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ACOUSTIC ABSORPTION IN SUBMARINE COMPARTMENTS

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ABSTRACT

Treatments to reduce environmental noise are more readily incorporated at the design stage of a project, such as a building, than when the project is completed. Treatments found to be required after the project has been completed can often necessitate re-working that is both costly and time consuming.

At the design stage of a new class of submarine, prediction techniques are used to calculate onboard environmental noise levels. Where noise targets are expected to be exceeded, one can then identify the acoustic treatments needed to be incorporated in the submarine design so that the crew can work and rest, free from hazardous or intrusive noise.

One aspect of the prediction techniques used in submarines is the calculation of acoustic absorption in compartments. This paper discusses how acoustic absorption is calculated for areas within submarines, and case studies utilising these calculated values are used to compare predicted sound pressure levels with those measured onboard.

1. INTRODUCTION

The submarine is basically a stiffened steel cylinder subdivided by decks and bulkheads into a number of compartments including machinery spaces, stores, command areas and accommodation. As such, the submarine is unlike any other environment in which people have to work and rest over long periods of time. Although the conditions onboard submarines will be experienced by relatively few people, such as employees of the submarine constructor and naval personnel, the general public as a whole have some idea of life aboard submarines through the media of films and television.

Cramped and noisy are two adjectives that have been used to describe the conditions onboard submarines. Although space in submarines is always at a premium, conditions onboard modern Royal Navy submarines are certainly less cramped and more comfortable than say their Second World War counterparts. With regard to noise, a great deal of work has been directed over the years, at reducing the noise that the submarine radiates to the sea in order to minimise the risk of its detection.

Improvements also have been made to control environmental noise within the submarine through a combination of machinery design selection and acoustic absorption and acoustic isolation treatments. In addition, an environmental noise target level is assigned to each compartment. The highest target levels are set for machinery spaces where noise needs to be controlled to avoid hearing damage. Medium target levels are assigned to command and office areas where noise must be prevented from interfering with speech and communication, while the lowest target levels are reserved for accommodation areas where noise must not be allowed to disturb rest and sleep.

In common with more familiar projects, if potential environmental noise problems can be identified before the construction of a new submarine takes place, then the required acoustic treatments can be incorporated in the initial design. By doing so, this will save time and effort during the build and avoid costly reworking to include the treatments once construction has been completed.

The determination of acoustic absorption in compartments is important in establishing the contribution of noise sources to compartment environmental noise levels and hence the selection of appropriate acoustic treatments. This paper discusses various aspects of acoustic absorption in submarine compartments including the methods used to calculate absorption values for new submarine designs, and comparisons of calculated sound pressure levels determined using these values with actual levels measured onboard.

2. ACOUSTIC ABSORPTION MATERIALS

Acoustic absorption materials in submarines are used to increase the attenuation of reverberant sound in compartments, to inhibit the formation of standing waves between compartment sides and to reduce the focusing effects caused by the concave surface of the submarine hull. The absorption materials used in modern submarines are generally man-made fibre or foam based. Materials in slab or roll form are fitted to compartment boundaries (hull, bulkheads, deckhead), while preformed sections are applied to structure stiffeners. The acoustic absorption materials used today were originally developed from thermal insulants such as cork, which were fitted to the internal surface of the submarine hull, to reduce condensation and heat loss to the outside environment. Although the new fibre and foam materials have similar thermal properties to cork, they have much greater acoustic absorption coefficients.

The quantity of acoustic absorption material in a compartment differs according to the type and use of that space. For instance, in machinery areas absorbent material is fitted to all compartment boundaries, except the deck, to reduce levels of hazardous noise; in office areas it is usually only fitted to the deckhead for speech intelligibility purposes, while none is fitted in wet bilge areas for obvious reasons. Also, depending on the available space, the thickness of acoustic absorption material can range from 13 mm to 100 mm.

In accommodation areas of the submarine the acoustic absorption materials are usually faced with a thin perforated metal sheet to prevent it from being damaged and for decorative purposes. In machinery areas the absorbent material is usually faced with unperforated, impervious glass cloth to prevent damage and also to prevent ingress of dirt, oil and other liquids. Each of these facing treatments, however, tend to reduce the effectiveness of the acoustic absorption material particularly at high frequencies (Table 1). Although the glass cloth faced materials can be wiped clean, through the submarine's lifetime they are eventually painted several times to give them a clean appearance. This can further affect the acoustic absorption characteristics of the materials as shown in Table 1.

3. CASE STUDY A

The aim of this case study is to show how the methods of calculating acoustic absorption have been developed and applied to submarine compartments. Of particular interest are machinery spaces because these contain large numbers of noise sources and some of the highest onboard noise levels are expected in such areas.

For the purposes of this case study the example shown in Figure 1 of a fan in a machinery space will be used. Sound pressure levels due to the fan were measured at several locations in its reverberant field using a precision integrating sound level meter. These levels were averaged and are shown in Table 2. Sound intensity measurements were taken around the fan to obtain its sound power levels. Using these sound power levels and values of the acoustic absorption in the machinery space determined from the methods [1] discussed below, sound pressure levels in the reverberant field can be calculated (Equation 1) and are compared with the measured sound pressure levels in Table 2.

$$L_p = L_W + 10\log\left[\frac{4}{A}\right] \qquad (1)$$

The first technique used to obtain values of acoustic absorption in submarines was by means of the Sabine method (Equation 2) based simply on the surface areas of the compartment plate boundaries. Applying this method to the machinery space in Figure 1, acoustic absorption values were calculated using the surface areas and absorption coefficients in Tables 3 and 4. Reverberant sound pressure levels due to the fan were calculated (Equation 1) and the results are shown in Table 2.

$$A_S = \sum_{i=1}^{N} S_i \alpha_i \qquad (2)$$

Since the Sabine equation was originally developed for large open spaces such as auditoria, it is probably not surprising that the calculated levels in Table 2 for a cramped submarine machinery space are poor when compared to measured levels. The results in Table 2 clearly show that this method underestimates the amount of acoustic absorption in the machinery space, in particular at mid to high frequencies.

To improve the prediction, it was decided to include the effect of acoustic absorption due to materials on the hull, deck and bulkhead stiffeners. Surprisingly, calculations showed that the total surface area of the stiffeners was approximately equal to the total area of those boundary plates to which they were attached. Including these areas in the Sabine calculation (Equation 2) produces an improved set of predicted levels (Table 2), although comparison with measured levels is still poor in certain octave bands.

Consideration was then given to the acoustic absorption afforded by the items of machinery themselves. Data published by SNAME [2] regarding objects in machinery spaces onboard warships indicates that the surface area of "hard" objects is numerically equivalent to 50% of the compartment boundary surfaces, while soft object surfaces are numerically equivalent to 20% of the compartment boundary surfaces. Absorption coefficients of "hard" and "soft" object surfaces are shown in Table 4. By including the absorption due to objects in the Sabine calculation (Equation 2) further improvements in the predicted levels occur (Table 2).

Finally, knowing that the absorption coefficients of some of the acoustic absorption materials in the machinery space were high (Table 4), it was decided to fine tune the calculation of acoustic absorption by using the Norris-Eyring equation together with air absorption (Equation 3). As a result, Table 2 shows a further improvement in the calculated levels which now agree very well with the measured sound pressure levels.

$$A_{NE} = -S \ln\left[1 - \bar{\alpha}\right] + 4mV \qquad \text{where} \quad \bar{\alpha} = \frac{A_S}{S} \qquad (3)$$

4. CASE STUDY B

The aim of this case study is to compare sound pressure levels calculated in a number of submarine compartments using the Norris-Eyring method (Equation 3) to obtain acoustic absorption values, with those obtained using the reverberation time method [1] to determine acoustic absorption (Equation 4).

$$A_{RT} = \frac{0.161V}{T} \tag{4}$$

In this assessment a known sound power source was used and was placed in one of the corners of each compartment investigated. This was to ensure that the maximum number of acoustic room modes in each compartment would be excited to produce an even and diffuse reverberant sound field in those areas. Reverberation time measurements were taken at several locations in each compartment using a modular precision sound level meter and then averaged to reduce the effects of any localised anomalies in the sound field in these spaces.

The sound pressure levels calculated using the acoustic absorption values thus obtained are shown in Table 5. Also shown are calculated levels using the Norris-Eyring method (Equation 3) and actual measurements obtained using a precision integrating sound level meter. This Table shows that the vast majority of calculated sound pressure levels determined by the Norris-Eyring method are within 3 to 5 dBA of those obtained using reverberation time measurements. Similar agreement is also found by comparing the calculated levels with the actual measured sound pressure levels.

5. CONCLUSIONS

This paper has shown through these case studies how the methods to calculate acoustic absorption values when applied to submarine compartments have been developed. In the majority of compartments the calculated sound pressure levels determined using calculated absorption values or those obtained from reverberation time measurements agree well with measured levels. Having confidence in the predicted compartment levels for new classes of submarines, an accurate selection of acoustic treatments can then be made.

6. REFERENCES

[1] L.L. BERANEK, 'Noise and Vibration Control', Chapter 9, McGraw-Hill, 1971.

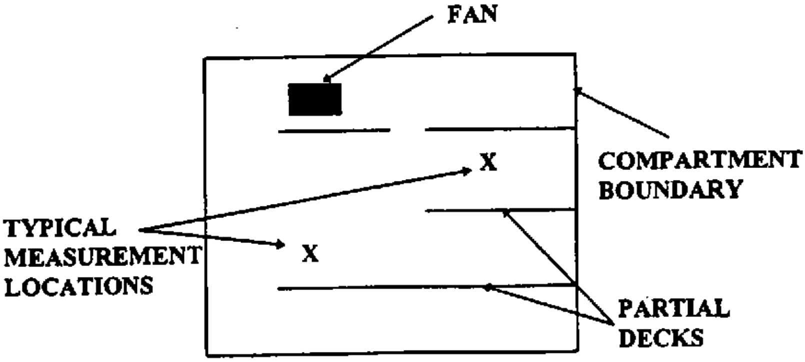
[2] R.W. FISCHER, C.B. BURROUGHS & D.L. NELSON, 'Design Guide for Shipboard Airborne Noise Control', Section 7, The Society of Naval Architects and Marine Engineers (USA), Technical & Research Bulletin 3-37, 1983.

[3] ISO 354-1985, 'Measurement of Sound Absorption in a Reverberation Room'.

GLOSSARY OF TERMS

L_p	-	Sound pressure level (dBA ref 2 x 10^{-5} Pa)
L_w	-	Sound power level (dBA ref 10^{-12}W)
A	-	Acoustic absorption (m^2)
A_S	-	Sabine acoustic absorption (m^2)
N	-	Number of boundary and object surfaces
S_i	-	Individual boundary or object surface area (m^2)
α_i	-	Individual boundary or object acoustic absorption coefficient
A_{NE}	-	Norris-Eyring acoustic absorption (m^2)
S	-	Total boundary surface area (m^2)
$\bar{\alpha}$	-	Average acoustic absorption coefficient
m	-	Air absorption coefficient (m^{-1})
V	-	Volume of compartment (m^3)
A_{RT}	-	Reverberation time acoustic absorption (m^2)
T	-	Reverberation time (s)

FIGURE 1 MACHINERY SPACE (ELEVATION LOOKING OUTBOARD)



Note: Other machinery removed for clarity

TABLE 1 EFFECT OF FACINGS ON ACOUSTIC ABSORPTION MATERIAL [3]

MATERIAL	ABSORPTION COEFFICIENTS							
	63	125	250	500	1k	2k	4k	8k
50 mm glass fibre in scrim cloth	0.06	0.19	0.53	0.96	0.92	0.82	0.80	0.73
50 mm glass fibre in scrim cloth with perforated metal facing	0.08	0.22	0.53	0.98	0.93	0.80	0.73	0.53
50 mm glass cloth faced glass fibre	0.15	0.35	0.75	0.70	0.25	0.15	0.10	0.05
50 mm glass cloth faced glass fibre painted (2 coats)	0.10	0.40	0.75	0.60	0.20	0.10	0.15	0.35

TABLE 2 SOUND PRESSURE LEVELS IN MACHINERY SPACE

	SOUND PRESSURE LEVELS (dBA ref 2×10^{-5} Pa)								
	OVERALL	63	125	250	500	1k	2k	4k	8k
Measured	65	45	48	55	59	60	60	57	50
Calculated (Sabine)	73	46	51	57	65	69	68	62	53
Calculated (Sabine with stiffeners)	69	44	49	54	61	65	64	60	49
Calculated (Sabine with stiffeners/objects)	66	39	47	53	60	62	60	56	48
Calculated (Norris-Eyring)	65	39	47	52	59	61	59	55	46

TABLE 3 SURFACE AREAS IN MACHINERY SPACE

MATERIAL	AREA (m^2)		
	BOUNDARY PLATES	STIFFENERS	OBJECTS
50 mm glass cloth faced glass fibre	478.5	159.8	-
13 mm glass cloth faced glass fibre	-	352.5	-
25 mm glass cloth faced foam	50.4	17.0	-
Bare steel	493.9	237.8	-
"hard"	-	-	895.0
"soft"	-	-	358.0

TABLE 4 ACOUSTIC ABSORPTION COEFFICIENTS [2, 3]

MATERIAL	ABSORPTION COEFFICIENTS							
	63	125	250	500	1k	2k	4k	8k
50 mm glass cloth faced glass fibre	0.10	0.40	0.75	0.60	0.20	0.10	0.15	0.35
13 mm glass cloth faced glass fibre	0.02	0.07	0.52	0.83	0.50	0.25	0.15	0.50
25 mm glass cloth faced foam	0.07	0.20	0.57	0.72	0.32	0.17	0.18	0.53
Bare steel	0.01	0.02	0.03	0.03	0.03	0.02	0.02	0.02
"hard"	0.10	0.09	0.05	0.02	0.01	0.01	0.01	0.01
"soft"	0.20	0.25	0.40	0.60	0.70	0.70	0.60	0.50

TABLE 5 SOUND PRESSURE LEVELS IN VARIOUS COMPARTMENTS

SUBMARINE COMPARTMENT	METHOD	SOUND PRESSURE LEVELS (dBA Ref 2 X 10^{-5} Pa)						
		125	250	500	1k	2k	4k	8k
Machine Space	A	69	80	81	87	90	89	86
	B	-	-	81	85	87	86	83
	C	69	74	78	84	86	85	81
Electrical Equipment Space	A	68	78	80	82	90	93	78
	B	75	80	83	86	87	86	84
	C	77	81	85	88	90	90	87
Office	A	62	75	74	80	86	87	69
	B	69	74	77	81	82	80	-
	C	68	75	81	83	85	84	81
Cabin	A	75	80	79	85	88	85	82
	B	73	79	83	86	87	86	84
	C	73	82	87	90	91	90	87
Laboratory	A	64	75	81	83	88	87	85
	B	-	76	79	83	85	84	81
	C	72	79	85	87	89	88	84

A = Measured
B = Calculated using reverberation time measurements
C = Calculated using Norris-Eyring equation