

Marine Trials - Scotland 2001

In order to gather independently verified data, University of Strathclyde lead an initiative on behalf of MCA to investigate the effectiveness of Directional Sound Evacuation on Ships.

A detailed programme of trials was devised by University of Strathclyde and MCA in consultation with University of Leeds and Caledonian MacBrayne Ferries - who kindly agreed to the use of two of their ro-ro vessels for the trials in June and October 2001. Both vessels were alongside due to the difficulties in ensuring volunteer safety and securing insurance for trials conducted at sea with a smoke filled vessel.

These trials set out to compare the effectiveness in corridors and staircases of Directional Sound Evacuation with Low Location Lighting, the currently approved evacuation guidance technology within SOLAS. In addition, bearing in mind the IMO focus on safety in Large Passenger Ships, evacuation in open spaces was also investigated.



MV Isle of Arran



MV Caledonian Isles

Background

Volunteers for the trials were recruited from the local population and represented ages from 17–67 of both genders. Each trial endeavored to obtain an evenly distributed age range and some included both hearing and visually impaired



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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, who had signed an informed consent document, were asked to imagine they were in a real fire/evacuation however there are obvious behavioural differences that occur between real and imaginary situations. [Link to full details of briefings given.](#) 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 sound beacons and fire alarms sounding simultaneously, have shown that this does not affect the ability of people to hear and respond to directional sound.



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Observers from MCA and Strathclyde University



Volunteer emerges, observer notes time and number



Volunteers complete questionnaires

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. All this primary source data is available for further analysis.

Format of Trials

Scenario 1 Cabins & Corridors

Trials were conducted in the crew accommodation area of the *Isle of Arran* to represent a night scenario. 20 volunteers partook in each trial all with no previous knowledge of the trial area. However on the inside of the cabin door,



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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 and all three or just one viable exit. The purpose of these trials was to determine the following:

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

Scenario 2 Open Spaces & Stairs

Trials took place onboard the *Caledonian Isles* 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 could be accessed via stairways to the deck above, while the farthest were the 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?

Scenario 3 Hidden Exit and Stairs

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.

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:



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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 vs. natural desire and visual signs to go up?

Summary of results

The Marine trials produced copious data on the effectiveness of directional sound evacuation guidance onboard ships in particular and information on human behaviour in evacuations in general.

Scenario	Detailed Description	Data & Analysis
1	Cabins & Corridors	Cabins & Corridors
2	Open Spaces & Stairs	Open Spaces & Stairs
3	Unusual route and Stairs	Unusual Route & Stairs

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.



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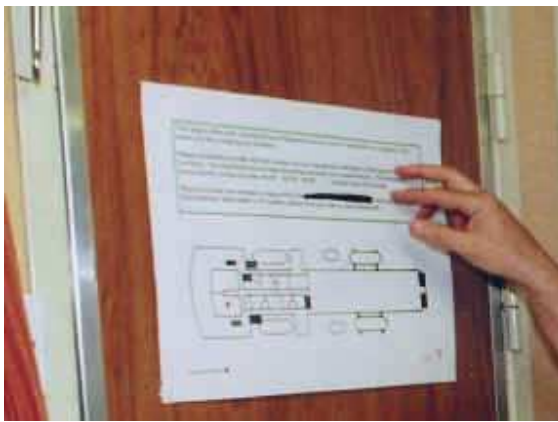
Open public spaces are becoming an increasing popular feature of cruise ships and ferries. Existing IMO SOLAS regulations regarding means of escape do not adequately address the need to provide escape guidance from these areas. If LLL were to be made a requirement in open public spaces it is likely to be so distant from the majority of passengers that in a smoke filled situation it would prove too difficult to locate. Under these conditions a more satisfactory solution to the guidance of passengers in an evacuation is an audible directional alarm.



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Marine Trials Scenario 1 - Cabins & Corridors - description

Trials were conducted in the crew accommodation area to represent a night scenario. 20 volunteers partook in each trial all with no previous knowledge of the trial area. However on the inside of the cabin door, there was a plan showing the three emergency exits for that area and correctly describing the aids to evacuation which were to be used in the forthcoming trial (plans were changed before each trial to ensure the correct description was provided).



All cases tested included smoke of 3% density. Trials were structured to combine Low Location Lighting (LLL) on/off, sound beacons on/off, briefings/no briefings on the sound and all three or just one viable exit. The purpose of these trials was to determine the following:

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

Method

Nine tests (and one repeat) were conducted with volunteers all lead to their cabins blindfolded so they had no prior knowledge of layout of corridors, or location of potential exits.



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Two exits lead to the bridge deck port and starboard and 1 to the open deck aft . At each exit, observers noted exit time and number of each volunteer.



Special equipment

Thermal imaging cameras – At either end of the corridor

Theatrical smoke machine and smoke density measuring instrument



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The trials

Volunteers entered via Gangway to Boat Deck and into Passenger Lounge area for assembly and briefing. Then when 20 assembled and wearing numbered bibs for video analysis, they were lead up stairs J and K onto Navigation Bridge Deck and assembled in Wheelhouse for safety briefing.

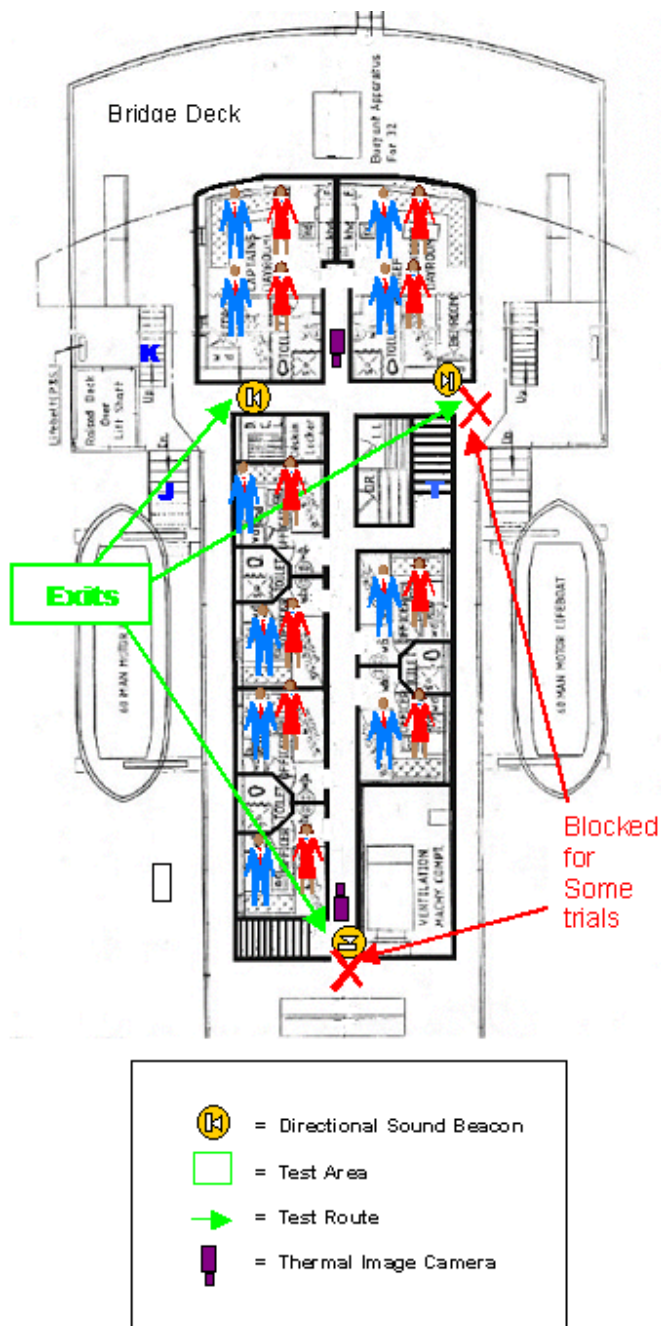
Taken down stairs from the navigation bridge, volunteers were then lead blindfolded to the predetermined cabins @ 2 per cabin, except Captains Dayroom and Chief Eng Dayroom which took 4 people each = Total per trial of 20 people. Participants remained in cabins, removed blindfolds and awaited the evacuation call (between 5 & 15 minutes). On hearing ships alarm and PA announcement, participants left cabins and headed for exit(s) – see below. 2 observers (one MCA and one Strathclyde University staff) at each exit timed and recorded volunteers as they exited and guided them down stairs J to Boat Deck and into Lounge Bar on starboard side for Questionnaire completion.

In every case there was no prior knowledge of the layout – although backs of cabin doors did have exit plans and correct briefing for each trial

Ten trials were completed, all with dense smoke (3%) using following conditions:

- s1-1. LLL, no sound beacons - 3 exits
- s1-2. LLL - no sound beacons - 1 exit
- s1-3. LLL – sound & briefing 3 exits
- s1-4. LLL - sound no briefing 3 exits
- s1-5. LLL – sound & briefing 1 exit
- s1-6. LLL – sound no briefing 1 exit
- s1-7. No assistance – 1 exit
- s1-8. Sound & briefing – 1 exit
- s1-9. Sound no briefing – 1 exit
- s1-10. repeat of test 4

Six trials using 20 people per trial = total of 200 volunteers



Marine Trials - Scenario 1 - Cabins & Corridors

Results Data and Statistical Analysis



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

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

All thee Exits available

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%**).

Trial	LLL	Sound	Briefed	18 th exit time (secs)
S1-1	Yes			66
S1-3	Yes	Yes	Yes	59
S1-4 & S1-10	Yes	Yes		55 & 60

Table 1 - Exit times when all 3 Exits available

Only one Exit available

In the trials with only one exit available the difference was greater, as represented in Table 2. Comparing the cases without sound to the ones including sound, a reduction in exit time of more than 50% (**47-71%**) was observed.



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Trial	LLL	Sound	Briefed	18 th Exit time (sec)
S1-7				286
S1-2	Yes			205
S1-9		Yes		109
S1-5	Yes	Yes	Yes	102
S1-6	Yes	Yes		100
S1-8		Yes	Yes	82

Table 2 - Exit times when only one Exit was available

Generally, as seen in *Fig 3*, 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 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. Volunteers re-entered cabins in their attempts to seek a viable exit route. 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 trials which *included* directional sound beacons (with the volunteers briefed or non-briefed on the meaning of the sound) 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, reassured they were going in the right direction.

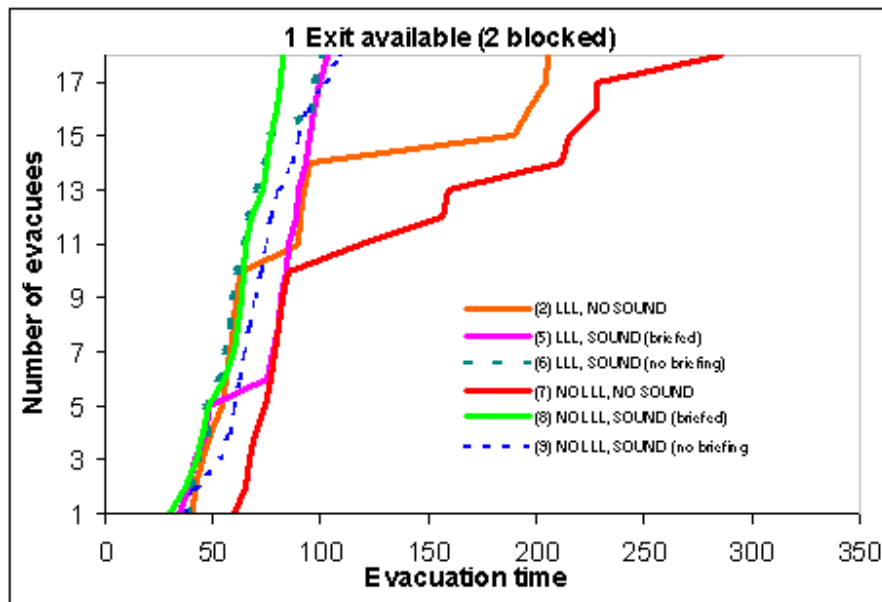


Fig 3 - Exit times with only one Exit available


Marine Trials Scenario 2 - Open Spaces & Stairs - description

Trials took place onboard the *Caledonian Isles* during October 2001 in the forward restaurant and lounge areas. These are large open public spaces were furnished with tables and chairs. The 20 subjects were released at 15 sec intervals. There was a choice of four exits, the two nearest could be accessed via stairways to the deck above, while the farthest were the main exits to the central area of the ferry. These latter exits were visible in no-smoke conditions. 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?



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Sound beacons,  (Port and Starbd) at exit doors from restaurant to café lounge, to Main entrance Area E & F, at bottom of 2 staircases C and D - with upward swoops and also at top of stairs at exit doors on boat deck. Galley and Cafeteria Servery sealed off.

On arrival, 40 subjects were given safety briefing, identification bibs and signed disclaimers in the terminal building.

Each trial had 20 subjects who were briefed on their specific trial, and then sent down stairs B at 15 second intervals into the open space trial ground.

There were 4 exit routes available. Observers outside exits doors at top of staircases C and D on Boat Deck and at exit doors E & F to main entrance area recorded exit times and sequence. Subjects then completed questionnaires in Passenger Lounge.

Six tests were conducted:

- s2-1. Smoke - no sound beacons
- s2-2. Smoke - with sound beacons and no briefing
- s2-3. Smoke - with sound beacons and briefed on sound
- s2-4. No Smoke - no sound beacons
- s2-5. No Smoke - with sound beacons and no briefing
- s2-6. No Smoke - with sound beacons and briefed on sound

No prior knowledge of layout in every case.

Upper Deck



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Marine Trials Scenario 2 - Open Space & Stairs

Results Data and Statistical Analysis



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 on the sound

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 by the briefing. 'Family' groups were found to influence exit times as members waited to re-group.

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

In smoke conditions the effect of sound beacons is marked. Comparing scenario 2.1 with 2.2 and 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, with directional sound and briefing, are most passengers choosing the nearest exit.



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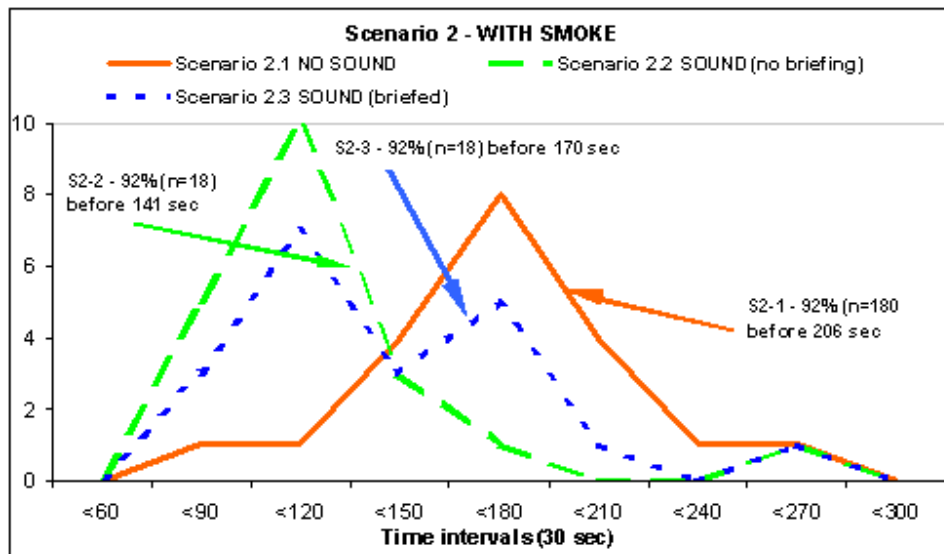


Fig 5: Exit times - with smoke - uncorrected

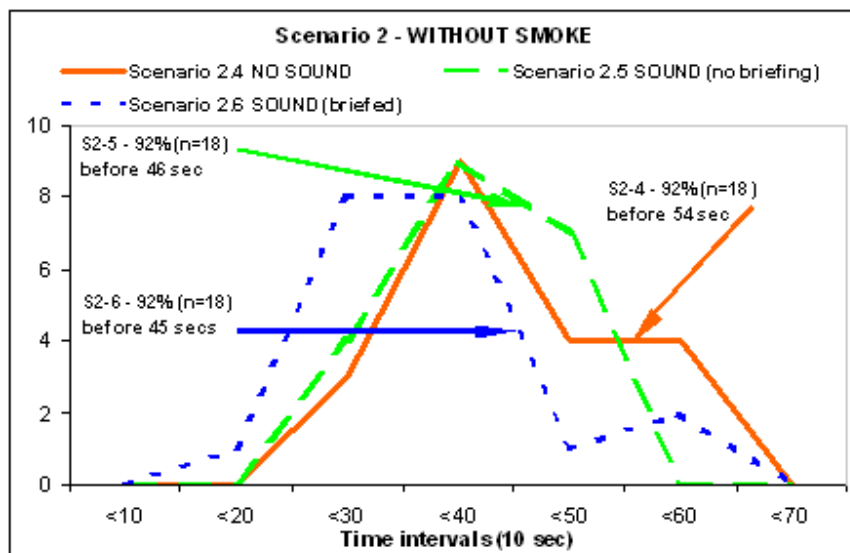


Fig 6: Exit times - without smoke - uncorrected

The outcome of the post-trial questionnaires pointed out that a number of the volunteers were either familiar with the vessel or could clearly see the main exit for most part of the route.

Further analysis - family groupings

Since the white paper was released for translation to IMO, further analysis of the video tapes has been possible, together with questionnaires from which it is

clear that volunteers who came as a group of friends or family acted as a group. This had a significant impact on the total exit times since the first member of the group waited at the top or foot of the stairs for the other members of the group to arrive. In addition, some volunteers took a long time travelling down the stairs to the start of the trial. Fig 7 and 8 show the corrected average travel times for 90% of each group from the foot of the stairs at the start of the trial to the point of exit.

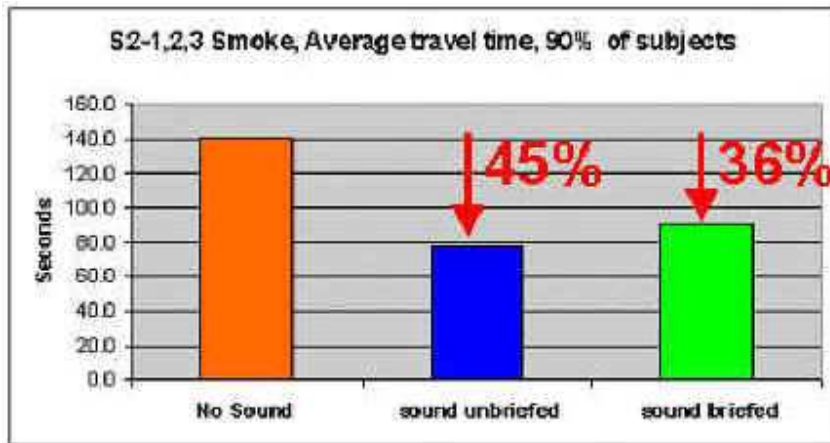


Fig 7 Average travel times with smoke - corrected

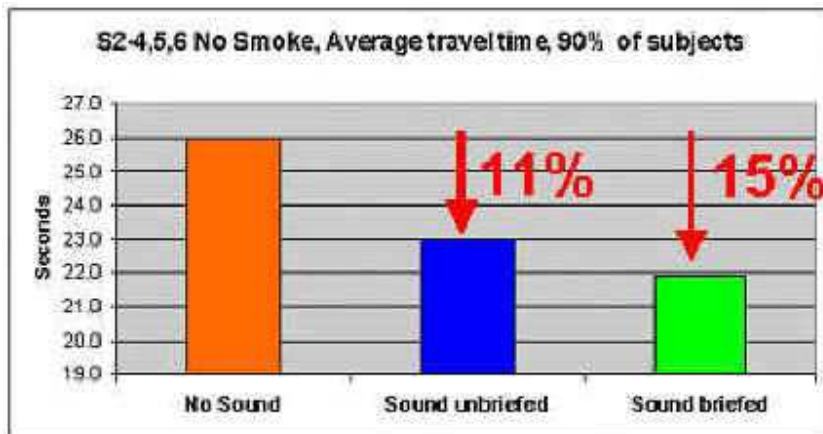


Fig 8 Average travel times without smoke - corrected

From this further analysis it is clear that sound provided a significant reduction in travel times particularly in smoke with , between 36% and 45% improvement, and between 11% and 15% without smoke.

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. 82% of volunteers said that the sound 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.

In trials with smoke, 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. Observations confirmed that volunteers were more confident in their movements and made fewer mistakes when following directional sound (see Human Behaviour).



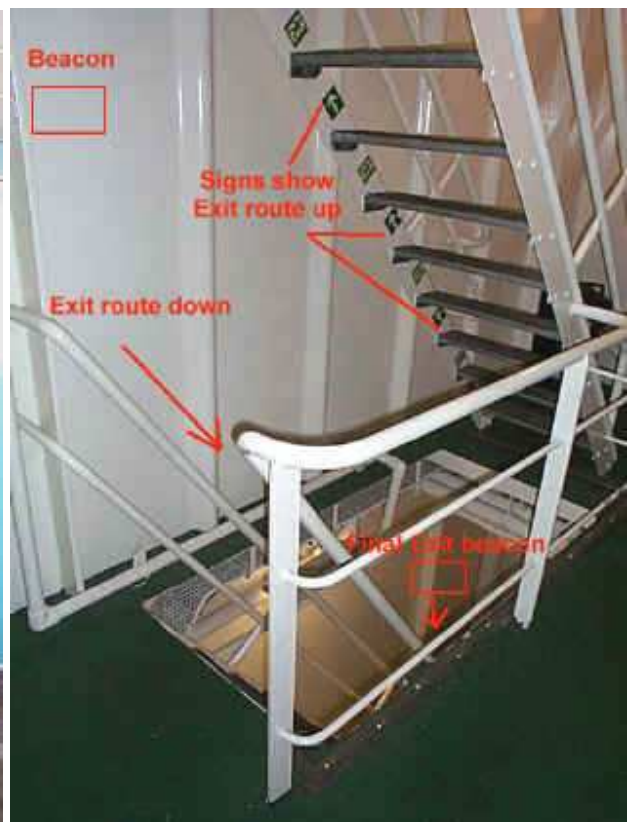
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Marine Trials Scenario 3 - Hidden Route & Stairs - description

Trials took place onboard the *Caledonian Isles*, in the after section of the ferry. Volunteers with prior knowledge of the area were divided into groups of 13/14 and released into the test area in turn. The four normal exits were blocked, the purpose was to find the one viable exit, marked as Crew Only, down a narrow corridor, but still a valid emergency exit and marked by LLL.



Crew Only Exit, hidden down narrow corridor, LLL is shown on right




Crew stairs, exit route marked upward, location of sound beacons and LLL is visible

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:



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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 vs. natural desire and visual signs to go up?

Sound Beacons  at entrance to hidden corridor, above hidden “crew only” exit door, at top of stairs leading down to car deck (with “down” sound) and at foot of staircase exit to car deck.

Normal green “running man” signs and arrows in the stairwell directed people to go UP.

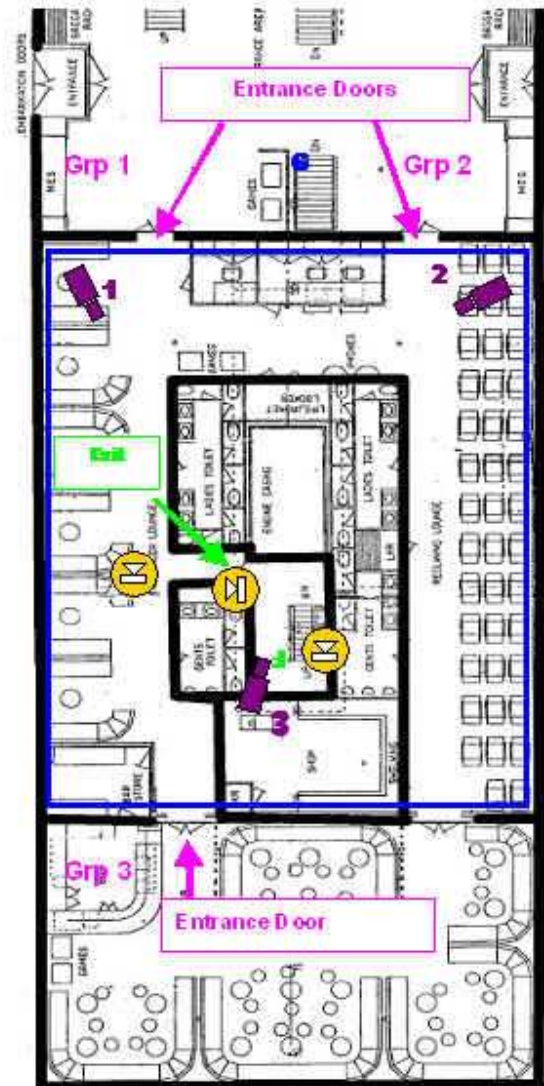
Test Area - Passenger and Reclining Lounges on Upper Deck. Volunteers were familiar with Lounge having completed Questionnaires from Scenario 2 in same location. Using those volunteers who had just completed Scenario 2, they were briefed then split into three groups and taken to areas out of the entrance doors whilst the test area was prepared. Fire doors at all exit doors were closed to prevent volunteers seeing into test area. Each group was sent in on its own to run the trial.

Marshals were placed behind each of 4 normal exits doors to prevent exit that way. Marshals at top of hidden stairwell sent volunteers back down. Observers noted exit times and sequence at bottom of stairwell exit to car deck.

When sound was used, volunteers were briefed on sound.

Four tests were done – each with three runs
(Groups 1,2,3):

- S3-1. No smoke - no sound beacons
- S3-2. No smoke - with sound beacons
- S3-3. Smoke – no sound beacons
- S3-4. Smoke – with sound beacons



Marine Trials Scenario 3 - Hidden Route & Stairs

Data and Statistical Analysis



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. 9 details the mean exit times for the four different trials.

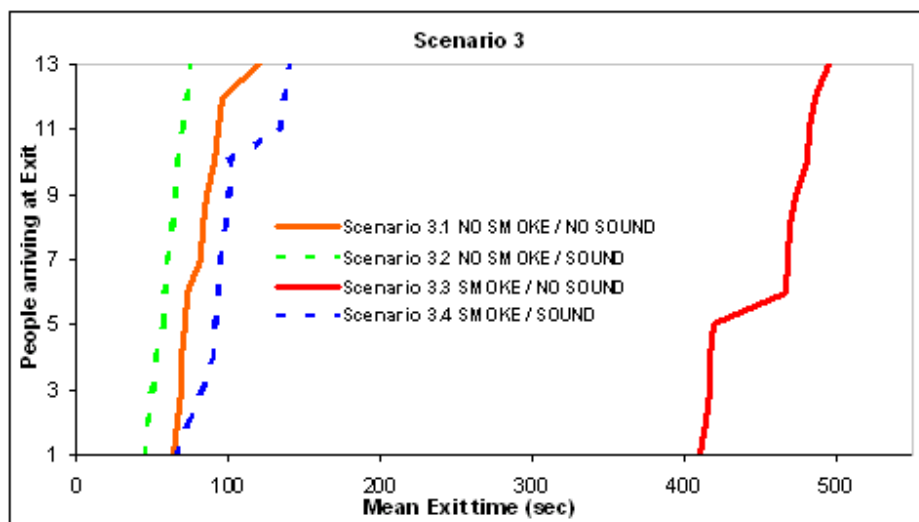


Fig 9: Scenario 3 exit times

The scenario 3 trials were the only trials where smoke and no smoke times were comparable since in clear conditions the location of the exit was not clear. Results of trial S3-3 illustrate the difficulty associated with locating the exit. In this trial none of the volunteers found the exit within 5 1/2 minutes, 4 had to be escorted to the exit. It was obvious from observations that volunteers were reluctant to use an exit marked 'Crew Only'. Some volunteers failed to open this door believing it to be locked. However, when directional sound beacons were used, the decision to use that exit was reinforced and none of the volunteers had



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any difficulty opening the door.

Once through the 'Crew Only' exit, volunteers had the opportunity to climb or descend a stairway which was clear of smoke in all the trials. 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.

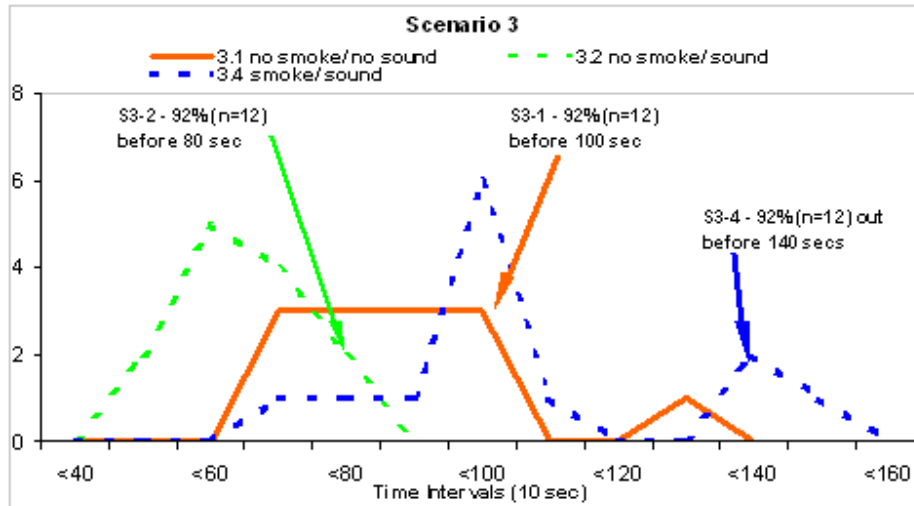


Fig 10: Scenario 3 exit times