SUB-COMMITTEE ON FIRE PROTECTION
46th session
Agenda item 11

FP 46/INF.9
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LARGE PASSENGER SHIP SAFETY

Results of analysis carried out by the University of Strathclyde

Submitted by the United Kingdom

SUMMARY

Executive Summary:	This document contains the results of an analysis, carried out by the University of Strathclyde on evacuation trials performed onboard two ro-ro ferries. It concludes that directional sound can offer at least an equivalent level of safety to existing aids on routes of escape and provide a solution to evacuation guidance in open public spaces where no acceptable solutions have yet been proposed.
Action to be taken:	Paragraph 3
Related documents:	MSC 74/WP.6 and FP 46/11/2

General

1 "Directional sound" has been successfully tested as an aid to evacuation guidance in buildings, where such systems have been installed, and by the aircraft industry. Following a demonstration given to the Sub-Committee at its forty-fifth session, the United Kingdom's Maritime and Coastguard Agency agreed that shipboard trials should be carried out to assess the effectiveness of this new technology in the orderly and timely mustering of people on passenger ships.

2 Trials were conducted in June and October of 2001 onboard two ro-ro ferries to determine the effectiveness of directional sound beacons in accommodation areas, along corridors, on stairways and in open public spaces. Conditions during the trials were varied such that comparisons could be made with existing evacuation guidance systems required for escape routes, especially low-location lighting. Examination of these comparisons by an independent organisation (the University of Strathclyde) concluded that directional sound beacons offer at least an equivalent level of safety to that afforded by existing requirements. Technical papers detailing the science and research behind directional sound technology, together with full details of the trials and the data analysis, including stills taken from thermal imaging video, are available on the internet at www.directionalsoundevacuation.com. Copies of the trials video data are available on CD ROM from the UK MCA Passenger Shipping Branch tel +44 (0)23 8032 9519 e-mail passenger_ships@mcga.gov.uk.

Action requested of the Sub-Committee

3 The Sub-Committee is invited to note the information attached at annex in its consideration of FP 46/11/2.

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ANNEX

RESULTS OF ANALYSIS CARRIED OUT BY THE UNIVERSITY OF STRATHCLYDE

Introduction

Research on survivors of evacuation incidents has shown that finding the nearest available exit is the most important determinant of survival. It is therefore essential that individuals be guided to available exit routes in the least possible time. To achieve this and ensure balanced exit usage individuals must assisted to identify and find their optimal exits using the most effective sensory information.

Given that vision is the primary sense it is understandable that the majority of emergency exit aids, such as lighting, signage and photo-luminescent guidance strips are all visual aids. However the assistance given by visual aids may be reduced or rendered totally ineffective in a smoke filled environment.

This paper covers the investigation into the use of directional sound as a means of guidance onboard passenger vessels.

Evacuation Considerations

Behavioural studies have repeatedly shown that the most natural instinct in the event of an evacuation is to leave by the same route used for entry since this route is known. Frequently these exits are neither the quickest nor the most appropriate. People fail to notice nearby exits, and in some cases walk straight past visible fire exits. During evacuation the circulation routes used for normal everyday movement may encounter higher population flows than they were designed for. This results in overcrowding and a slowing down of the evacuation process.

The visual clutter of information and advertising signage may seriously impair identification of an optimal exit route, even in normal visibility. In some instances the nearest exit may not be visible and at present there is nothing to draw attention to it.

The process of evacuating a large passenger ship is a complex one, not least because it involves the management of a high population density on a moving platform. The design and layout of ships, often with narrow confined corridors and very few external reference points, can create difficulties in passenger orientation since most will be unfamiliar with the environment

When evacuating a ship while at sea, vessel motion is a factor that affects both mobility and way-finding abilities. When subjected to motion, the brain is occupied with maintaining balance while moving hence the ability to process information and make judgement is impaired, consequently way-finding abilities decrease. Motion sickness and nausea are results of visual/vestibular mismatch, (sensation of movement with no visual evidence) which reduces mental awareness. Sound localisation is primarily, a subconscious task and as such does not add to the burden of visual/vestibular mismatch. In view of this the use of directional sound may be more suitable as a guidance aid onboard ships.

Data from the UK Building Research Establishment show that well illuminated visual signage is unusable at a distance greater than 1.5m in 3% smoke density. There are many examples of evacuations through smoke in which the inability to find exits has resulted in multiple fatalities.

In April 1990 a fire onboard the ferry SCANDINAVIAN STAR killed 158 passengers. Many deaths occurred in passageways close to emergency exits and in cabins. Many survivors claimed that it was impossible to see the emergency exits in the smoke filled corridors. The Norwegian Fire Research Laboratory performed a series of evacuation trials on a reconstructed section of the SCANDINAVIAN STAR using the original emergency signage. It was found that 40% of test subjects failed to find the emergency exit. They either passed it, or tried to exit through the wrong door. In their summary the Norwegian researchers stated, "*We do know that emergency lighting and marking signs do not help to distribute people among the evacuation routes available*."

Norwegian Official Report NOR 1991:1E on the SCANDINAVIAN STAR Disaster stated "*The committee recommends that a requirement be introduced that audible signals with a sound that clearly distinguishes them from the alarm bells be installed by the exit doors in escape routes on board passenger ships, as directions for escape in conditions of reduced visibility*".

The Technology

Sound is used in emergency evacuations to provide an "alarm" which merely alerts people to an imminent danger. Irrespective of whether this information is provided by conventional alarm tones or through voice messaging these give no information concerning the direction to, or location of, the nearest exits. These alarms are positioned to alert as wide an area as possible but even if they were placed over exit doors they would still be very difficult to locate quickly. To understand why these devices would not suffice as exit locators, it is necessary to describe how we locate sounds in space to an accuracy of 2-4 degrees.

For accurate localisation the brain has to decode three types of sound cues, which individually convey only limited amounts of spatially ambiguous information. The first two are known as *binaural* cues as they make use of the fact that we have two ears separated by the width of our head. A sound that emanates from either side of the midline of the head will arrive first at the ear closest to it and will also be louder. It is this difference in path length that forms the basis for binaural processing.

Unfortunately, there are further complications with binaural cues. Firstly, the brain is very sensitive to the phase of an incoming waveform at frequencies below 1 kHz, so interaural time differences (the time difference between each ear, ITDs) are only really applicable at frequencies below this threshold. In addition, for the loudness differences (or interaural intensity differences, IIDs) to work the source must emit a sound that has frequency components with wavelengths smaller than the diameter of the head (about 3 kHz and above). The use of these two types of cue is known as the "duplex" theory and was proposed by Lord Rayleigh as long ago as 1906.

There are further problems however as the ITD and IID are virtually identical for sounds emanating either directly in front of or behind the head. To solve this ambiguity, the auditory system uses a third type of cue, the spectral cue for localisation. These spectral cues are provided by the way in which the external ear, or pinna, modifies the spectrum of the received sound such that some frequencies are attenuated whilst others are amplified.

To provide complete localisation knowledge, information from all three cues must be combined. For a sound to be accurately located it must contain as much of the audible frequency range as possible (20-20000 Hz). This is 'broadband' sound and can most easily be described as the sound of a rushing river or waterfall. Neither conventional alarms nor speech, which are narrowband frequencies, will work as directional sound aids.

Marine trials

Background

A series of marine trials were devised by Strathclyde University and performed onboard two ro-ro vessels in June and October 2001. Both vessels were alongside.

Volunteers for the trials were recruited from the local population and represented ages from 17–67 of both genders. Each trial endeavoured to obtain an evenly distributed age range and some included both hearing and visually impaired subjects. A new group of volunteers was used for each trial in scenarios 1 & 2. Volunteers in scenario 3 had already experienced scenario 2.

In total 360 volunteer evacuees participated in this study. Due to the time of day of Scenario 1, and the "rewarding incentive" of £20 per head, it attracted some individuals who may have been under the influence of drugs and/or alcohol. This is not considered to be unrepresentative since the observing ship's crew commented that passengers are sometimes in a similar condition on board cruise ships or ferries.

For safety reasons smoke used in the trials was theatrical rather than real smoke. Theatrical smoke provides the visual disability associated with real smoke but not the toxic effects. The absence of real smoke meant that the volunteers in the trial were not forced to go close to the ground in order to breathe. The gases in real smoke cause a reflex closing and watering of the eyes consequently vision is almost immediately impaired and may be totally disabled.

Volunteers were asked to imagine they were in a real fire/evacuation however there are obvious behavioural differences that occur between real and imaginary situations. Nevertheless, it is common practise to use non-emergency tests for validation.

During trials on both vessels there was no continuous alarm ringing throughout the evacuation in order to minimise disturbance to the off duty crew. Trials in buildings, with directional beacons and fire alarms sounding simultaneously, have shown that this does not affect the ability of people to hear and respond to directional sound.

Evacuation times were recorded for all individuals in every trial, thermal-imaging cameras were used to enable further analysis and all participants completed questionnaires related to their particular trial.

Format of Trials

Scenario 1

Trials were conducted in the *Isle of Arran* (659 passengers 3300 gt) crew accommodation area to represent a night scenario. 20 volunteers took part in each trial, all with no previous knowledge of the trial area. However on the inside of the cabin door, there was a standard plan showing the three emergency exits for that area. All cases tested included smoke of 3% density. Trials were structured to combine Low Location Lighting (LLL), sound beacons on/off, briefings/no briefings (on the relevance of the sound) and all three or just one viable exit. The purpose of these trials was to determine:

1. How directional sound compares to assistance/no assistance from LLL?
2. What happens when a pre-planned route is blocked?
3. Do multiple sound beacons cause confusion?
4. Is a briefing on the meaning of the sound essential?

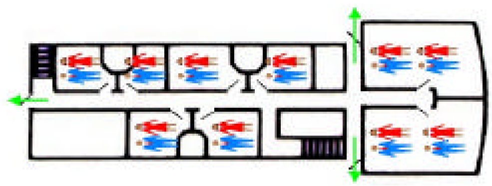

Fig 1: ISLE OF ARRAN crew accommodation

Scenario 2

Trials took place onboard the ferry *Caledonian Isles* (1000 passengers, 5221 gt) in the forward restaurant and lounge areas. These are large open public spaces were furnished with tables and chairs. The 20 volunteers were released at 15 sec intervals. There was a choice of four exits, the two nearest accessed via stairways to the deck above, while the farthest were wide main exits to the central area of the ferry. These latter exits were visible in no-smoke conditions, see *Fig. 2*. The purpose of scenario 2 trials was to determine the following:

1. Does directional sound reduce the evacuation times in open spaces both with and without smoke?
2. How does directional sound impact when in addition to LLL on edges of corridors and stairs?
3. How do passengers choose between alternative available exits – flat vs. upstairs?
4. Is there confusion with multiple sound beacons?
5. Is a briefing on the meaning of the sound essential?

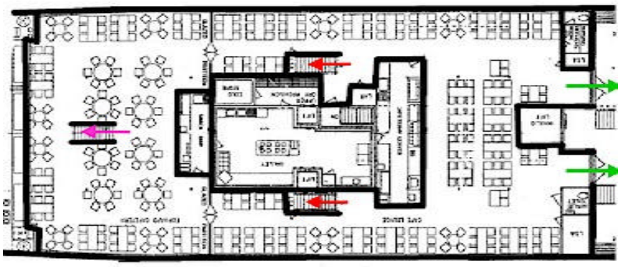

Fig 2: CALEDONIAN ISLES lounge and restaurant.

Scenario 3

Trials took place onboard the *Caledonian Isles*, in the after section of the ferry. Volunteers with no prior knowledge of the area were divided into groups of 13/14 and released into the test area in turn. The purpose was to find the one viable exit, marked as Crew Only, but still a valid emergency exit and marked by LLL, see *Fig. 3*.

The Crew Only exit led to a stairway and required a decision to go up or down. All visual exit signs pointed up, however the correct route was down two decks to the car deck. The purpose of scenario 3 trials was to determine the following:

1. Can passengers be directed to an unconventional route by sound alone?
2. How does smoke affect evacuation performance?
3. In stairs, can passengers be encouraged by sound to go down, against the natural desire and visual signs to go up?

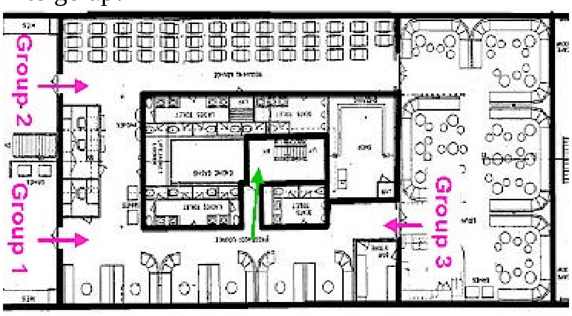

Fig 3: CALEDONIAN ISLES public rooms

Summary of results

The Marine trials produced copious data on the effectiveness of directional sound guidance onboard ships in particular and information on human behaviour in general. However in this paper only the data relating to the objectives of the trials are presented.

Scenario 1

The 10 trials of 20 volunteers each were divided into two main groups:

- four trials with all three exits available
- six trials with one exit made available

In trials where all three exits were available, and passengers were able to follow their pre-planned route, the exit times were relatively short and the positive effect of the sound beacons was limited (a reduction in total exit time of **9-17%**).

In the cases with only one exit available the difference was greater, as represented in *Fig. 4*. Comparing the cases without sound to the ones including sound, a reduction in exit time of more than 50% (**47-71%**) was observed. Generally, as seen in *Fig. 4*, the exit times for the first 10 volunteers are more or less comparable, this is due to the number of people who had already chosen the *available* exit as their exit. The problem arises when the volunteers who have planned a different exit, encounter a locked door. In trials without sound, (as observed via thermal imaging recorders) volunteers returned along the passageway searching for an alternative exit. Since the

LLL	Sound	Briefed	18^{th} Exit time (sec)
			286
Yes			205
	Yes		109
Yes	Yes	Yes	102
Yes	Yes		100
	Yes	Yes	82

Table 1: Exit times of 18^{th} person

smoke was of 3% density the only aid was the handrail fitted to one side of the passageway. Open cabin doors and a 'blind alley' became major confusion factors. Passageways were so constrained that bottlenecks occurred quite rapidly. It was observed that volunteers, rather than standing in line, lost patience and started searching for alternative exits which in this trial did not exist.

In the cases studied which *included* directional sound beacons (briefed or non-briefed) the results were significantly different. At the start of the trials volunteers left their cabins and moved towards their pre-planned exit, but after a short time turned around to move towards the available exit. Open cabin doors were a minor delaying factor, those few volunteers entering the blind alley quickly realised the mistake.

Observations confirmed that volunteers would queue patiently for an exit confirmed as available by the presence of directional sound beacons.

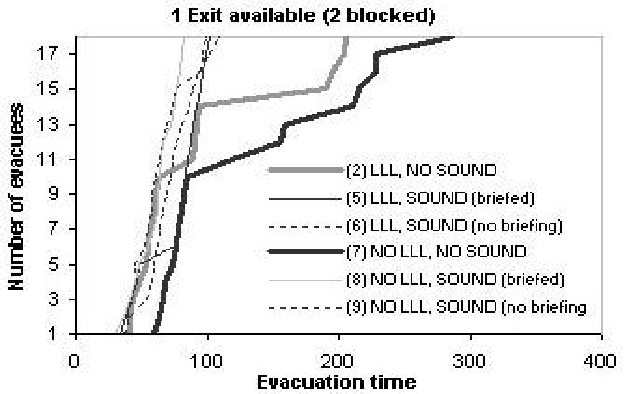

Fig 4: Scenario 1-Exit times

Scenario 2

The 6 trials, 20 volunteers in each, included the following combinations:

- with and without smoke
- with and without directional sound beacons
- with and without briefings

Table 2 and *Figs 5 & 6* show the exit choice and exit rate, respectively. The presence of directional sound beacons improved the rate at which the volunteers reach the exit. The difference in briefed and non-briefed groups was only clear in their choice of exit; the final exit time was not greatly affected. 'Family' groups were found to influence exit times as members waited to re-group.

In smoke conditions the effect of sound beacons is marked. Comparing scenario 2.1 with 2.2 2.3 it is clear that sound assisted location of the nearest exit. In no-smoke conditions the difference is not as clear. Only in scenario 2.6 are most passengers choosing the nearest exit. The outcome of the post-trial questionnaires pointed out that a number of the volunteers were either familiar with the

Trial	Smoke	Sound	Briefed	Nearest Exit
2.1	Yes			30%
2.2	Yes	Yes		**100%**
2.3	Yes	Yes	Yes	**95%**
2.4				55%
2.5		Yes		45%
2.6		Yes	Yes	90%

Table 2: Exit choice

vessel or could clearly see the main exit for most part of the route.

The assistance given by LLL in open spaces appears limited. In trials with smoke, but without sound beacons, volunteers felt their way along walls, tables and chairs until an exit was located. Only then did LLL have an effect in confirming that their choice was an exit.

In trials where sound beacons were used, 95% of volunteers indicated that sound guided them to an exit and 85% considered it to be the most helpful aid.

In trials with no smoke – none of the participants looked at the LLL since exit signs were obvious

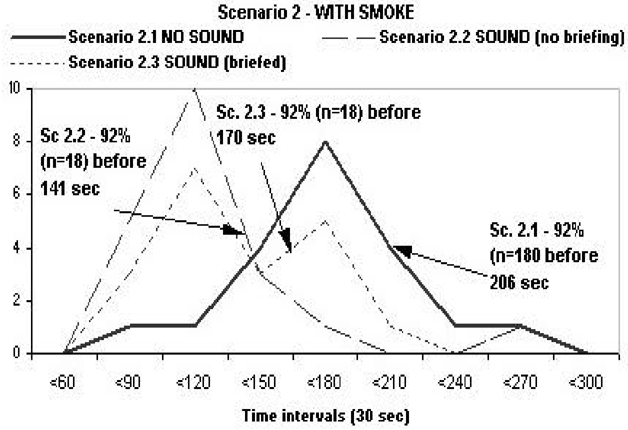

Fig 5: Exit times - with smoke

In clear conditions, 82% of volunteers said that the beacons led them to an available exit, however they indicated that exit signs were the most obvious help, and the sound was a confirmative aid.

Regarding the presence of multiple beacons, 84% answered that they were aware of more than one beacon, and 88% chose to move towards the loudest one.

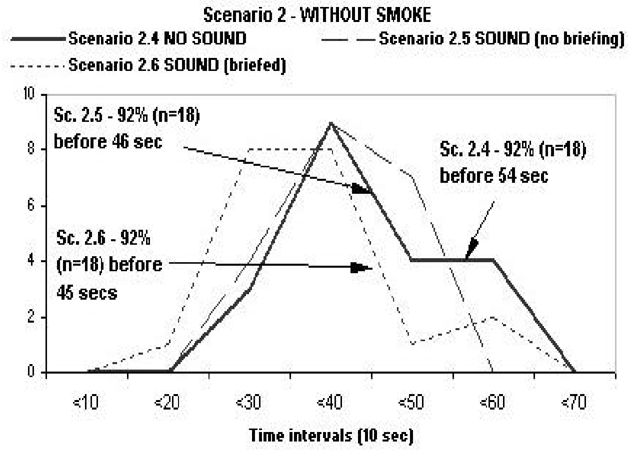

Fig 6: Exit times - without smoke

In with smoke trials 85% of the volunteers indicated they would rather rely on sound beacons than LLL, while 15% said they would prefer to rely on both sound and LLL. In the no-smoke cases, 73% of the volunteers said they would rather rely on sound, 22% said they would rather rely on LLL and 5% said both.

Scenario 3

Trials took place in the aft section of the CALEDONIAN ISLES, four trials were performed, 2 without smoke (with/without sound) and 2 with smoke (with/without sound). All 3 groups of 13/14 volunteers were briefed on the use of directional sound beacons. *Fig. 7* details the mean exit times for the four different trials. The scenario 3 trials were the only trials where smoke and no smoke times were comparable since in clear conditions the location of

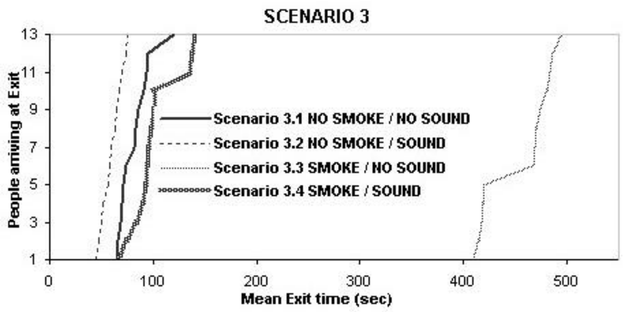

Fig 7: Scenario 3 exit times

the exit was not clear. Results of trial 3.3 illustrate the difficulty associated with locating the exit. It was obvious from observations that volunteers were reluctant to use an exit marked 'Crew Only'. When directional sound beacons were used, the decision to use that exit was reinforced.

Once though the 'Crew Only' exit volunteers had the opportunity to climb or descend a stairway clear of smoke. In trials with no sound all volunteers chose to ascend, as instructed by existing exit signs. In the trials where sound was used, all volunteers heard the 'down sweep' instruction, descending on the intended route, to the car deck.

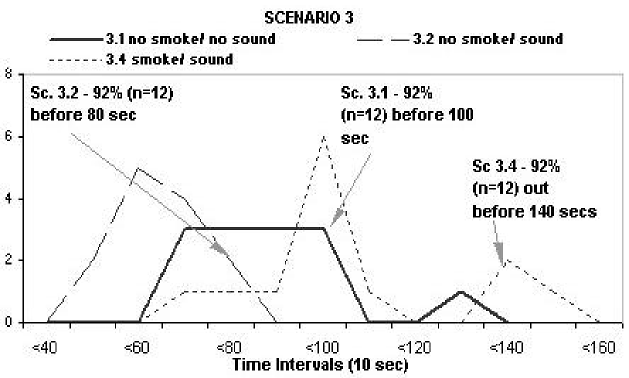

Fig 8: Scenario 3 exit times

Conclusions

The results of the trials appear to be conclusive in that under the given conditions and acknowledged limitations of trial evacuations there is a clear benefit in the use of sound as an aid to guidance. In trials using smoke it was evident that there was little reliance on LLL since in 3% density smoke lighting assistance was not visible.

The theatrical smoke used in the trials was 'cold smoke' and as such does not stratify in the same manner as would heated smoke generated by a fire. Stratified heated smoke may, under certain conditions, permit LLL to be more clearly seen than was the case in the trials. It is also the case that real smoke causes reflex closing and intense irritation of the eyes, which may render visual aids of little or no use.

In constrained passageways passengers will always be in close proximity to LLL and thus, under favourable circumstances, may be guided to an exit. Analysis of the results of trials in which the benefits of directional sound and LLL may be directly compared indicate that in both smoke and no-smoke conditions directional sound offers at least an equivalent level of safety to that of LLL.

Open public spaces are not considered to constitute an escape route and consequently LLL is not required under the SOLAS convention.

Open public spaces are becoming an increasing popular feature of cruise ships and ferries. Existing IMO SOLAS regulations regarding means of escape do not adequately address the need to provide escape guidance from these areas. If LLL were to be made a requirement in open public spaces it is likely to be so distant from the majority of passengers that in a smoke filled situation it would never be located. Under these conditions the only solution to the guidance of passengers in an evacuation is an audible directional alarm.

Standard of Approval

It is envisaged that any manufacturer able to meet the requirements of a performance-based standard could supply directional sound evacuation beacons. Such a standard would require suppliers to demonstrate their product's ability to create a sound that can be accurately located to within prescribed limits of accuracy.

Full trials details and data analysis including stills taken from thermal image video footage are available on the internet at www.directionalsoundevacuation.com.

Technical papers detailing the science and research behind directional sound technology are listed on the website. Copies of the trials video data are available on CD ROM from MCA Passenger Shipping Branch, tel +44 23 80 329 519, email passenger_ships@mcga.gov.uk