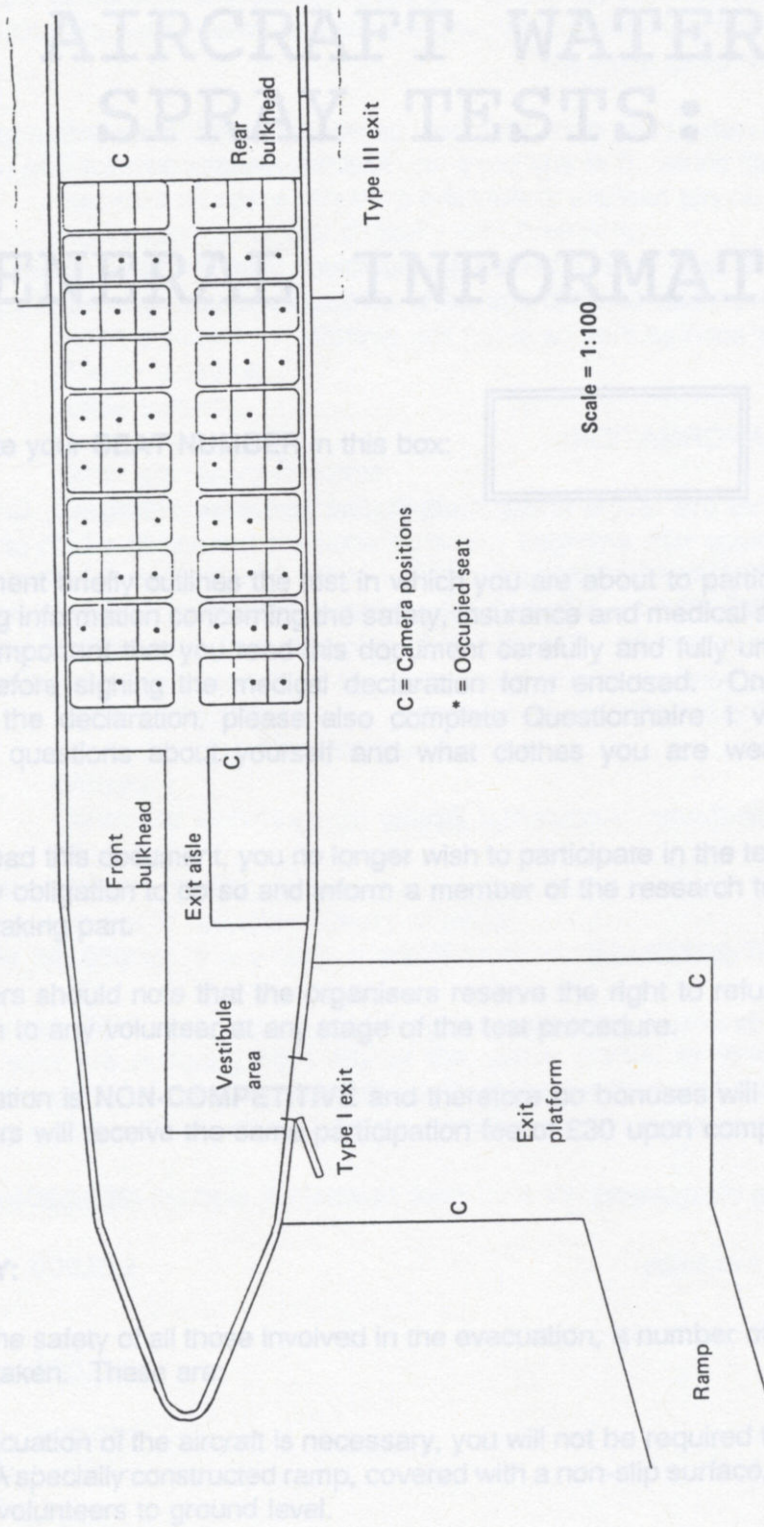

Figure A1 Plan of the 707 aircraft at Cardington

Appendix B

CRANFIELD INSTITUTE OF TECHNOLOGY
APPLIED PSYCHOLOGY UNIT

AIRCRAFT WATER SPRAY TESTS:

GENERAL INFORMATION

Please write your **SEAT NUMBER** in this box:

This document briefly outlines the test in which you are about to participate as well as providing information concerning the safety, insurance and medical aspects of the test. It is important that you read this document carefully and fully understand the contents before signing the medical declaration form enclosed. Once you have completed the declaration, please also complete Questionnaire 1 which asks a number of questions about yourself and what clothes you are wearing for the evacuation.

If, having read this document, you no longer wish to participate in the test, please do not feel any obligation to do so and inform a member of the research team that you will not be taking part.

All volunteers should note that the organisers reserve the right to refuse continued participation to any volunteer at any stage of the test procedure.

This evacuation is **NON-COMPETITIVE** and therefore no bonuses will be awarded. All volunteers will receive the same participation fee of £30 upon completion of the evacuation.

A) SAFETY:

To ensure the safety of all those involved in the evacuation, a number of precautions have been taken. These are:

1) If an evacuation of the aircraft is necessary, you will not be required to use safety chutes. A specially constructed ramp, covered with a non-slip surface, will be used to guide volunteers to ground level.

<PTO>

2) Several members of the evacuation staff will be present on the aircraft throughout the evacuation. These individuals will make themselves known to you and may be easily identified from their light blue sweatshirts or cabin staff uniforms. All members will be carrying personal alarms should the need to abandon the evacuation arise. This alarm will be demonstrated before the test begins. If you hear one of these alarms sounded during the evacuation, it means that a problem has arisen and that you should halt your progress and await further instruction from a member of the evacuation staff.

3) A doctor, along with a number of additional personnel with first-aid experience, will be on hand at all times. If at any point you feel the need to consult one of these people, please do not hesitate to do so.

4) Changing rooms have been provided so that those groups of volunteers who evacuate with the water spray in operation will be able to dry off and change their clothing as soon as they have left the aircraft.

B) INSURANCE INFORMATION:

You are advised that this test is undertaken at your own risk. However, Cranfield Institute of Technology has arranged personal accident insurance which provides benefit in the event of your sustaining accidental bodily injury. No further claims will be admissible, nor shall the Institute be liable in the event of any accidental injury or damage outside these benefits. Participants should note that, by supplying incorrect information to the organisers at any point, they will be automatically negating their insurance cover. The benefits are as follows:

Scope of Insurance Cover: Accidental Bodily Injury

Benefit:	Amount:
Temporary total disablement	£50 per week
(or, where not otherwise gainfully employed)	£25 per week
(NB: Maximum 104 weeks excluding first two weeks of every claim)	
Permanent total disablement	£20,000
Loss of one or two limbs	£20,000
Permanent total loss of sight of one or two eyes	£20,000
Death	£20,000

<PTO>

C) MEDICAL CONSIDERATIONS:

The evacuation in which you are about to participate may be physically demanding and therefore you must not take part if any of the following states currently apply to you:

- Severe anxiety;
- Fear of enclosed spaces;
- Nervous diseases requiring treatment;
- Active asthma or any difficulty with breathing;
- Any current chest disease;
- Fainting attacks, blackouts or uncontrolled epilepsy;
- Heart disease;
- Previous stroke;
- Ankle swelling;
- Deafness;
- Other significant illnesses;
- Pregnancy or suspected pregnancy.

In addition, there are several states which may allow you to participate in the evacuation, for which you are requested to seek medical advice before agreeing to participate. These are:

- Current infections;
- Controlled high blood pressure;
- Diabetes;
- Controlled asthma;
- Allergies;
- Marked obesity;
- Recent or recurrent history of pains;
- In receipt of any other medical treatment (excluding the contraceptive pill).

All those who are suffering from any of the above states, or who have recently undergone surgery, or who are currently suffering from cold or 'flu symptoms, should consult the medical officer on duty before agreeing to participate.

Now please sign the medical declaration form over the page.

<PTO>

MEDICAL DECLARATION FORM

If none of the medical states listed on the previous page apply to you, please sign Declaration A (below). Otherwise, sign Declaration B and consult the medical officer on hand when requested to do so.

DECLARATION A:

I, (please **print** name here) ______________________, have read and understood the information contained within this document and believe that I am sufficiently fit to cope with the work involved in the evacuation test that is to be conducted today. I am not suffering from any of the states listed on the previous page and therefore have no reason to consult with the medical officer.

I undertake that all information that I have provided is correct.

Signature: ______________________ **Date:** __________

DECLARATION B:

If you **do** suffer from one of the states which **may** preclude you from participation in the evacuation, you must complete the following section and see the medical officer before you will be allowed to continue.

I, (please **print** name here) ______________________, am currently receiving medical treatment, or believe that I may not be eligible to participate in the evacuations for medical reasons, and therefore request to see the medical officer. The reason for this is (please specify below):

However, I believe that I am fit enough to cope with the work involved in the evacuation.

I undertake that all of the information that I have provided is correct.

Signature: ______________________ **Date:** __________

-----------------------------#-#-#-----------------------------

To be completed by the Medical Officer:

I have consulted with the above named person and believe that there is no reason why they should not participate in the cabin evacuation today.

Signature: ______________________ **Date:** __________

AIRCRAFT WATER SPRAY TESTS: QUESTIONNAIRE 1

Please write your **SEAT NUMBER** in this box: ☐

1. Please indicate the clothes you are wearing for the evacuation on the checklist below. Tick as many boxes as are appropriate.

CLOTHING CHECKLIST:

Light trousers .... ☐

Heavy trousers (eg. jeans) .... ☐

Tracksuit/jogging bottoms .... ☐

Shorts .... ☐

Shirt/blouse .... ☐

T-shirt .... ☐

Dress .... ☐

Skirt .... ☐

Thin pullover/sweatshirt .... ☐

Thick pullover .... ☐

Thin jacket/coat (eg. denim/canvas) or waterproof .... ☐

Thick jacket/coat .... ☐

Flat shoes or boots (not trainers) .... ☐

Heeled shoes or boots .... ☐

Trainers .... ☐

<PTO>

2. Are you wearing glasses or contact lenses?

GLASSES ☐ CONTACT LENSES ☐ NEITHER ☐

The next few questions concern your own flying experience. Please respond by placing a tick in the appropriate box.

3. How many times have you flown commercially? Please count outward and return journeys as two flights.

NEVER	☐	- If **NEVER**, go to Q5.
1 - 5	☐	
6 - 10	☐	
11 - 15	☐	
15 - 20	☐	
21 - 25	☐	
26 - 30	☐	
OVER 30	☐	

4. What is the main purpose of your air travel? Is it mainly:

Business .... ☐

Leisure .... ☐

Roughly equal business & leisure .... ☐

Other (please specify): .... ☐

<PTO>

5. Have you previously experienced any other aircraft safety tests at Cranfield?

YES ☐ **NO** ☐

If **YES**, which one(s) ______________________________

In the final section of this questionnaire, we would like you to provide a few details about yourself.

6. How old are you? ______ years

7. Are you: **Female** ☐ **Male** ☐

8. What is your approximate height? __________

9. What is your approximate weight? __________

PLEASE ENSURE THAT YOU HAVE ANSWERED ALL QUESTIONS IN FULL.

IN A FEW MOMENTS YOU WILL BE GIVEN A FULL BRIEFING CONCERNING THE EVACUATION IN WHICH YOU ARE ABOUT TO PARTICIPATE.

AIRCRAFT WATER SPRAY TESTS: QUESTIONNAIRE 2

Please write your **SEAT NUMBER** in this box:

1. On the following scale. please indicate the ease of your escape by circling the appropriate number.

Very Easy — **Very Difficult**

1--------------2--------------3--------------4--------------5--------------6--------------7

2. Briefly describe how you reached the exit from your seat.

____

____

____

____

____

____

3. Who or what was the most help in your escape? Please describe briefly.

____

____

____

____

<PTO>

4. Please indicate the extent to which each of the following factors **HELPED** or **HINDERED** your escape by circling the appropriate number on each scale below.

	HINDERED CONSIDERABLY	HINDERED SOMEWHAT	HAD NO EFFECT	HELPED SOMEWHAT	HELPED CONSIDERABLY
a) The seats	1	2	3	4	5
b) Instructions from cabin staff	1	2	3	4	5
c) Parts of the cabin interior	1	2	3	4	5
d) Other passengers	1	2	3	4	5
e) Floor surface	1	2	3	4	5

f) In addition, please note any other factors which you felt **SLOWED DOWN** your escape.

____

____

____

5a. Was the water spray in operation during your evacuation?

YES ☐ **NO** ☐

If **YES**, go to Q5b (over). If **NO**, go to Q7 (over).

<PTO>

5b. Did the water spray affect your escape in any way?

YES ☐ **NO** ☐

If NO, go to Q6.

If **YES,** how did it affect you? Please specify below.

____

____

____

6. How **un**comfortable did you feel whilst evacuating with the water spray in operation? Please indicate your choice by circling a number on the scale below.

Extremely uncomfortable	**Not at all uncomfortable**

1--------------2--------------3--------------4--------------5--------------6--------------7

7. How clearly were you able to see the location of the exit corridor as you left your seat to escape from the aircraft?

Not at all	**Perfectly clearly**

1--------------2--------------3--------------4--------------5--------------6--------------7

8. How clearly were you able to hear the instructions given by the cabin staff whilst you were escaping?

Not at all	**Perfectly clearly**

1--------------2--------------3--------------4--------------5--------------6--------------7

<PTO>

5b. Did the water spray affect your escape in any way?

YES ☐ **NO** ☐

If **NO**, go to Q6.

If **YES**, how did it affect you? Please specify below.

____

____

____

6. How uncomfortable did you feel whilst evacuating with the water spray in operation? Please indicate your choice by circling a number on the scale below.

Extremely uncomfortable — **Not at all uncomfortable**

1-------------2-------------3-------------4-------------5-------------6-------------7

7. How clearly were you able to see the location of the exit corridor as you left your seat to escape from the aircraft?

Not at all — **Perfectly clearly**

1-------------2-------------3-------------4-------------5-------------6-------------7

8. How clearly were you able to hear the instructions given by the cabin staff whilst you were escaping?

Not at all — **Perfectly clearly**

1-------------2-------------3-------------4-------------5-------------6-------------7

<PTO>

9. Did you suffer any ill effects, however slight, during or after the evacuation?

YES ☐ **NO** ☐

If **NO**, go to Q10.

If **YES**, please note them in the space below.

____

____

____

10. Do you think that there would be a need for any special precautions to protect passengers if water spray systems were used in an emergency?

YES ☐ **NO** ☐

If **NO**, go to Q11.

If **YES**, what do you think these precautions would be?

____

____

____

11. If you have any additional comments about anything to do with the test you have just participated in, please write them in the space provided below.

____

____

____

____

PLEASE ENSURE THAT YOU HAVE ANSWERED ALL QUESTIONS IN FULL.

FINALLY, THANK YOU VERY MUCH FOR YOUR TIME AND CO-OPERATION.

Appendix C

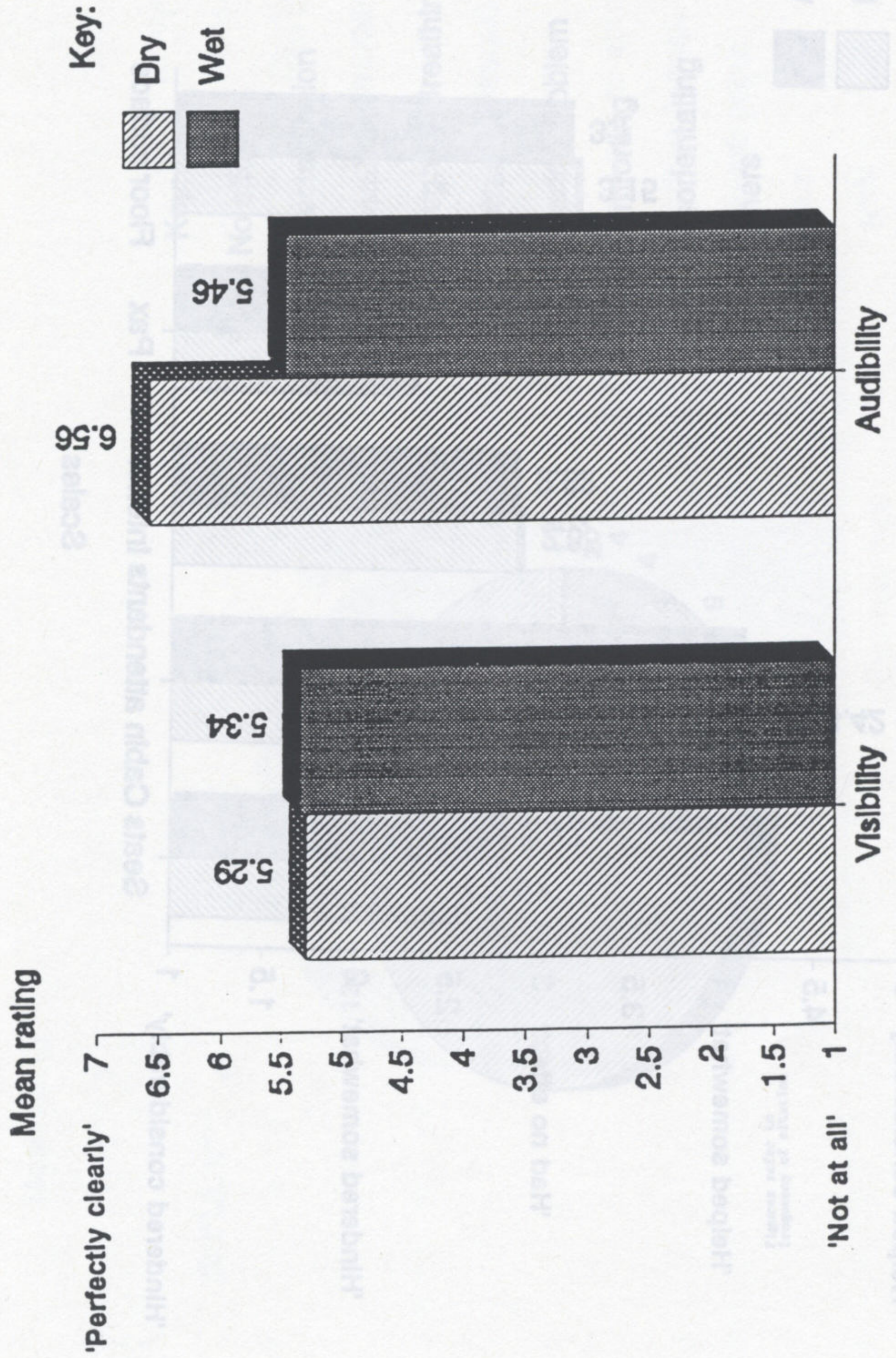

Figure C1 Subjective ratings of visibility and audibility within the cabin

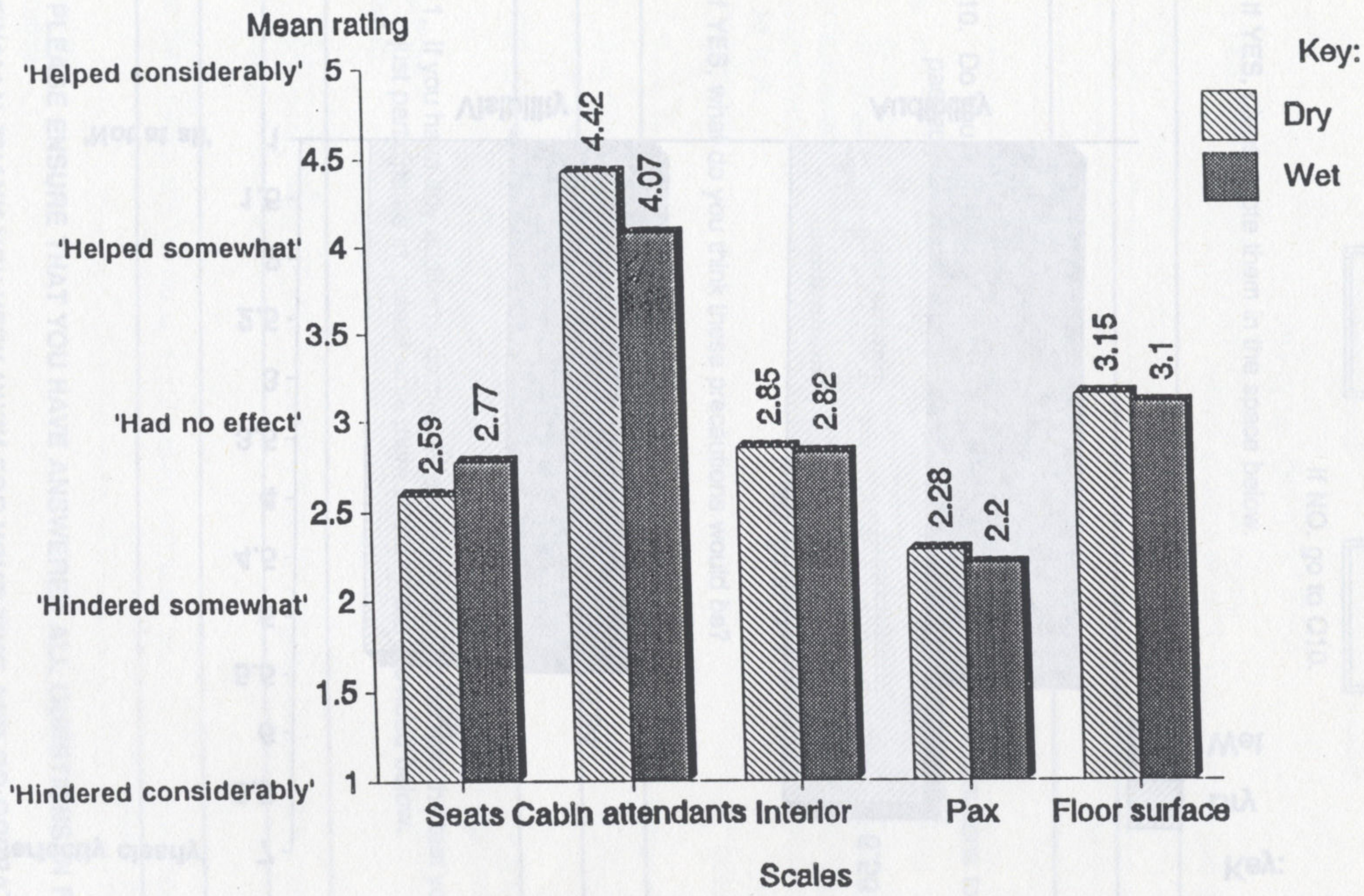

Figure C2 Help and hindrance in evacuating the cabin: factor ratings

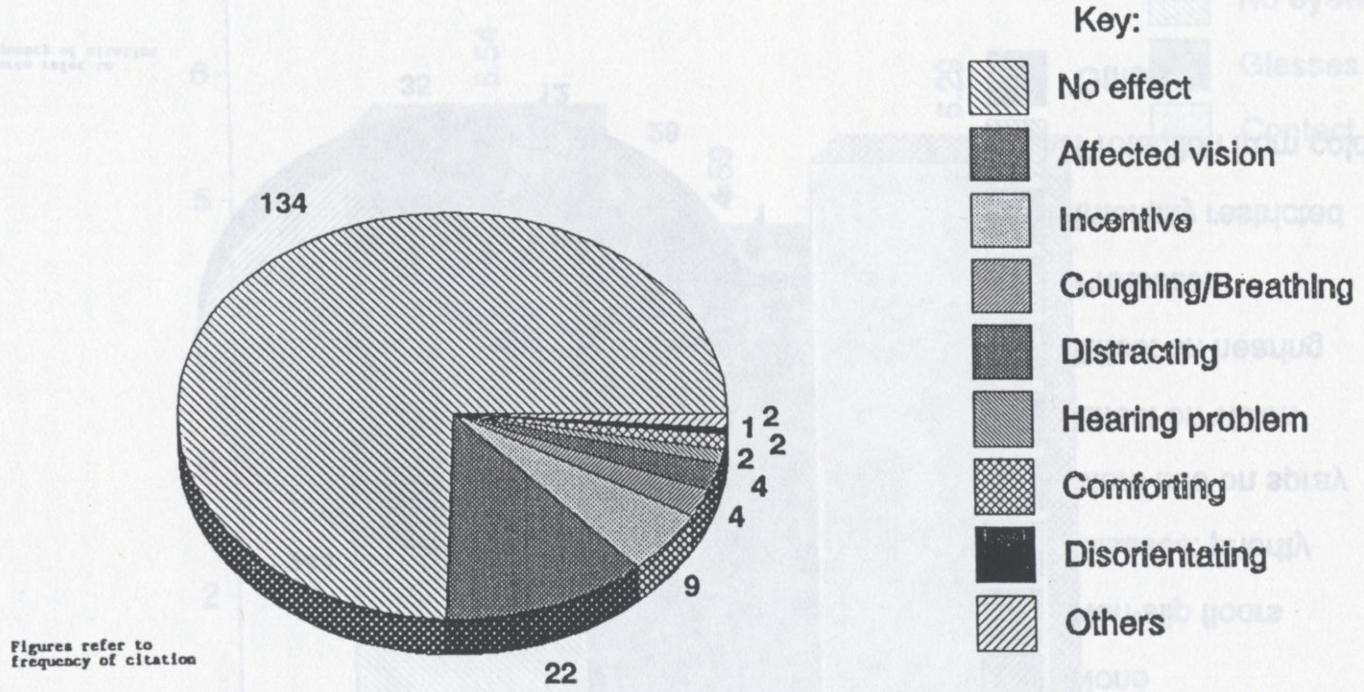

Figure C3 Reported effect of water spray upon evacuation

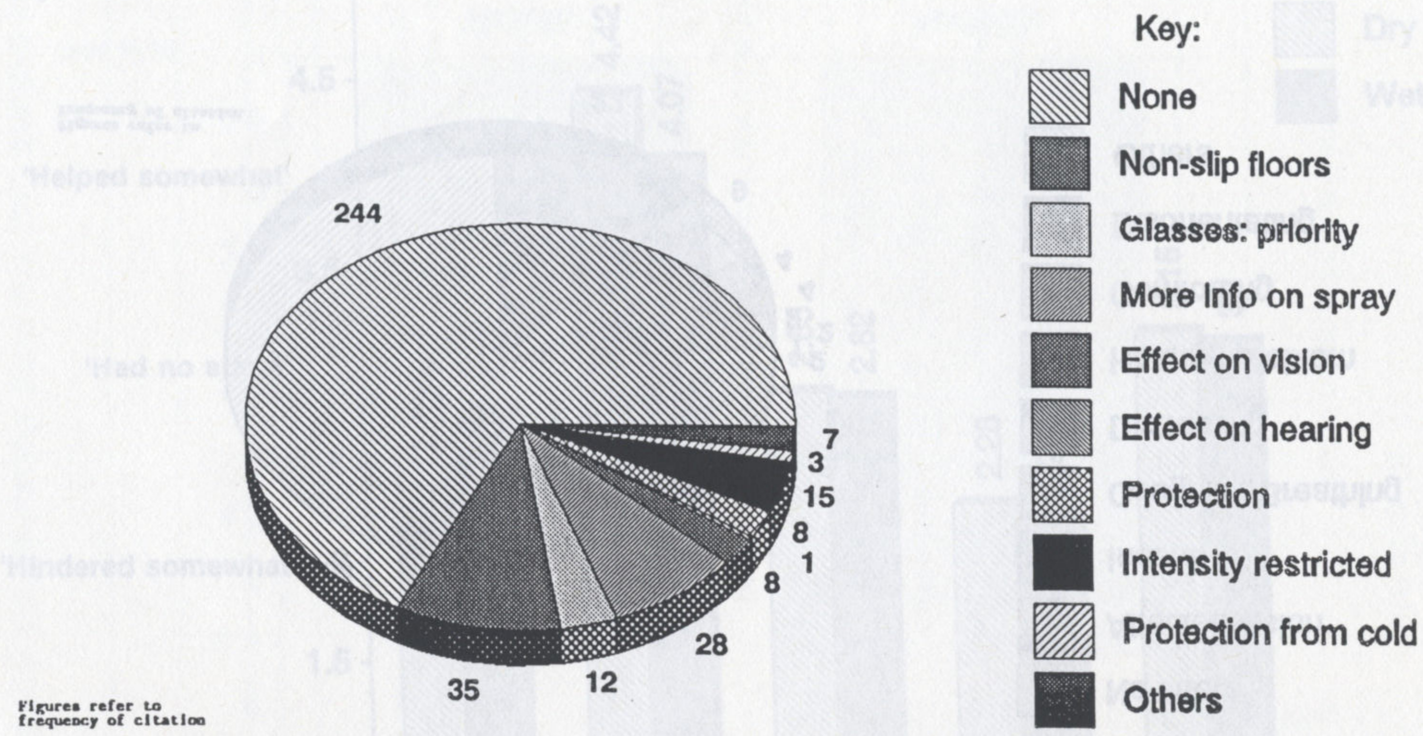

Figure C4 Suggested precautions to be adopted by operators

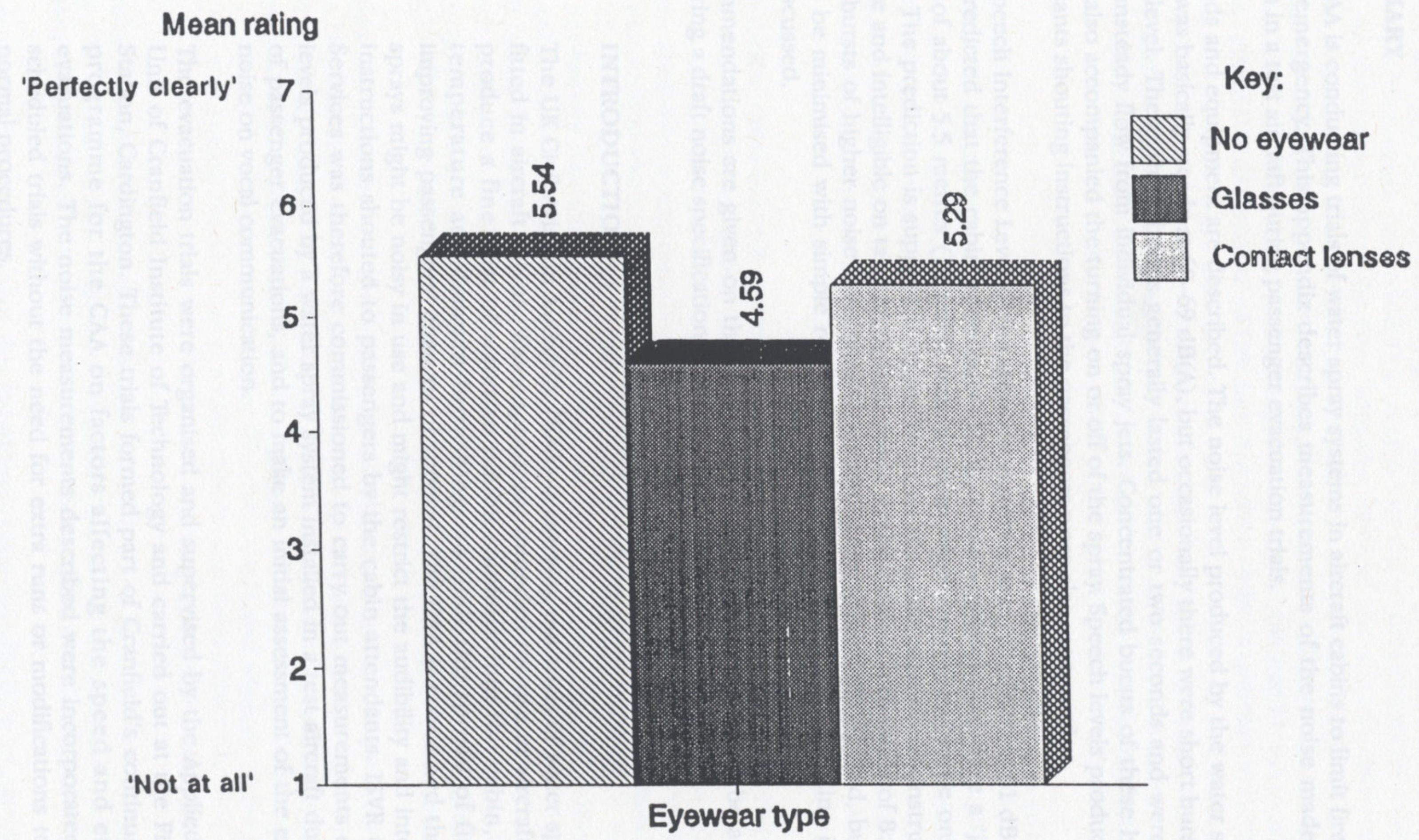

Figure C5 Subjective visibility ratings by eyewear type

Appendix D ISVR Acoustic Measurements

SUMMARY

The CAA is conducting trials of water spray systems in aircraft cabins to limit fire and smoke in an emergency. This appendix describes measurements of the noise made by a spray system in a test aircraft during passenger evacuation trials.

Methods and equipment are described. The noise level produced by the water sprays in the cabin was basically steady at 68–69 dB(A), but occasionally there were short bursts of higher noise level. These short bursts generally lasted one or two seconds and were associated with unsteady flow from individual spray jets. Concentrated bursts of these higher noise levels also accompanied the turning on or off of the spray. Speech levels produced by cabin attendants shouting instructions to the passengers were also measured.

The Speech Interference Level of the steady spray noise was calculated as 61 dB from which it is predicted that the cabin attendants shouted instructions would have a 'just reliable' range of about 5.5 metres (18 feet), assuming the water sprays to be the only source of noise. The prediction is supported by the fact that the cabin attendant's instructions were audible and intelligible on tape recordings made in the cabin at a distance of 8 metres. The short bursts of higher noise level would prevent some words being heard, but the effect would be minimised with simple repeated messages. Other factors affecting intelligibility are discussed.

Recommendations are given on the main aspects which would need to be addressed in preparing a draft noise specification for water sprays.

1 INTRODUCTION

The UK Civil Aviation Authority (CAA) is carrying out trials of water spray systems fitted in aircraft cabins. Water sprays are intended for use in aircraft fires. They produce a fine mist of water to inhibit smoke within the cabin, reduce the temperature and dampen furnishings to limit the spread of fire, thereby improving passengers' chances of survival. The CAA is concerned that the water sprays might be noisy in use and might restrict the audibility and intelligibility of instructions shouted to passengers by the cabin attendants. ISVR Consultancy Services was therefore commissioned to carry out measurements of the noise levels produced by a water spray system installed in a test aircraft during a series of passenger evacuations, and to make an initial assessment of the effects of the noise on vocal communication.

The evacuation trials were organised and supervised by the Applied Psychology Unit of Cranfield Institute of Technology and carried out at the Fire Research Station, Cardington. These trials formed part of Cranfield's continuing research programme for the CAA on factors affecting the speed and efficiency of evacuations. The noise measurements described were incorporated within the scheduled trials without the need for extra runs or modifications to Cranfield's normal procedures.

2 MEASUREMENTS

The noise within the cabin was recorded on three separate occasions. The first occasion, Tuesday 7 July 1992, was during a trial run shortly after the aircraft had been refitted, to test the water sprays, equipment and experimental procedures. For the trial run the only 'passengers' were observers from the CAA and Fire Research Station and research staff from Cranfield. The second and third occasions were evacuations with between 40 and 45 volunteers, carried out on Saturday 25 July and Saturday 8 August. These were the first and third of four evacuations organised by Cranfield, and will be referred to as the first and third evacuations throughout this report to be consistent with Cranfield's report. ISVR Consultancy Services was responsible only for making noise measurements. All other aspects of the evacuations including all noise and speech recordings played through loudspeakers in the aircraft cabin to add realism were provided by Cranfield.

2.1 The aircraft and water spray system

The aircraft used for the trials was a Boeing 707-436 belonging to the CAA. This is shown in Figures D1a and D1b. The fuselage without wings or tail was mounted on a stand inside the large hangar used as a laboratory by the Fire Research Station. A wide ramp provided access to and from the forward left exit. This was the only access to the aircraft and the only exit available to passengers during the evacuations.

During the trials volunteers were restricted to the forward cabin, which is shown in Figure D2a. This cabin had been refitted throughout by the Fire Research Station. Wood and hardboard panels replaced the original interior cabin shell, bulkheads and luggage racks which had been damaged in previous trials. One unusual consequence of the refit was the lack of any windows in the cabin.

The cabin ceiling was made of translucent plastic panels with low voltage lighting above. A number of water spray nozzles protruded through the ceiling. Similar jets were fitted at intervals along the join between the luggage racks and the cabin walls. Figure D2b shows one of the jets. To give an idea of the scale, the overall diameter of the fitting was measured as 20 mm while the jet aperture had a diameter of about 1.5 mm.

Figure D3 shows the locations and orientations of the waterjets, the seating plan of the aircraft, and the passageway from the cabin to the single available exit. This figure has been drawn from measurements made within the aircraft and is approximately to scale. The Figure also shows the locations of two microphones used to measure noise levels.

2.2 Noise recording equipment

Before the series of trials ISVR Consultancy Services installed two microphone cables from inside the aircraft cabin to a portable office outside. The portable office was used as a control room. The cables were left permanently in place.

Miniature microphones were installed in the aircraft cabin on each occasion that noise levels were measured. The microphones were both Knowles Electronics Type BT-1759. These microphones were chosen not only for their electroacoustic performance but because their small size, 8 mm x 5.5 mm x 2 mm, makes them very unobtrusive in use and very easy to install. The microphones were installed at the positions marked on Figure D3. Microphone number 1 was placed where the luggage rack met the ceiling roughly half way down the length of the cabin, 3.9 metres from the bulkhead at the forward end of the cabin. It was above the aisle seat of the fifth row from the front of the aircraft (labelled row ø12). Microphone 2 was placed on the cabin wall immediately below the luggage rack where the rack met the wall. This microphone was slightly further back from the first, 5 metres from the bulkhead. It was above the window seat of seventh row back (labelled row 15 as row 14 was omitted from the number sequence).

The microphone positions were chosen so that they were out of the way of the passengers, and between or to the side of the spray jets where they would not get too wet. Each microphone was between 0.4 and 0.5 metres from the nearest jet or jets. This is roughly comparable to the distance between a jet and the ear of a passenger passing it.

During the initial trial run a small square of thin, low density polyurethane foam was placed over each microphone. This type of foam is often used for microphone windshields as it is effectively acoustically transparent. It was intended to protect the microphone from water. Following the test run the foam was found to be dry and the patterns of water on the cabin surfaces showed the microphones to be clear of the sprays. Consequently the foam was not used during the evacuations with passengers.

The microphones were held in position by white fabric adhesive tape. The microphone cables were approximately 3 mm in diameter and were unobtrusive. The cables were taken to a point behind the rear row of seats. The leads were taped to the cabin surfaces along their entire length, again using white fabric tape, so that there was no possibility of passengers catching on the leads during evacuations. Each microphone was powered by its own small battery power supply hidden behind the rear seats. The two microphone signals were then amplified by 24 dB (16 times voltage gain) before being fed via the permanently-installed extension cables to the control room. The microphone power supplies and signal amplifier were designed and built at ISVR. In the control room the two microphone signals were recorded on a Sony TCD-D10 portable digital audio tape (DAT) recorder.

Both channels of the entire recording system were calibrated before and after each set of recordings. A Brüel and Kjær Type 4230 sound level calibrator was placed over each microphone in turn and the tone produced was recorded on the tape. The sound level calibrator provides an accurate reference sound level of 94 dB at a frequency of 1 kHz. The recording level control of the tape recorder was sealed throughout the calibrations and measurements. This calibration is traceable to the National Physical Laboratory (NPL) via precision microphones and sound sources ('pistonphones') calibrated annually at NPL and held at ISVR Consultancy Services as laboratory standards.

The microphone power supplies and amplifiers in the aircraft were sealed in polythene bags for protection. Both of the microphones and all items of equipment apart from the permanent extension leads were removed from the aircraft immediately after each evacuation in which water sprays were used so that they would not be damaged by the heat and the humidity while the aircraft was being dried out. Between trials the connectors and ends of the permanent extension cables were sealed in a polythene bags containing silica gel desiccant as a precaution.

All equipment used for making noise recordings was battery powered for safety.

2.3 Recordings made

On each occasion two separate evacuations were tape recorded. The first was always a 'dry' evacuation for which the water sprays were not used. The second was always a 'wet' evacuation with the sprays. Wet and dry evacuations differed only in whether the sprays were used or not.

The evacuations occurred during simulations of an emergency during take-off. Following a briefing, passengers boarded the aircraft and were shown to their seats by two female cabin attendants. A pre-flight briefing was given during which the exit available was pointed out. One cabin attendant took a seat in the front row of the cabin, the other seat in the back row. Tape recorded engine noise was played through loudspeakers above the cabin ceiling, initially at a low sound level for about 55 seconds and then at a higher sound level. After about 55 seconds at the higher level the engine noise was cut, there was a pause of 15 seconds, then a recorded announcement instructed volunteers 'undo your seat belts and get out'. The two cabin attendants immediately took command. The one at the front shouting 'this way, this way' and 'come on, this way' as loudly as possible from a position in the vestibule close to the exit, the one at the back shouting 'forward, go forward' repeatedly as she moved forward from the rear shepherding the volunteers in front. During the evacuation Cranfield replayed sound effects of panicking passengers to add to the realism.

During the wet evacuations the water sprays came on at the commencement of the pause between the engine noise cutting out and the instruction to 'undo your seat belts and get out'.

3 ANALYSIS OF RECORDINGS

The recordings of the evacuations were analysed at ISVR. A time history, or graph of sound level varying with time, was first obtained to assist with further analysis of each recording. The time histories are shown in Appendix E.

Each recording was then replayed to a B&K Type 2133 Dual Channel Analyser to obtain representative sound levels and spectra of the noise in the cabin during various phases of evacuations. The spectra were analysed with octave and one-third octave band frequency resolution.

The analyser was also used to provide time histories of short portions of recordings with greater accuracy than the chart recordings in Appendix E.

4 DISCUSSION

The sound level analysis was concentrated on two aspects, the noise levels produced by the water sprays and the sound levels produced by the cabin attendants shouting instructions. Other sounds heard during the evacuation, for example the recorded safety announcements or recorded engine noise were not measured because these were sound effects included to create an atmosphere of urgency and reality. They were simulations not necessarily typical of a real-life evacuation. The water sprays and the shouting cabin attendants on the other hand were real. The sound levels from the water sprays would be the same if the system were used for a real evacuation. The shouts from the cabin attendant were at a vocal level which would be achievable in a real evacuation with similar, smoke-free cabin conditions.

4.1 Noise produced by water sprays

It should be noted that the measured noise levels apply only to the particular design and installation of spray fitted for the test and under the conditions of the test. Noise levels from other installations in other circumstances may differ owing to, amongst other factors, the particular design and diameter of the spray jets, the number and spacing of the jets, and the water pressure, flow rate and flow stability achieved.

The most useful recording for determining the sound levels of the water sprays was that obtained during the trial run with the CAA observers in place of the volunteers. This recording enabled noise levels to be measured most of the time with little interference from other significant noise sources.

4.1.1 *Characteristics of the noise*

The noise from the water spray system showed quite distinct characteristics. For most of the time while the spray was operating the water flow was stable and the noise was a steady hiss at a remarkably constant sound level. But for the first few seconds after the spray was turned on, before the stable flow was established, there were several short bursts of higher noise levels. Listening to the two channels of the tape recording simultaneously showed that these short bursts were local, from individual jets, and were not synchronised. Similar short bursts of higher sound level were heard when the water flow was turned off, suggesting that the bursts are a result of unstable flow conditions rather than any initial clearing of air from the pipes. Some short bursts were noticed during the steady flow stage, but these were isolated and infrequent. The prolonged period of use of the sprays during the initial trial run, Figure E2 in Appendix E, shows about 14 short bursts of noise in a 100 second period as a worst case, while the long period of use at the end of the third evacuation, Figure E6, shows only two major bursts of noise in an 85 second period.

4.1.2 *Noise levels*

The noise levels measured at each of the two microphones are given in Table D1. Points to note are that noise levels during the stable flow were very similar at the two microphone positions and remarkably constant from trial to trial, although trials were weeks apart. The A-weighted noise level for this installation was typically between 68 and 69 dB.

Table D1 does not show a full set of measured noise levels for each of the evacuations. Although high quality noise recordings were obtained, some difficulty was encountered in measuring the noise levels and spectra produced by the water sprays when volunteers were present. Within a second or two of the sprays coming on during the first full trial the volunteers in the aircraft groaned in unison and masked the sound of the sprays. Figure D4 shows the variation in noise level during this part of the evacuation and illustrates the difficulties. To a lesser extent the same happened in the third evacuation. During the first evacuation the sprays were turned off before the tape recorded volunteer noise and it was not therefore possible to analyse the steady flow noise. For the third evacuation the water sprays were allowed to continue after all volunteers were out and after the recorded noise was stopped thereby providing a good recording of the sprays alone.

The noise levels which were obtained during the initial trial and the two evacuations provided sufficient information. But to be practicable, any future specification for measuring noise levels from water sprays will need to specify measurements to be made in the absence of passengers.

4.1.3 *Noise spectra*

The spectrum of the noise as well as the overall sound level is important in determining the effect on speech intelligibility.

Figure D5 shows the one-third octave spectrum of the noise from the water spray system at each of the two microphone positions measured under steady flow conditions during the initial trial. The spectrum at microphone 1 is shown with an unbroken line, that for microphone 2 is shown dotted. Figure D6 shows the equivalent spectra obtained during the third evacuation measured just after all the volunteers were out. All these spectra are remarkably similar.

Figure D7 shows spectra measured during the first few seconds of use before the flow had stabilised. The spectra are broadly similar in shape to those obtained during steady flow, but the noise levels are higher. All the spectra are essentially flat from the 1 kHz band upwards with a low-frequency fall off below 1 kHz at a rate of roughly 5 dB per octave.

The two prominent bands at 100 and 200 Hz visible in the spectra are really present in the acoustic noise in the cabin: although possible harmonics of the electrical mains frequency they are not electrical noise in the recording system, but could be attributable, for example, to the water pump or other powered equipment. Figure D8 shows the background noise measured in the empty cabin and these two frequencies are only present at a very low level. Whatever the cause of the prominent bands, the effect is of little practical consequence.

4.2 *Voice levels of cabin attendants*

The sound levels of the warnings shouted by the cabin attendants are also given in Table D1. The levels measured during the evacuations inevitably include the noise produced by the volunteers and the pre-recorded sound effects of a panicking crowd. As far as possible these background noises were avoided by selecting the parts of the sound recordings which were analysed. No crowd sound effects were played during the initial trial run so the sound levels of the cabin attendant's shouted instructions could be measured accurately. Since the sound levels measured during the evacuations are similar to those measured during the trial run these are taken to be accurate.

The sound levels of the cabin attendant's shouts were of the order of 20 dB above the sound levels of the water sprays with fully developed flow. This is a satisfactory margin and the water sprays would not greatly degrade the audibility of shouted warnings if they were the only noise source. In practice there may be other background noise sources – noise from passengers, possibly engine noise, noise from burning fires, emergency vehicle sirens from outside – and if these other sources are louder than the water sprays by more than a few decibels then these other sources rather than the sprays will determine the audibility of shouted instructions.

An important observation is that, in every case, the shouted instructions of the cabin attendants were always audible and intelligible on the tape recordings made through the miniature microphones in the cabin.

4.3 Audibility and intelligibility of shouted instructions

It would be desirable to be able to predict the intelligibility of shouted speech from the noise measurements of the water sprays. There is a measure of noise known as the Speech Interference Level (SIL) which is designed to do this. Speech Interference Level is defined in American Standard ANSI S3.14 (Ref 11). There is no equivalent British Standard but a draft International Standard (Ref 12) is in preparation. SIL is the arithmetic mean of the sound levels in the four octave bands centred on 0.5, 1, 2 and 4 kHz. These bands effectively cover the range of the sound frequencies in speech and noise within these bands has the most effect on speech intelligibility. SIL has been found to give a good indication of speech intelligibility and is widely used. Although originally intended for outdoor use it has been found to be equally useful indoors (Refs 12 and 13) provided the distance from speaker to listener does not exceed about 8 metres and provided the room or other occupied space is not reverberant (reverberation time less than 1.5–2 seconds (Refs 11, 12 and 13).

Calculating the SIL of the noise from the water sprays gives a value of 61 dB. To interpret this we refer to Figure D9 which is redrawn from the American Standard. Entering the graph with an SIL of 61 dB on the x-axis and reading off from the line marked 'shout' we find this corresponds to a distance on the y-axis of approximately 5.5 metres (18 feet). This means that 'just reliable' communication should be possible in a shouting voice at up to about 5.5 metres in the noise level produced by the water sprays, assuming the water sprays are the only significant noise source.

During the periods of higher noise level when the flow from the water sprays is not stable the range for speech communication will be severely restricted. These periods of higher noise level are generally of short duration, and local in that individual jets are affected. Consequently some words will be missed but provided instructions are simple and continually repeated occasional missed words should not prevent the message being understood. These short periods of temporary difficulty in hearing may serve to draw attention to the water sprays and passengers may overestimate the effect of the noise on communication.

How applicable the SIL prediction is to evacuations from aircraft cabins may be questioned. Firstly for a notional passenger towards the rear there may be a number of other passengers in front obstructing the direct sound path from the person shouting instructions. this obstruction will occur whether sprays are used or not. Secondly, the presence of the water mist may affect the passage of sound, though this is unlikely to be a large effect at speech frequencies. Both these effects may *reduce* the distance at which the shouter is heard. Conversely the shape of the aircraft, a long thin tunnel, will mean that sound will propagate easily along the length of the cabin with sound reflected off the cabin surfaces. As the cabin is narrow the reflected sound will reinforce the direct sound without significant reverberation effects. These effects will tend to *increase* the distance at which shouted instructions are audible, and tend to cancel the other effects.

We do not have quantitative information which would enable us to predict whether the effects tending to reduce the distance exceed those which tend to increase the distance at which communication is reliable. However, as has already been observed, the shouted instructions of the cabin attendants were always audible and intelligible on the tape recordings made through the miniature microphones in the cabin. These microphones were about 7 metres and 8 metres from the exit, and the member of cabin staff at the exit was intelligible at these distances. This suggests that the factors tending to reduce the range of shouted instructions are at least compensated for by those factors which tend to increase the range, and that the SIL can be used to assess the distances for reliable communication within the cabin.

There are other very important factors which affect the effectiveness of shouted instructions. Shouted instructions may be audible and intelligible to an attentive listener at a given distance, but a passenger in a real emergency may be concentrating so much on the main task of escaping that he or she may not even notice them. Even under excellent acoustic conditions with little noise the passenger might miss the shouted instructions completely. That speech intelligibility should not be reduced by excessive noise is therefore necessary to allow communication, but is not of itself sufficient.

In predicting the range of reliable communication it has been implicitly assumed that the talker and listeners are fluent in the language in which the instructions are given, and that the listeners have reasonably normal hearing. These assumptions will not always be valid.

Source of noise other than the water sprays may further limit the range of communication.

4.4 Noise specifications for water sprays

It is beyond the scope of this project to produce a noise specification for water spray systems in aircraft. The noise measurements described above are data which must be considered along with existing knowledge of water sprays, and more experience and further work would be needed to set an actual noise limit. However these trials have provided valuable experience and the main features of a specification could at this stage be outlined in a draft for comment.

A draft noise specification would address the following points:

- the quality and minimum performance characteristics of the microphones and associated equipment used for noise measurement;

- the locations of microphones relative to the water sprays and precautions to be taken to ensure valid noise measurements are obtained;
- the procedure to be used, including number of measurements to be made and the conditions under which those measurements should be made, eg we would recommend that measurements should be made in the absence of passengers;
- a basic maximum noise level would need to be specified for the spray system during steady water flow conditions – possibly the maximum level might vary according to the size of the aircraft, spacing of exits, and hence the range over which communication must be reliable;
- the percentage of the time for which the basic maximum noise level above could be exceeded during any given time period, to allow for occasional unsteady flow, and the maximum continuous period during which the noise limit could be exceeded, especially when the spray is initiated.

The noise specification would form an integral part of a more general specification, since noise limits cannot be taken in isolation. The spray system must primarily perform efficiently and effectively in minimising fire and smoke. The noise limits must then be met in addition, and any noise limits should not compromise the effectiveness of the spray.

5 CONCLUSIONS RELATING TO ACOUSTIC MEASUREMENTS

The noise levels produced by a water spray system in an aircraft cabin were measured during a series of passenger evacuation trials. The noise level was constant for long periods when the water flow through the jets was stable, and was the same on each occasion. The steady noise level was 68–69 dB(A).

There were periods during which the noise levels were much higher. The main period was the first few seconds after the water had been turned on before the flow was stable. There were other periods when the flow was not stable, causing the spray jets to splutter, but these were usually short, lasting 1 or 2 seconds, and infrequent.

The range for 'just reliable' communication by shouting above the noise of the water sprays was predicted to be approximately 5.5 metres. This prediction was based on calculating the 'Speech Interference Level' of the water spray noise in accordance with an American standard. The calculated Speech Interference Level was 61 dB. It is argued that the Speech Interference Level is a valid measure for predicting intelligibility within the aircraft cabin.

On the sound recordings made inside the cabin, the instructions shouted by cabin attendants were always audible and intelligible above the steady noise of the water sprays. The furthest microphone used for the recordings was about 8 metres from the member of cabin staff at the aircraft exit. This supports the prediction that reliable communication should be possible at up to 5.5 metres.

During the periods of higher noise level when the flow from the water sprays is not stable the range for speech communication will be severely restricted. These periods of higher noise level are generally of short duration, and local in that individual jets are affected. Consequently some words will be missed but using simple repeated instructions should minimise difficulties caused by occasional missed words. These very short periods of temporary difficulty may however draw attention to the water sprays and passengers may overestimate the effect of the noise on communication.

These trials have provided valuable experience which would enable an outline noise specification to be produced, though actual numerical noise limits would need to be further considered.

Measured noise levels and other results apply only to the particular design and installation of spray fitted for the test and under the conditions of the test. Noise levels from other installations in other circumstances may differ owing to, amongst other factors, the particular design and diameter of the spray jets, the number and spacing of the jets, and the water pressure and flow rates and flow stability achieved.

Table D1 Measured sound levels

Measurement occasion	Evacuation type	Measured A-weighted sound levels (L_{Aeq}), dB(A)					
		Water spray, steady flow		Water spray, developing flow		Cabin attendants (and volunteers)	
		Microphone 1	Microphone 2	Microphone 1	Microphone 2	Microphone 1	Microphone 2
Trial evacuations	dry	–	–	–	–	89.5	90.5
	wet	69.0	68.5	78.0	82.0	–	–
First main evacuations	dry	–	–	–	–	85.5	79.5
	wet	–	–	81.5	80.0	90.0	85.5
Third main evacuations	dry	–	–	–	–	90.0	86.0
	wet	69.0	68.5	–	–	89.0	86.0

5 CONCLUSIONS RELATING TO ACOUSTIC MEASUREMENTS

The noise levels produced by a water spray system in an aircraft cabin were measured during a series of passenger evacuation trials. The noise level was constant for long periods when the water flow through the jets was stable, and was the same on each occasion. The steady noise level was 68–69 dB(A).

There were periods during which the noise levels were much higher. The main period was the first few seconds after the water had been turned on before the flow was stable. There were other periods when the flow was not stable, causing the spray jets to splutter, but these were usually short, lasting 1 or 2 seconds, and infrequent.

The range for 'just reliable' communication by shouting above the noise of the water sprays was predicted to be approximately 5.5 metres. This prediction was based on calculating the 'Speech Interference Level' of the water spray noise in accordance with an American standard. The calculated Speech Interference Level was 61 dB. It is argued that the Speech Interference Level is a valid measure for predicting intelligibility within the aircraft cabin.

On the sound recordings made inside the cabin, the instructions shouted by cabin attendants were always audible and intelligible above the steady noise of the water sprays. The furthest microphone used for the recordings was about 8 metres from the member of cabin staff at the aircraft exit. This supports the prediction that reliable communication should be possible at up to 5.5 metres.

During the periods of higher noise level when the flow from the water sprays is not stable the range for speech communication will be severely restricted. These periods of higher noise level are generally of short duration, and local in that individual jets are affected. Consequently some words will be missed but using simple repeated instructions should minimise difficulties caused by occasional missed words. These very short periods of temporary difficulty may however draw attention to the water sprays and passengers may overestimate the effect of the noise on communication.

These trials have provided valuable experience which would enable an outline noise specification to be produced, though actual numerical noise limits would need to be further considered.

Measured noise levels and other results apply only to the particular design and installation of spray fitted for the test and under the conditions of the test. Noise levels from other installations in other circumstances may differ owing to, amongst other factors, the particular design and diameter of the spray jets, the number and spacing of the jets, and the water pressure and flow rates and flow stability achieved.

Figure D1a The Boeing 707 fuselage in the hangar at Cardington

Figure D1b The Boeing 707 fuselage in the hangar at Cardington

Figure D2a View of the cabin looking forward

Figure D2b Close up of a spray jet

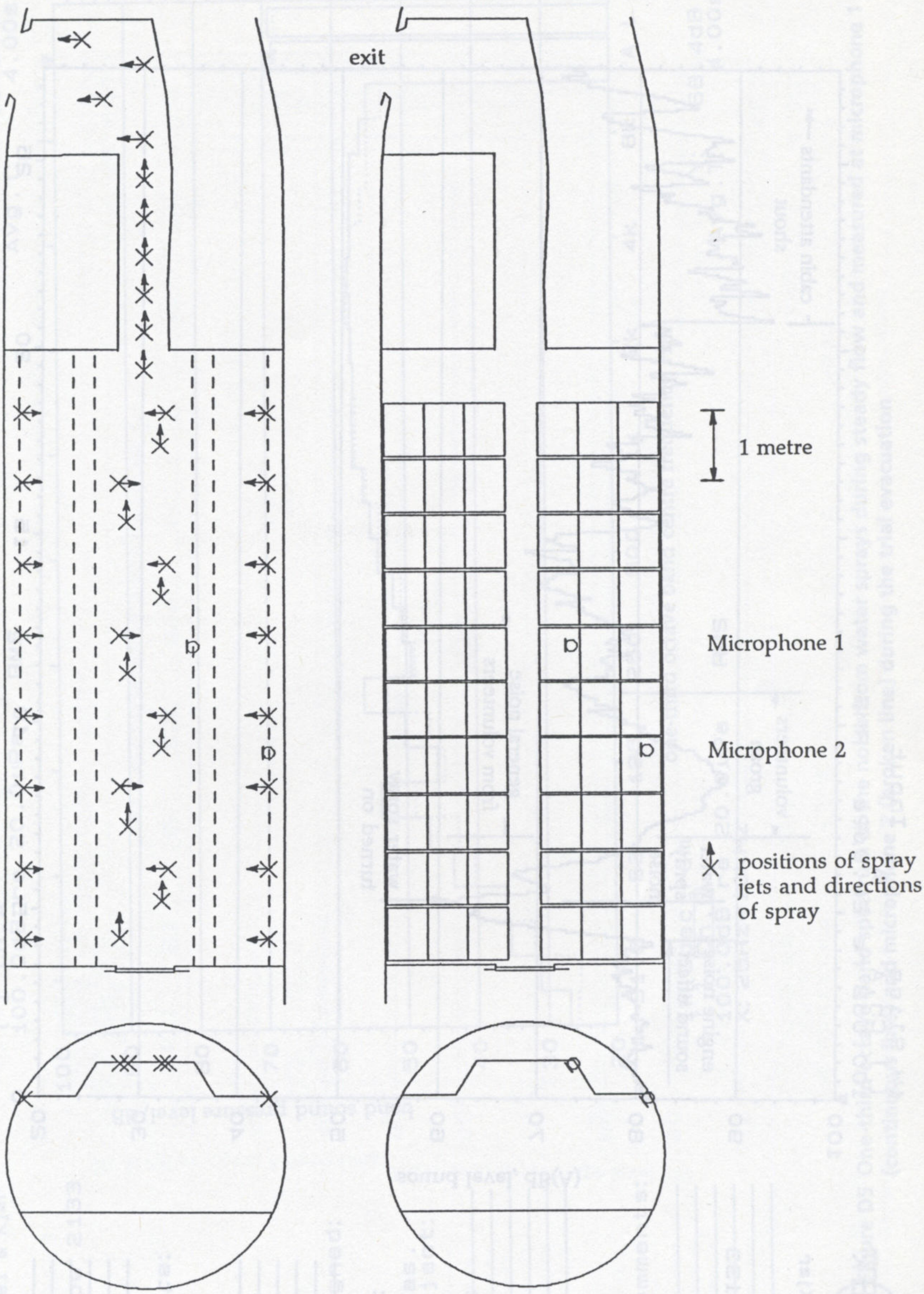

Figure D3 Plans and cross sections of the cabin showing locations of spray jets (left) and seating (right), the exit and the positions of the microphones used to record the noise

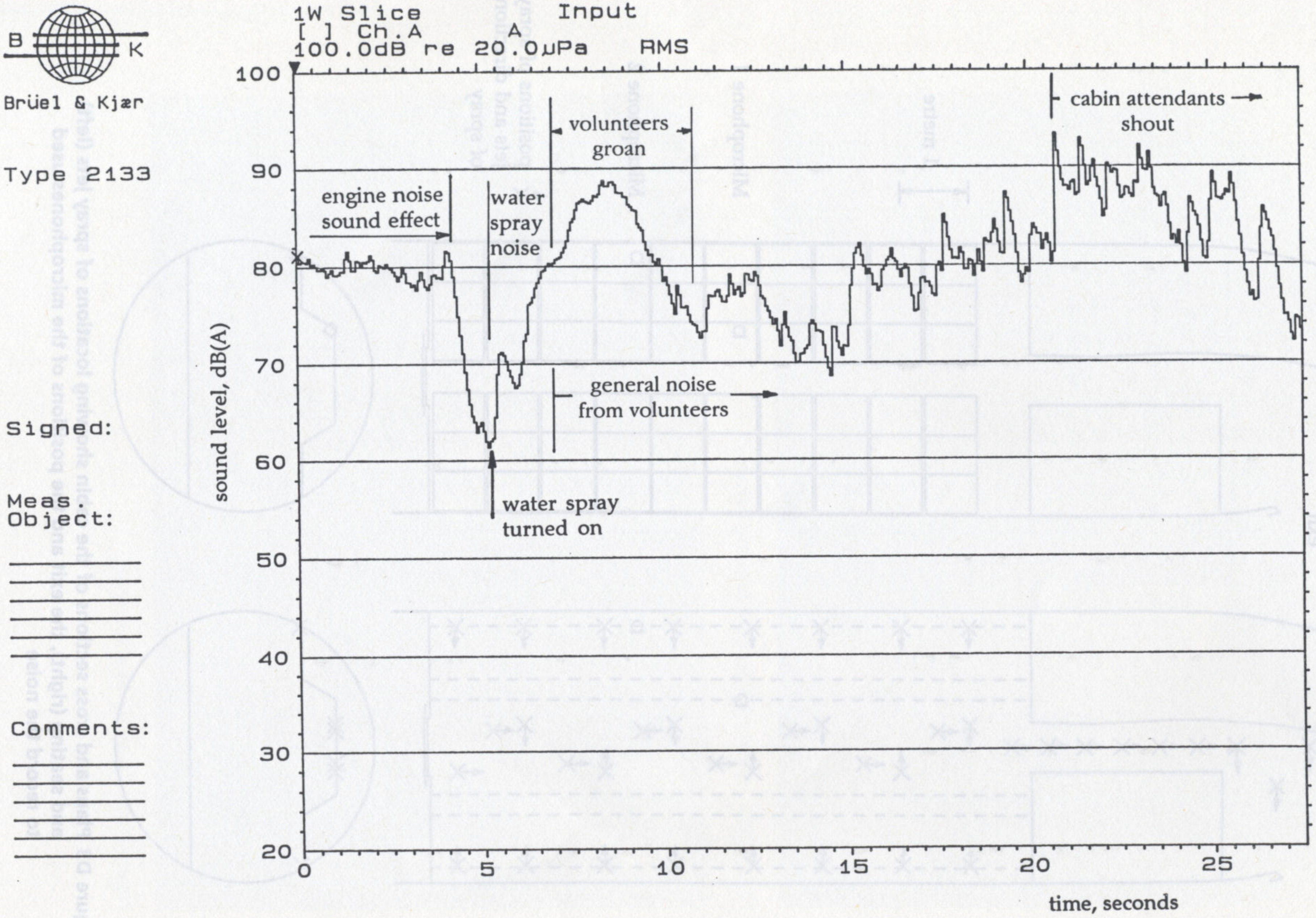

Figure D4 The variation in sound level with the sequence of events when the water sprays were turned on during the first evacuation

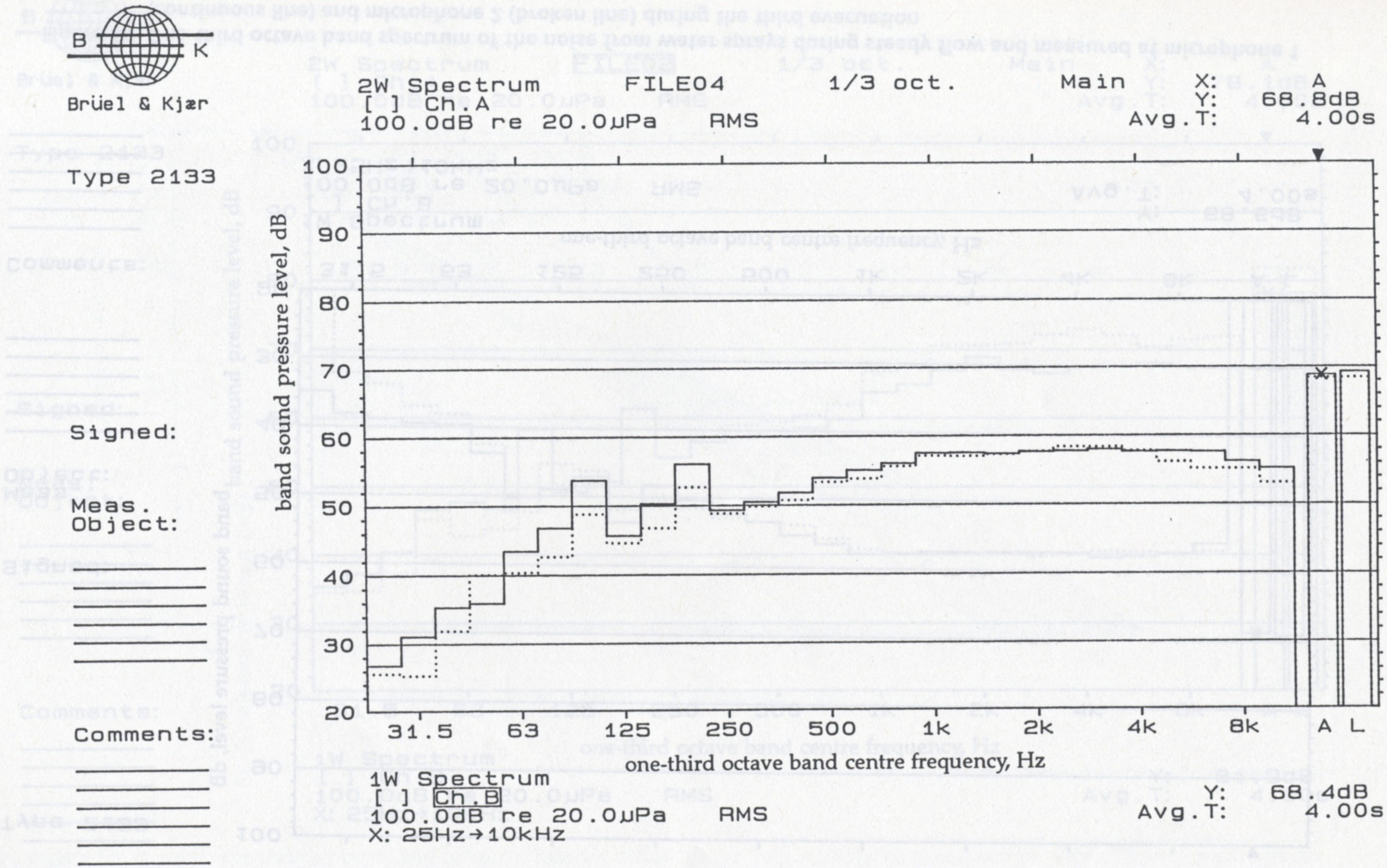

Figure D5 One-third octave band spectrum of the noise from water sprays during steady flow and measured at microphone 1 (continuous line) and microphone 2 (broken line) during the trial evacuation

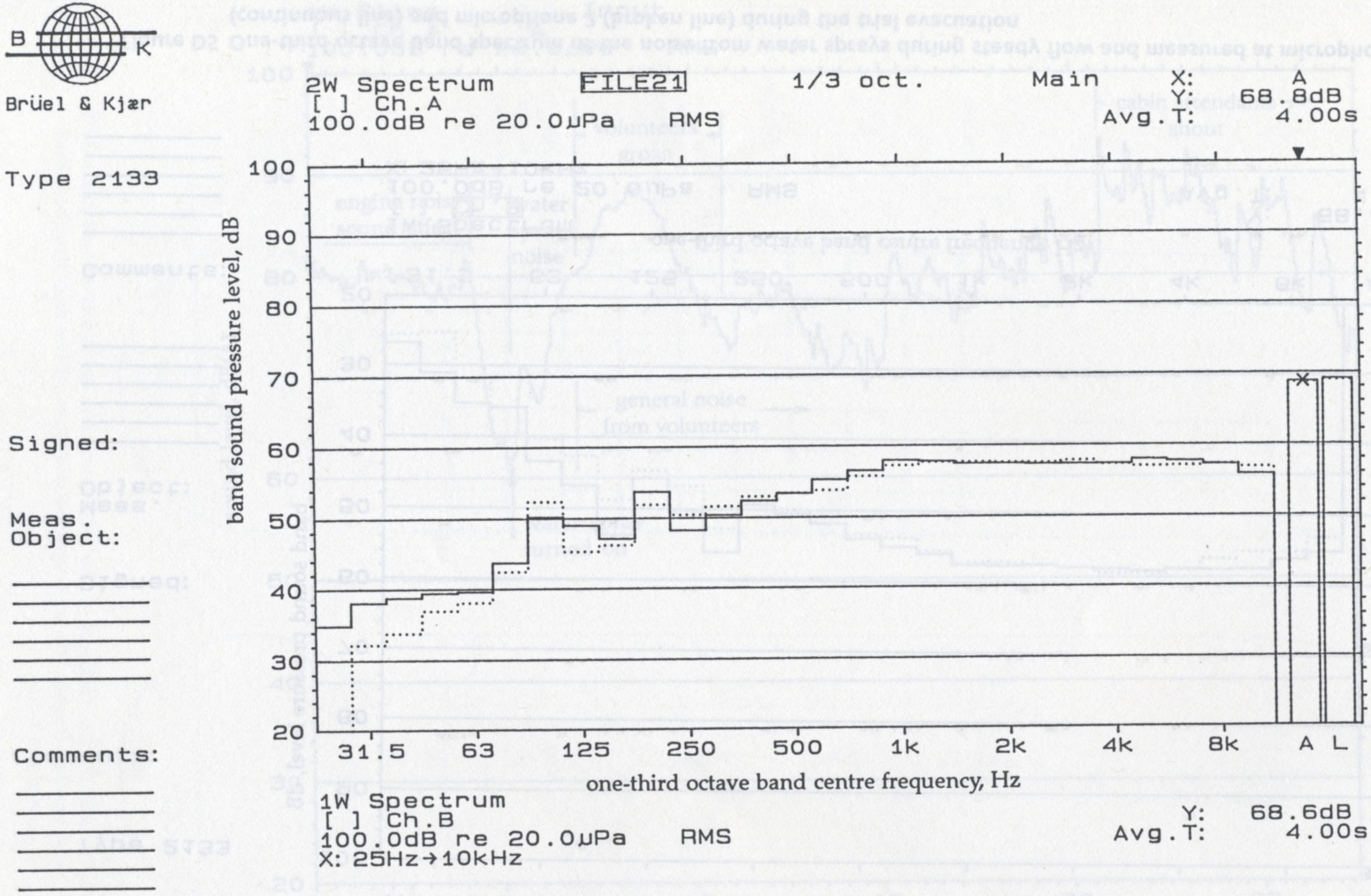

Figure D6 One-third octave band spectrum of the noise from water sprays during steady flow and measured at microphone 1 (continuous line) and microphone 2 (broken line) during the third evacuation

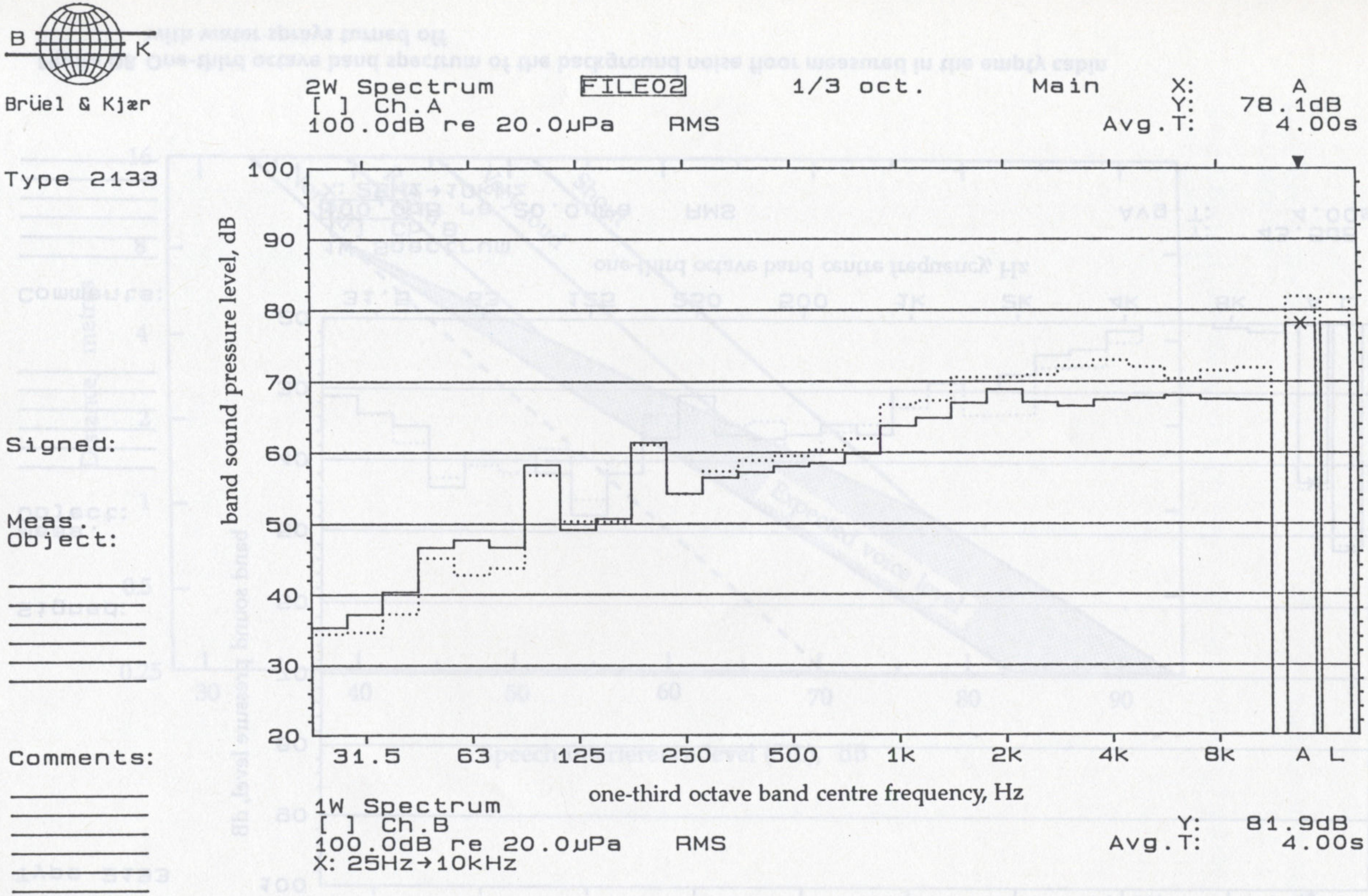

Figure D7 One-third octave band spectrum of the noise from water sprays averaged over the first four seconds and measured at microphone 1 (continuous line) and microphone 2 (broken line) during the trial evacuation

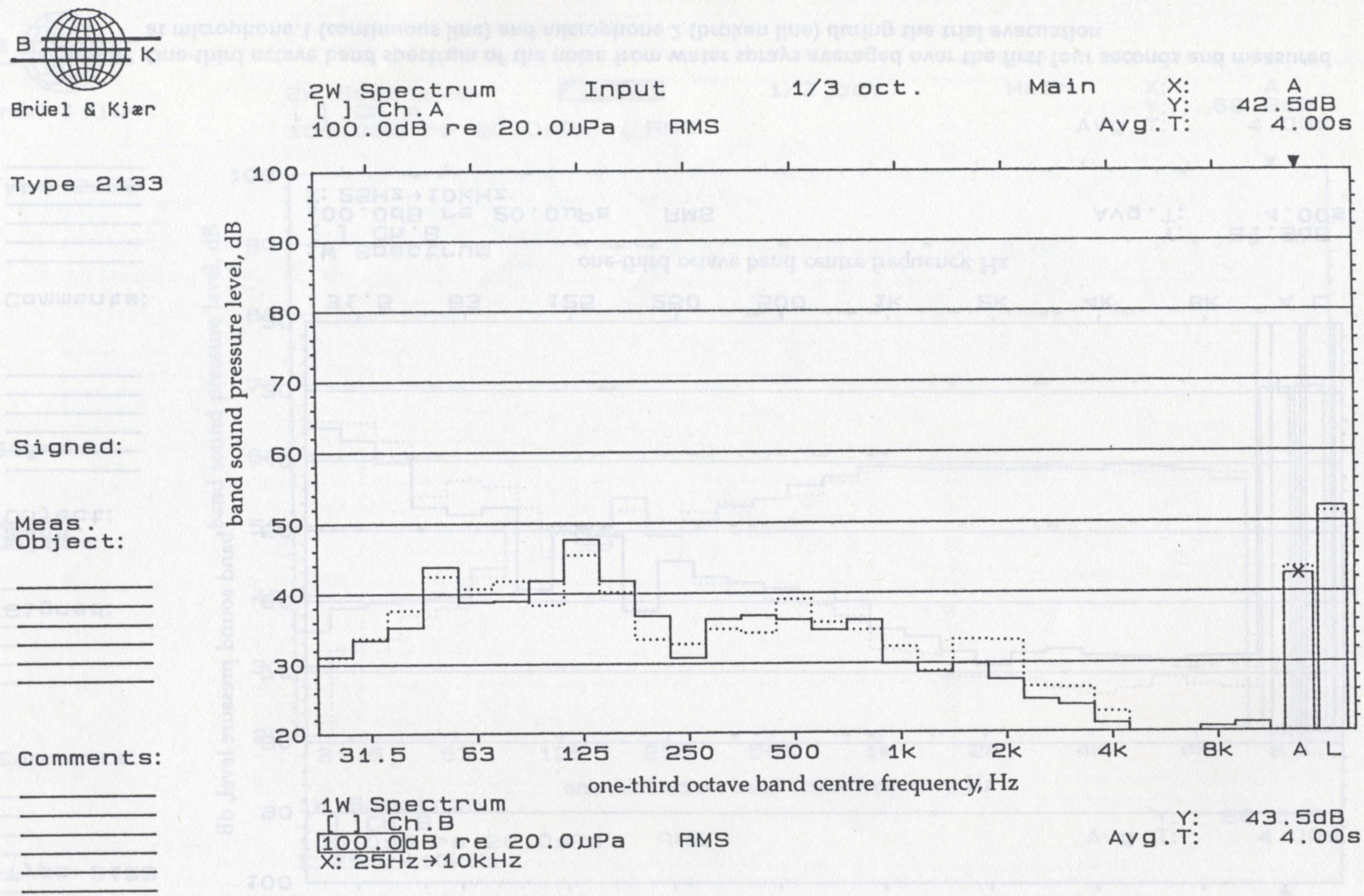

Figure D8 One-third octave band spectrum of the background noise floor measured in the empty cabin with water sprays turned off

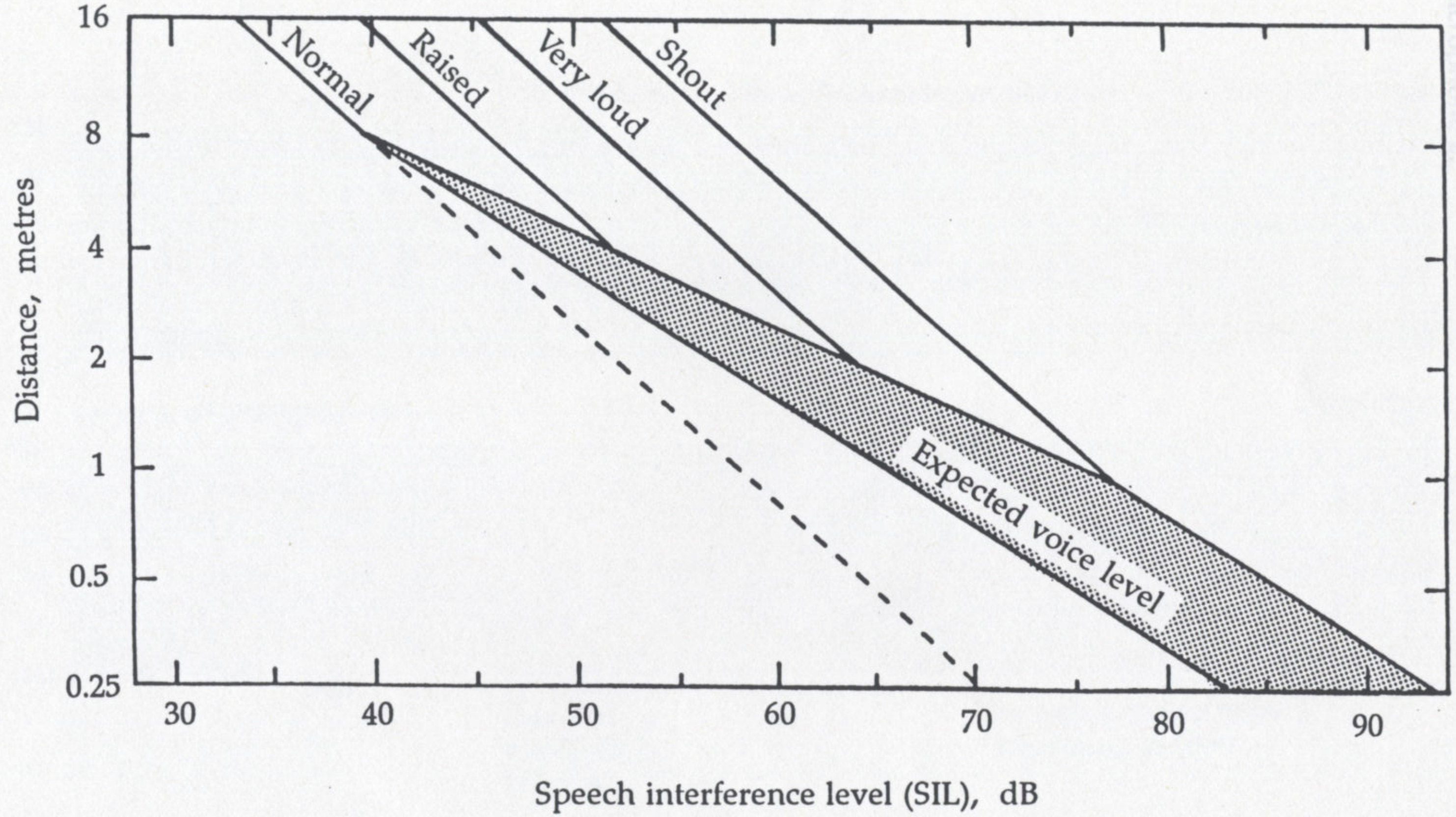

Figure D9 Speech Interference Level and talker to listener distances for 'just reliable' communication with different vocal efforts
(Based on ANSI Standard S3.14–1977)

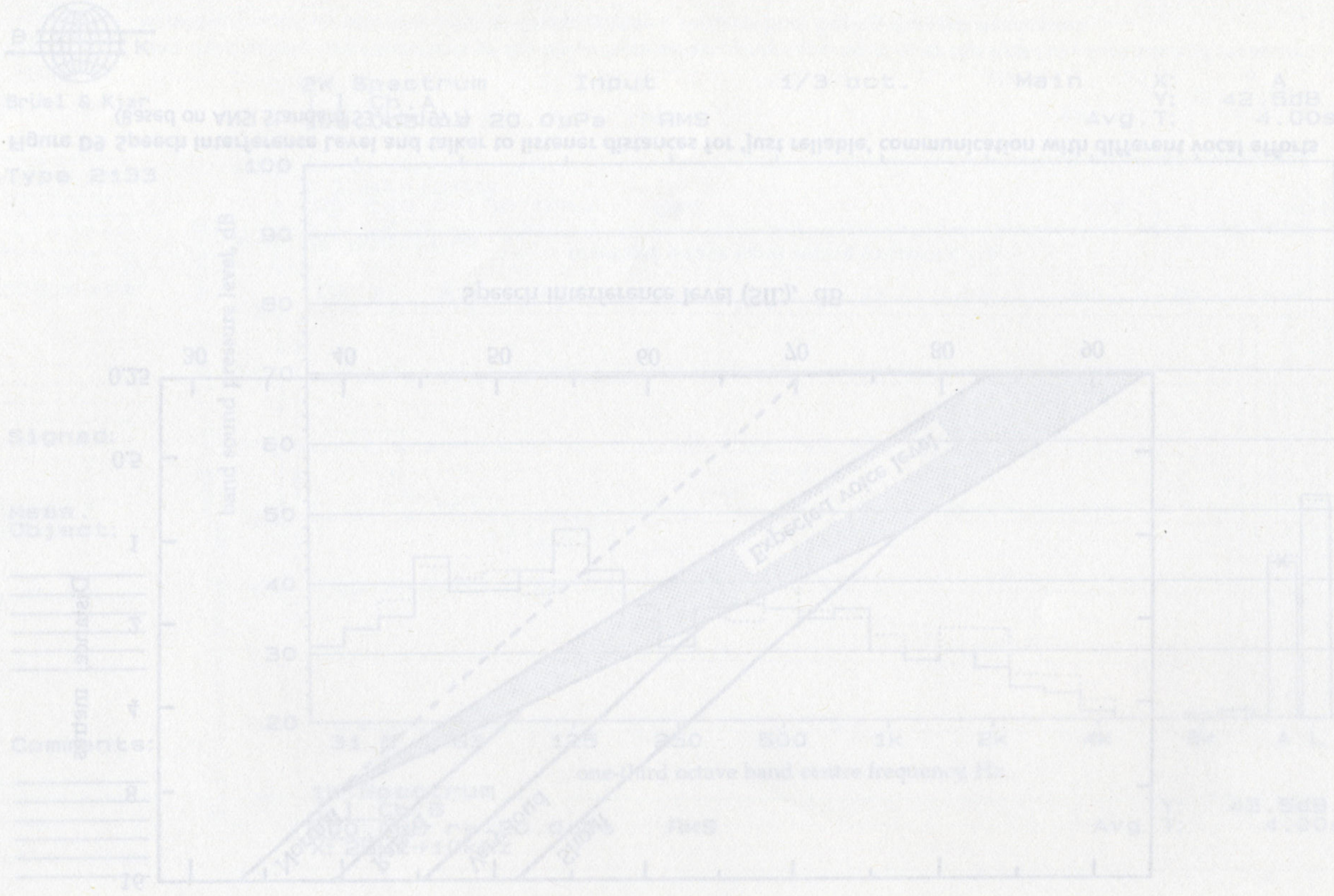

Figure D8 One-third octave band spectrum of the background noise floor measured in the empty cabin with water sprays turned off

Appendix E

TIME HISTORIES OF A-WEIGHTED SOUND LEVELS DURING EACH OF THE EVACUATIONS

In the following figures the upper graph was recorded at microphone 1 and the lower trace at microphone 2.

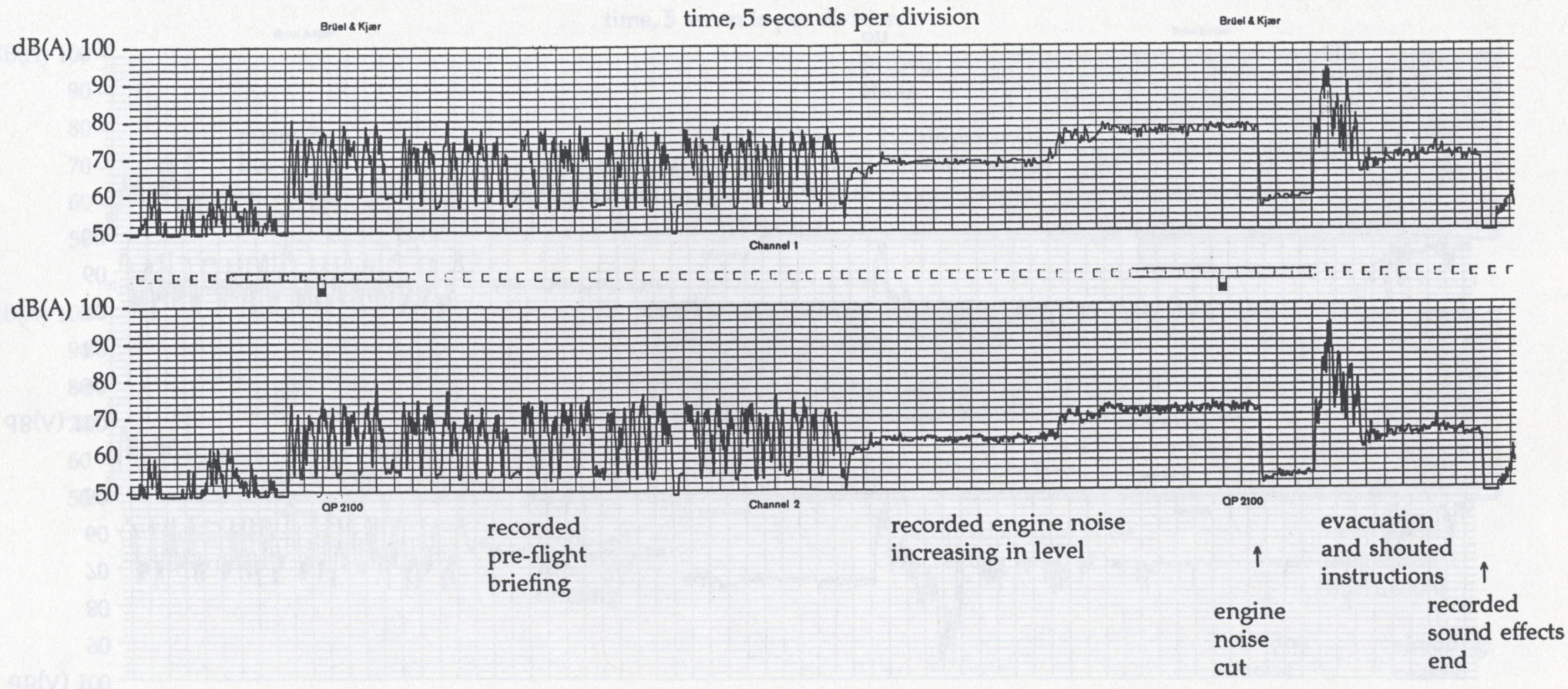

Figure E1 Sound levels measured during the initial 'dry' trial evacuation

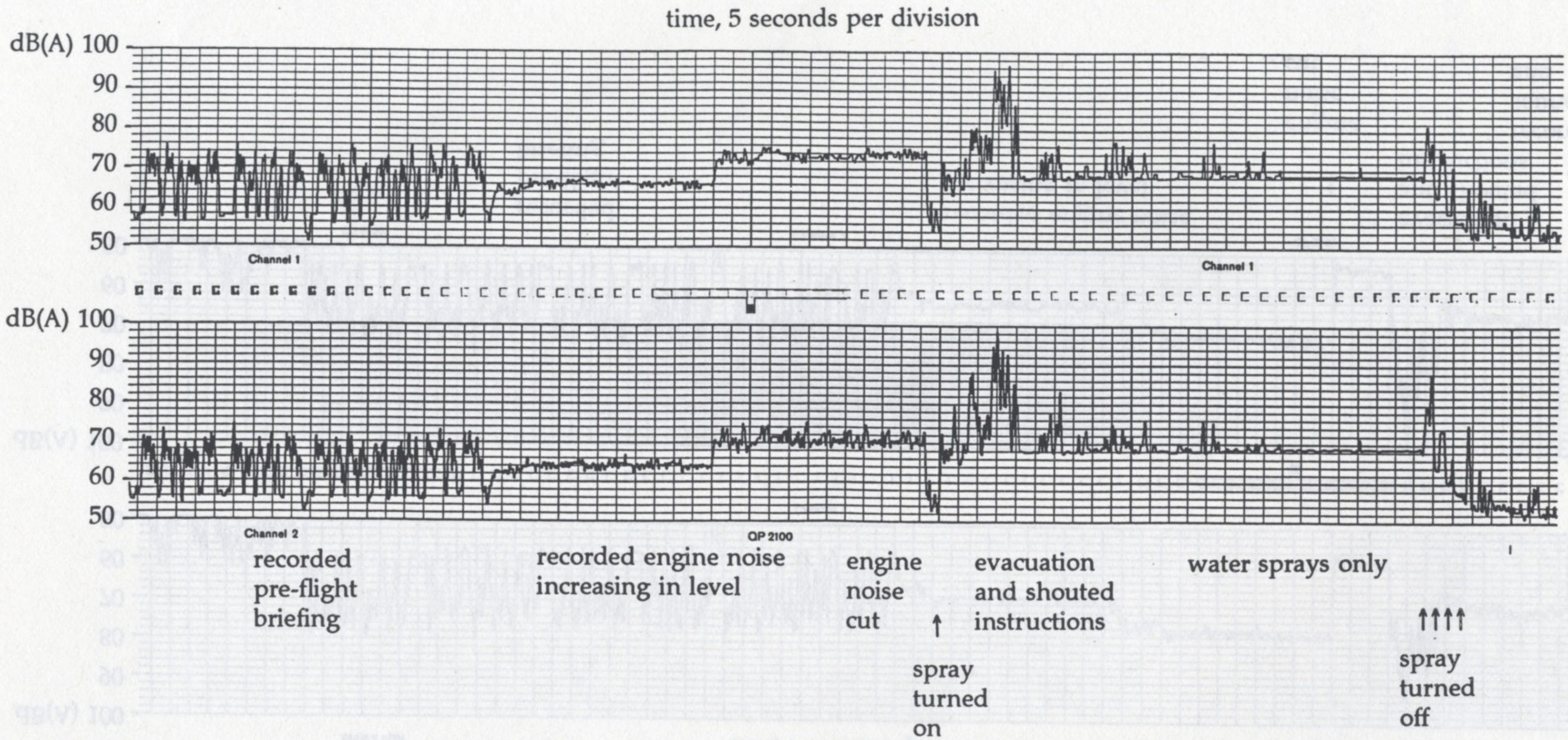

Figure E2 Sound levels measured during the initial 'wet' trial evacuation

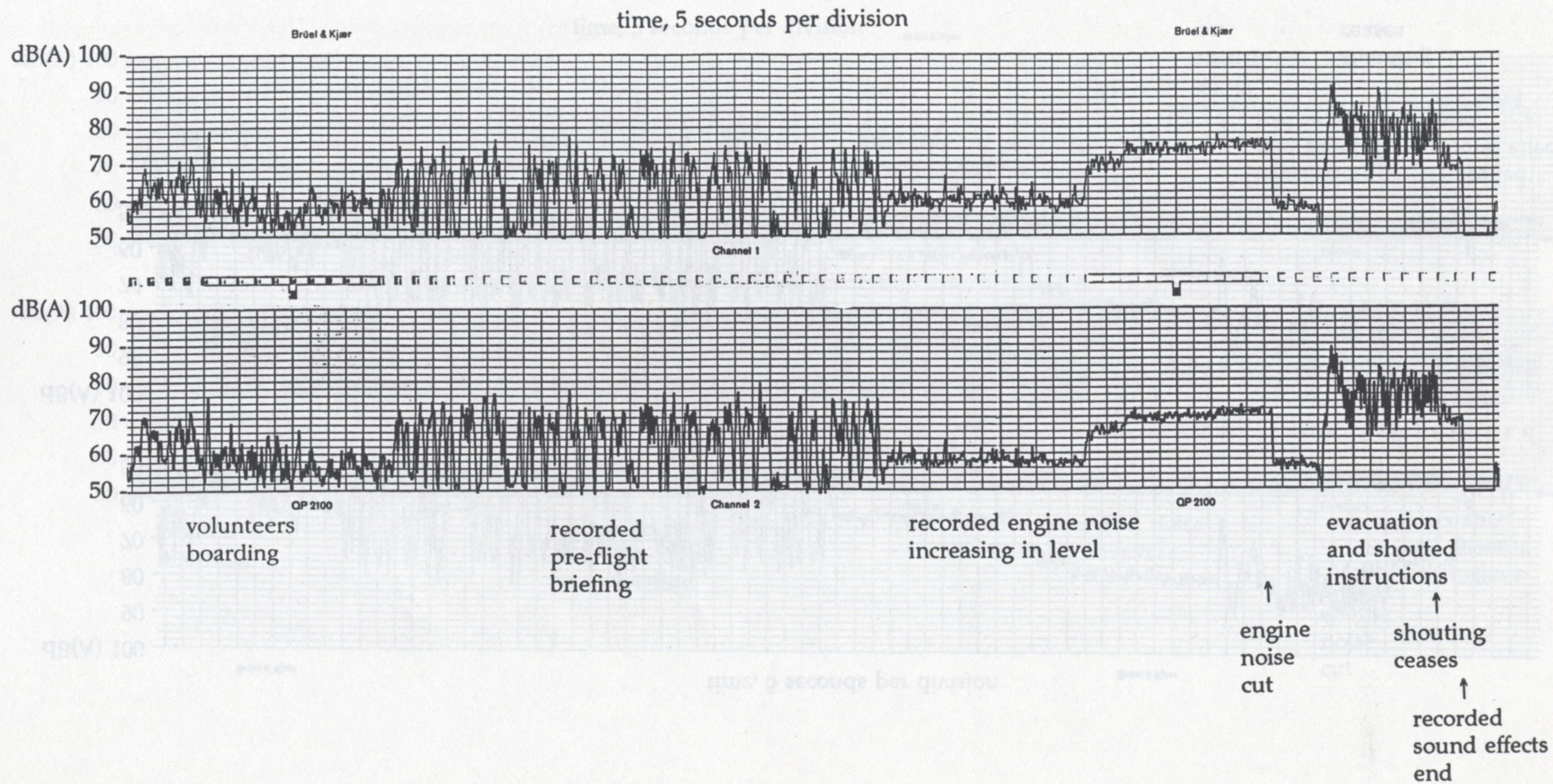

Figure E3 Sound levels measured during the first 'dry' evacuation

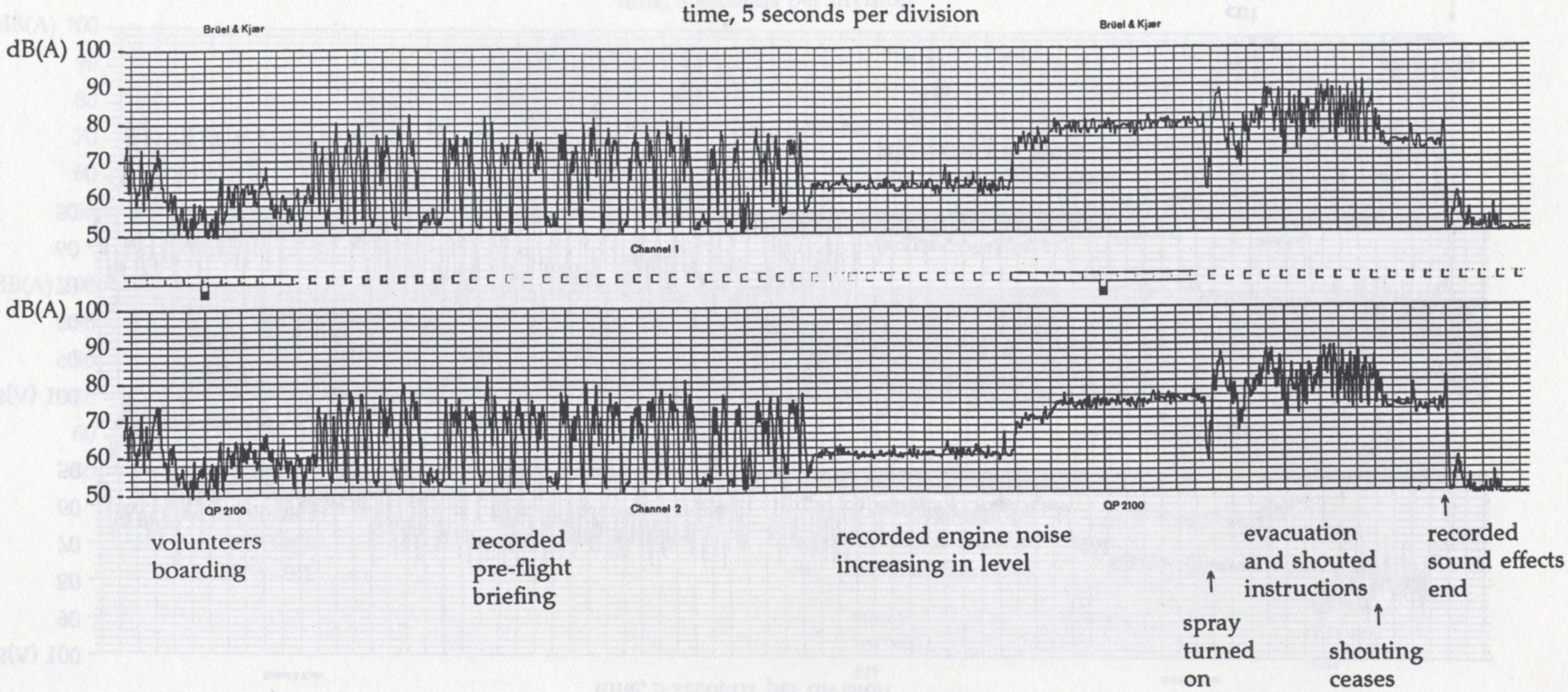

Figure E4 Sound levels measured during the first 'wet' evacuation

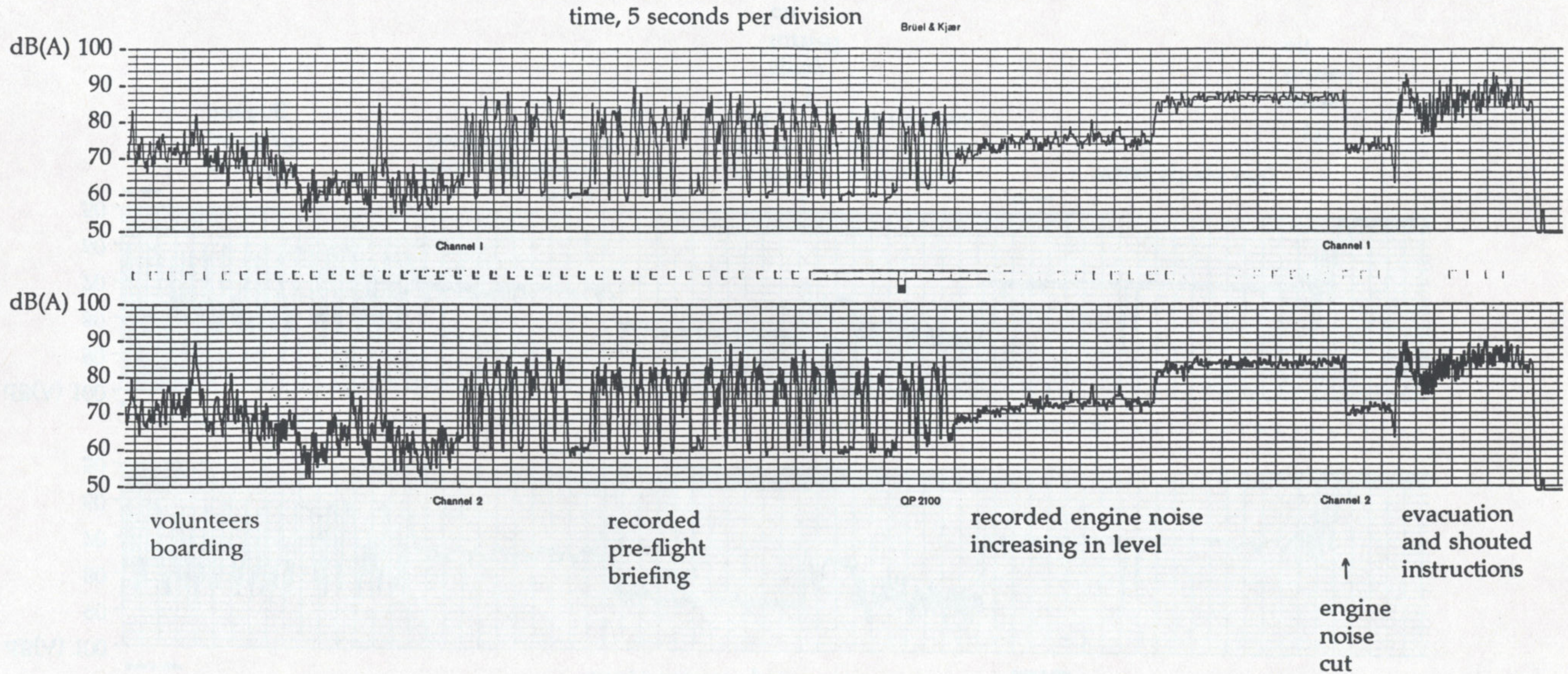

Figure E5 Sound levels measured during the third 'dry' evacuation

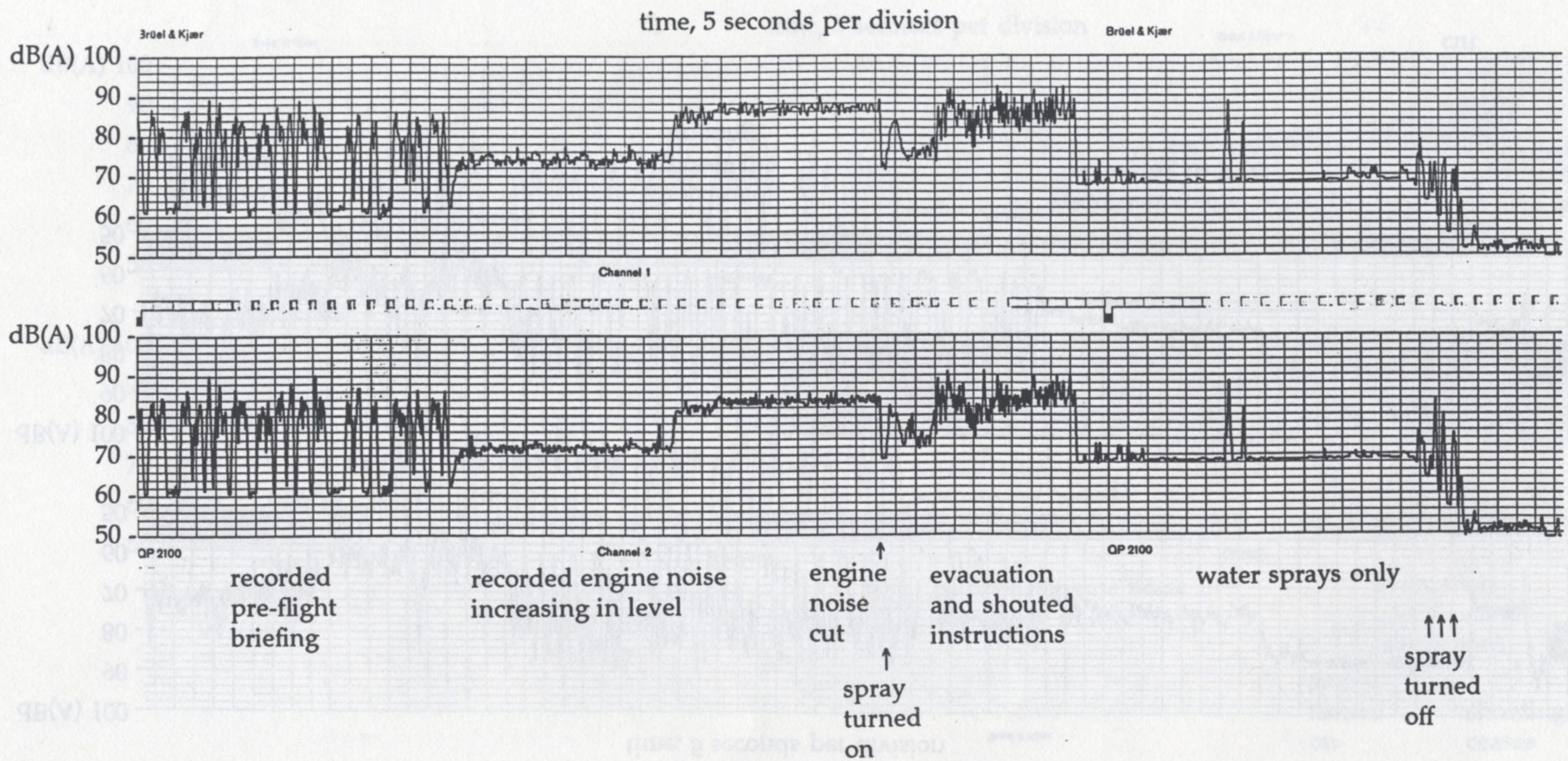

Figure E6 Sound levels measured during the third 'wet' evacuation