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# MODEL EXPERIMENTS ON SOUND TRANSMISSION FROM ENGINEROOM TO ACCOMMODATION IN MOTORSHIPS

## (MODELONDERZOEK OMTRENT DE GELUIDSOVERDRACHT VAN MACHINEKAMER NAAR VERBLIJVEN AAN BOORD VAN MOTORSCHEPEN)

by

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## VOORWOORD

In het kader van het research programma betreffende geluidhinder werd reeds enige jaren geleden om verschillende redenen de behoefte gevoeld het onderzoek aan boord van schepen tot een minimum te beperken. Analoog aan vele andere takken van research zou naast theoretisch onderzoek, het onderzoek met modellen veel sneller tot een beter resultaat kunnen leiden. Voorzover toen bekend, waren echter dergelijke modelexperimenten nog niet eerder uitgevoerd.

Daarom werd in 1963 besloten de mogelijkheid voor het geluidhinderonderzoek met modellen te laten nagaan, waartoe een opdracht werd verstrekt aan de Technisch Physische Dienst TNO-TH.

Gezien het voorgaande werd het nodig geacht uit te gaan van betrouwbare meetgegevens, verkregen aan boord van een bepaald type schip. In dit verband mag met erkentelijkheid worden vermeld dat de N.V. Koninklijke Maatschappij „De Schelde" enige schepen van hetzelfde type ter beschikking stelde voor het uitvoeren van geluidmetingen aan boord. Daaraanvolgend werd veel werk verzet en een grote inspanning verricht voor de vervaardiging van een vereenvoudigd model van een deel van het schip waarin uiteindelijk het akoestisch gedrag kan worden gereproduceerd.

De eerste resultaten zijn bekend gemaakt in een voordracht voor de „Acoustical Society of America" te Washington D.C. in juni 1965. Aangevuld met daarna verkregen gegevens is alle thans beschikbare informatie over dit onderwerp in dit rapport gepubliceerd.

Hoewel nog een aantal aspecten nader zullen worden onderzocht, is toch reeds vast te stellen dat model experimenteel onderzoek over de akoestische eigenschappen van een schip zeer goed mogelijk is. Hiermede is een goede basis verkregen om met betrekkelijk lage kosten onderzoek betreffende de geluidoverdracht aan boord van schepen en maatregelen tegen geluidhinder uit te voeren.

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## PREFACE

Within the scope of the research programme for noise-control it was felt some years ago that for several reasons the investigations aboard ships should be restricted to a minimum. Analogous to many other branches of research, investigations with models besides theoretical research, could lead much faster to better results. However, as far as known at that time such model experiments had not been carried out earlier.

Therefore it was decided in 1963 to survey the possibility for noise-control investigations with models, which subject was ordered to the Technisch Physische Dienst TNO-TH.

In view of the foregoing it was considered essential to start with reliable measurements aboard a certain type of ship. In this respect it may be gratefully acknowledged that Messrs. N.V. Koninklijke Maatschappij „De Schelde" placed at our disposal several ships of one type for carrying out acoustic measurements taken aboard. Subsequently much work and effort have been invested into the construction of a simplified model of a part of the ship concerned wherein finally the acoustic ship behaviour could be reproduced.

The first results were presented at a meeting of the "Acoustical Society of Amerika", Washington D.C. in June 1965. Supplemented with further results all the at present available information on the subject has been published in this report.

Although there are still several aspects going to be more fully investigated, it can already be stated that model experimental research on the acoustical behaviour of ships is very well possible. Herewith a sound basis has been obtained to carry out research on sound transmission in ships and evaluate measures for noise-control at relatively low costs.

THE NETHERLANDS SHIP RESEARCH CENTRE TNO

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# LIST OF SYMBOLS

| | | |
|---|---|---|
| $a$ | airborne, auxiliary | (suffix) |
| $b$ | borne , bulkhead | (suffix) |
| $c$ | casing , corridor | (suffix) |
| $d$ | deck | (suffix) |
| $D$ | difference in level | (sound pressures only) |
| $e$ | (main) engine | (suffix) |
| $f$ | foundation (suffix), frequency | |
| $fab$ | fabric of the ship | (suffix) |
| $h$ | hull | (suffix) |
| $L_p$ | sound pressure level $= 10 \log (p^2 / p_0^2)$, where $p_0 = 2.10^{-5}$ N/m$^2$ | |
| $L_v$ | particle velocity level $= 10 \log (v^2 / v^2_0)$, where $v_0 = 5.10^{-8}$ m/s | |
| $me$ | measured (suffix) | |
| $p$ | alternating (or sound) pressure (suffix) | |
| $s$ | side (of ship's hull; suffix) | |
| $v$ | alternating (or particle) velocity (suffix) | |
| $V$ | difference in level (for sound pressure compared to particle velocity) | |

# MODEL EXPERIMENTS ON SOUND TRANSMISSION FROM ENGINEROOM TO ACCOMMODATION IN MOTORSHIPS

by

Ir. J. H. JANSSEN

*Summary*

Sound transmission, both airborne and structureborne, from engine room to accommodation was investigated on board a 14000-DWT shelterdeck dieselmotor ship with accommodation around the engine casing near midship. Typical ship noise in cabins is shown not to originate in engine room airborne noise. This is in agreement with data obtained by other workers. As mathematical models for sound radiation by decks and bulkheads did not explain the experimental facts satisfactorily and further experiments on board were impossible, a 1 : 10 scale model was built. It consists of one side of the casing with two adjacent decks, stiffeners, deck beams etc. made from steel plate. A model cabin is mounted between the decks. Airborne sound transmission in model and prototype turned out to be very similar. Consequently structureborne sound transmission was investigated. Agreement again is satisfactory. The model is now in use for studying resiliently mounted exhausts and other piping. This research was carried out under contract with the Nederlands Scheeps-Studiecentrum TNO (Netherlands Ship Research Centre TNO).

## 1 Introduction

The many large sea-going passenger and cargo ships propelled by internal combustion engines of the diesel-type present the marine acoustician with some challenging problems. Besides the high noise levels on bridge wings and open decks due to the exhaust pulses, the airborne and structureborne sound transmitted from the engineroom to the accommodation are notorious.

Especially for the low-frequency components of the noises it is of considerable importance to know how this transmission takes place. Recently excellent literature on the subject became available; workers in the United Kingdom and in Germany notably published interesting results[1] [2]. However, we still need more insight into the mechanism of the sound transmission. Some experiments were carried out therefore on board three sisterships, early in 1960 and later. The ships concerned were generously put at our disposal by Messrs. Koninklijke Maatschappij „De Schelde".

The main effort was directed towards obtaining data on structureborne sound transmission in the hull. For several reasons airborne sound measurements had to be postponed until the end of 1962. The greater part of the results was published [3]. Up to that time it had not been quite sure if also for low frequencies structureborne sound transmission into cabins was generally predominant [3] [4]. It turned out, from sound insulation measurements as well as from measurements during sea-trials, that for the type of ships investigated the airborne noise in the engineroom and casing can be neglected as a sound source for the cabins.

The question remains, however, if this conclusion is valid for other ships or other engines. Now, acoustical investigations in ships are always somewhat intricate. The major part of the noice sources can not be switched on and off separately.

Also, the fabric of the ships is rather complicated. Most of all, however, a merchant ship is hardly ever available for this kind of research work. It was therefore considered worthwhile to try and evaluate scale models of parts of a ship as aids in understanding the acoustical properties of a ship as a whole.

As a first step towards this aim a model scale 1 : 10 was built of a section of the bridgedeck and the boatdeck and the adjacent engine casing. A model cabin between the decks was also built. The results of some airborne and structureborne sound transmission measurements in the model were compared with the results from the prototype i.e. the ships mentioned before.

A profile of these ships is shown in figure 1. They are of the shelterdeck-type of approximately 14000 DWT. The accommodation is built around the engine casing. The propeller is driven by one 6-cylinder two stroke engine.

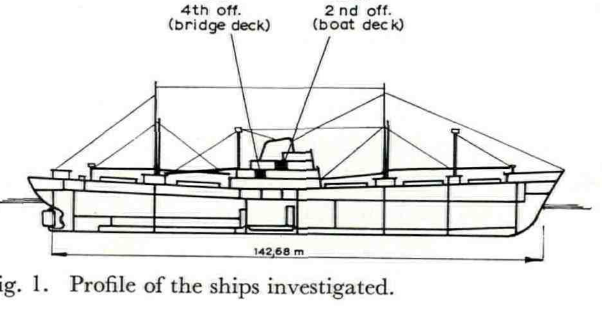



Fig. 1. Profile of the ships investigated.

Of the three ships two were identical twins, (main engine 7050 BHP at 115 rpm) the other differed slightly (6000 BHP at 131 rpm). Also the heat insulation of the engine casing for the latter ship was slightly different. It is thought, however, that these small dissimilarities do not influence the conclusions of this report.

For the accommodation on board ships like those of figure 1 the most important noise source is the engineroom. In this space the main engine and the auxiliaries produce high airborne sound pressures. Moreover in the engine seatings, the foundations of the machinery and in the piping intense structureborne noise is produced. It may safely be assumed that the distance between the propeller and the accommodation is sufficiently large to ensure that the propeller may be considered as an insignificant noise source, especially in view of the results of structureborne sound experiments published elsewhere [3].

The cabins indicated "4th officer" and "2nd officer" were chosen as being typical for noisy cabins in many other ships; see figures 1 and 2. Of course one might conceive of much noisier cabins but these should be exceptions, or their location is extremely bad and could easily be improved upon.

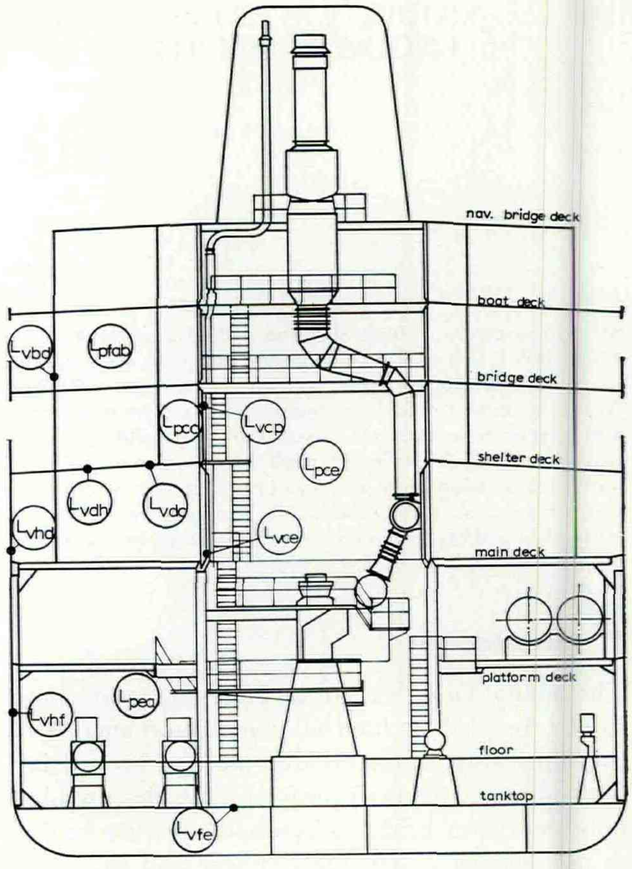



Fig. 2. Section through engine room. Deck beams above main deck are not shown. Symbols for possibly significant levels are indicated at appropriate positions.

## 2 Four a-priori sound paths

Of course it is not difficult to envisage many sound paths from the engines to the cabins. For an efficient method of describing the sound transmission in a ship's hull the art, however, is in limiting their number as much as possible. Depending on circumstances four essentially different paths seem to be important, viz. (see figure 2):

1. from the main engine *through the air* ($L_{pce}$) inside the enginecasing to the casing plates ($L_{vcp}$) and via the adjacent decks into the cabins; symbol: $L_{pac}$ for the radiated sound pressure level inside the cabin due to this path.
2. from the main engine *through the structures* of platforms, piping and stairs to the casing plates ($L_{vce}$) and via the adjacent decks ($L_{vdc}$) into the cabins; symbol: $L_{pcb}$.
3. from the auxiliaries *through the air* ($L_{pea}$) to the decks and shell structure and via the hull and the decks into the cabin; symbol: $L_{pas}$.
4. from the auxiliaries *through the structures* of the seatings and the foundations ($L_{vfe}$) mainly to the side and via the hull ($L_{vhf}$, $L_{vhd}$) and the decks ($L_{vdh}$) into the cabins; symbol: $L_{psb}$.

As to the symbols introduced in the text and in figure 2 it may be remarked that the sound pressure level $L_{pfab}$ in a cabin is designated by *fab* because of the characteristic feature of the acoustical phenomena under investigation: the transmission through the fabric of the ship ($p \triangleq$ pressure; $v \triangleq$ particle velocity due to vibration, i.e. structureborne sound; $d \triangleq$ deck; $h \triangleq$ hull; $f \triangleq$ foundation; $e \triangleq$ engine; $a \triangleq$ auxiliary or airborne; $c \triangleq$ casing or corridor).

It is supposed that the four contributions to $L_{pfab}$ are typical:

*ac* for airborne sound from casing
*cb* for casing structureborne
*as* for airborne from side
*sb* for side structureborne

The first path was investigated by placing two loudspeakers on a platform at the height of the cylinder heads just below main deck. The difference $D_{ac}$ in sound pressure level between the casing and two cabins was measured during excitation by means of these loudspeakers fed

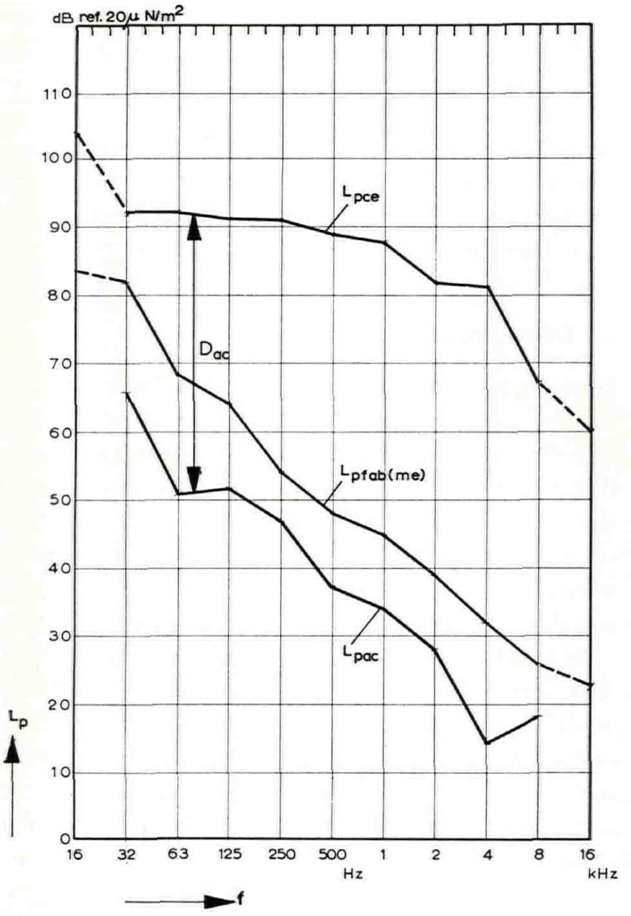



Fig. 3. Comparison of measured spectrum $L_{pfab}(_{me})$ in 4th officer's cabin under normal service conditions (119 rpm of propeller shaft) with calculated $L_{pac} = L_{pce} - D_{ac}$; here $L_{pce}$ is spectrum measured inside engine casing under same conditions, but $D_{ac}$ is airborne sound pressure level difference for loudspeaker excitation between inside casing and cabin.

with random noise. This pure-airborne sound level difference turned out to be greater than the difference in level between corresponding positions when the main engine was running.

A typical example is shown in figure 3. The difference $D_{ac}$ for pure airborne sound is subtracted from the sound pressure level $L_{pce}$ prevailing inside the engine casing under normal service conditions; see also figure 2. The resulting computed level $L_{pac}$ is significantly lower than the level $L_{pfab}$ as actually measured in the cabin during the seatrials. One may conclude that for this hull and this engine the above-mentioned airborne sound path is unimportant for the radiated engine noise in the cabin. For the third path mentioned – also airborne, but now from the auxiliaries – the pure-airborne sound level difference $L_{pea} - L_{pas}$ is even 10 dB greater than for the casing-borne path.

For the ships in question airborne sound transmission is ruled out. It would be outside the scope of this report to derive the conditions for which this conclusion might be valid for other ships as well. It will be clear, however, that important factors in this respect are: the amount of airborne sound relative to the structureborne sound transmitted by the engine to the adjacent parts of the ship on the one hand, and on the other hand the acoustical properties of the hull itself. In order to study these latter properties a scale model might be useful.

## 3 A scale 1 : 10 model

A "perfect" model, i.e. a model made from exactly the same materials as the prototype is, with all dimensions reduced according to the same scale, would give exactly the same relations between pressures and velocities as the prototype does provided the frequency for the model is scaled up at the same rate as the linear dimensions are scaled down and provided the loss factor of each material is frequency -independent. These sufficient conditions are never met exactly. Of course, moreover, they are not necessary, especially not in view of the accuracy required.

In order to deviate as little as possible, however, from these sufficient conditions a steel plate model was thought to be indispensable. This introduced the difficulty of soldering, or preferably welding. No method could be found that could also be used inside the model for the nearly inaccessible spots. Several methods for cementing were then tried. No satisfactory result could be obtained however, for the casing plates with stiffeners. Due to the large area the stiffeners were very easily peeled off by only minor movements of the plate. It was therefore decided to apply spotwelding for this large part of the model. The smaller parts were mounted with the aid of the Araldit-combination AW 106-HV 953 U.

In comparison with some other two-component adhesives this combination gave the best results in some preliminary experiments on natural frequencies of glued I-beams. Continued research in this respect however, would almost certainly result in better welding-substitutes. Another disadvantage is that cementing together the edges of two plates at right angles is practically impossible. A small strip bent in L-form is therefore used as a cementing-aid. This probably introduces extra rigidity in the joint. Of course, the most important shortcoming of the model is that it is only a very small part of the ship, or even of the superstructure. One may hope, however, that the essential acoustical properties of the full-scale section of the ship are preserved in the model.

In figure 4, a vertical cross-section of the model set-up is shown. A sandlime brick den (height 0.7 m, width 1.0 m, length 1.2 m) is used as transmission room (engine casing side). On top of it – as a kind of roof or cover – the casing plate is situated horizontally; the stiffeners cannot be seen in figure 5. Visible are, however, the bridge deck – on the right – and the boat deck – on the left hand side – in a vertical position. The deckbeams and the cabin walls of hardboard can be clearly seen.

The electrodynamical exciter is shown in one of the many positions tried.

When judging the results of the more or less preliminary experiments with the model described above one should keep in mind that the problem in question – the transmission of sound from the engineroom to the accommodation in a ship – is very complicated. Mathematically it is nearly unsolvable and anyhow, very experienced mathematicians and probably computers are needed for partial solutions. This model is relatively inexpensive and it was built by one patient and enthusiastic technical assistant who carried out the measurements with normal acoustical instruments. The questions how far this simple approach is justified by the results, how reliable this model is and if this kind of model technique is useful for investigating the acoustical properties of structures like ship hulls, must be studied separately. In this report only the results of some measurements have been given and these related questions have not been considered as yet.

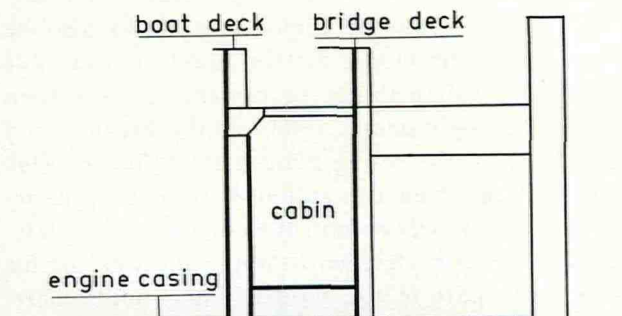



Fig. 4. Section through model investigated. Dimensions can be estimated, because drawing is to scale and deck height is approximately 2.6 m.

## 5 Some results

Four types of measurements have been carried out so far. Immediately after completing the model the first one was a check to determine the difference in level between the airborne sound in the engine casing and in the cabin. In order to do this the loudspeaker produced random noise which was measured with a microphone in the sandlime brick den (transmitting room).

Several microphone positions were tried in the den; the readings from four different microphone positions averaged turned out to be sufficiently accurate. In the modelcabin the sound pressure level was determined at three positions only.

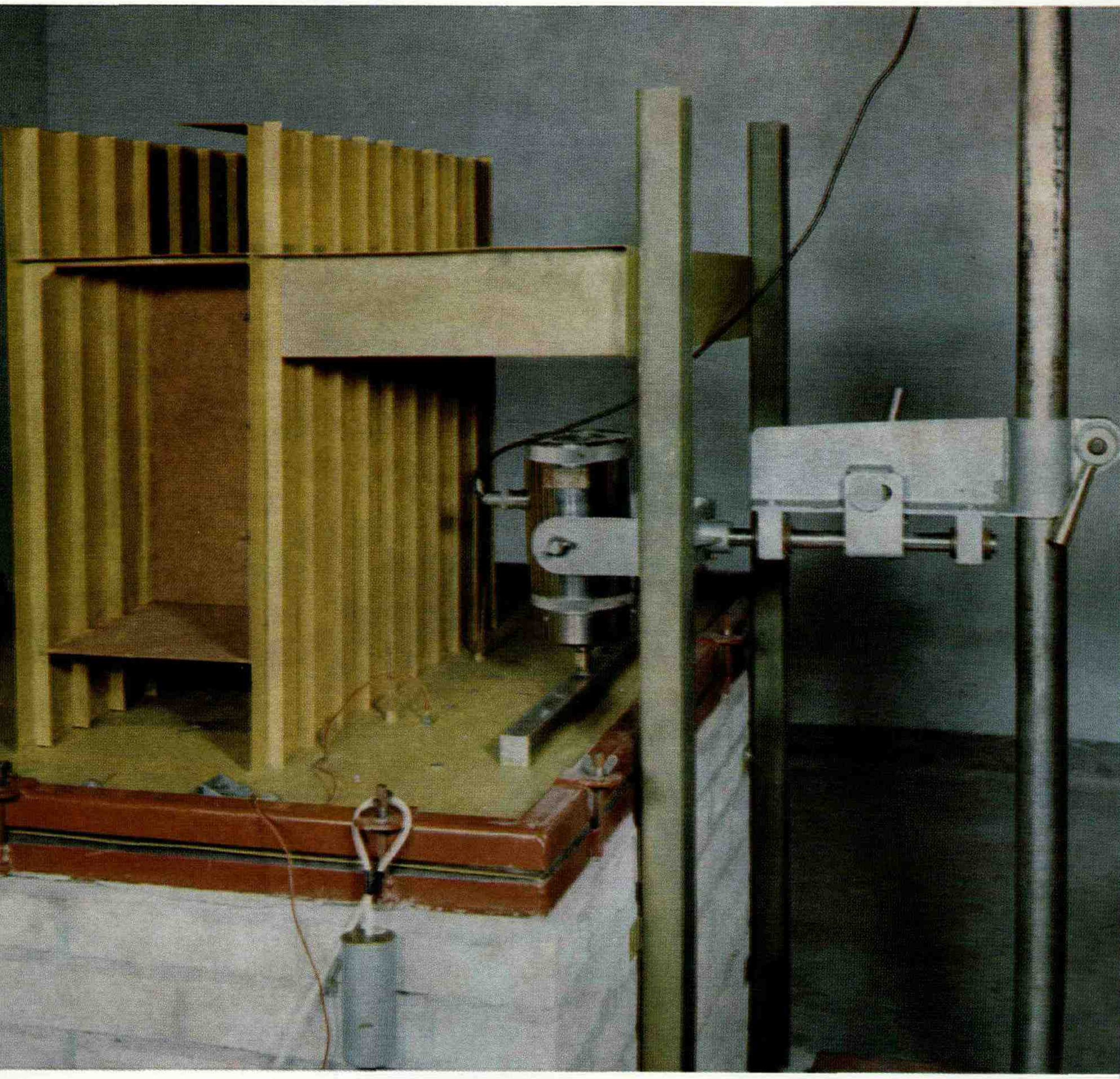
This probably is not sufficiently accurate for characterizing the sound field in the receiving room.

The measured sound pressure level difference $D_{ac}$ of the model turned out to be in encouraging agreement with the corresponding prototype results. This could be concluded from a comparison of the model results plotted at a factor 10 scaled-down frequencies with the two curves bounding the hatched area of figure 6.

One was inclined to conclude that the model is a good representation of the full-scale structure of the ship's accommodation.

As a matter of fact, however, the absorbing material present both in the real cabin and in the model cabin was not checked sufficiently at first. The second experiment, therefore, had to be a reverberation-time measurement. For the full-scale cabin some data were available [5]. The measurements were performed by means of blank pistol shots. In the model cabin the "same" could be done by means of electric sparks. The accessory logarithmic amplifier and measuring oscilloscope were made available by prof. dr. C. W. Kosten of the Acoustics Group of the Technological University Delft.

It appeared that the reverberation time in the bare model cabin was too long. Roughly, the amount of absorption present had to be increased by a factor 5 for the prototype frequencies greater than about 100 Hz. The ensuing 5 to 10 dB increase



odel during one of the structureborne sound transmission experiments. The engineroom casing has been mounted horizontally to facilitate testing.

ed in the good agreement between ototype as shown in figure 6.

reliminary investigations the results figure 6 were thought to justify third type of experiment, viz. he transmission of structureborne der to do this the casing plate was eans of an electrodynamical exciter ys, i.a. as shown in figure 5. For each on the average velocity level $L_v$ g to $L_{vce}$ of figure 2) of the plate d.

del cabin, moreover, the radiated e level $L_p$ (corresponding to $L_{pcb}$ of section 2) was measured at four positions and averaged. The level difference for one typical instance $V_{cb} = L_p - L_v$ as measured in the model is shown in figure 7 as a fully drawn curve. For comparison the hatched area shows approximately the same difference as measured on board in two instances; again for apparently similar situations the level differences $V_{cb}$ were considerable.

The agreement is not as good as for the airborne sound path, although it is surprisingly satisfactory if one considers the far-reaching simplifications of the model.

Without going into details which will be reported elsewhere it should be mentioned that

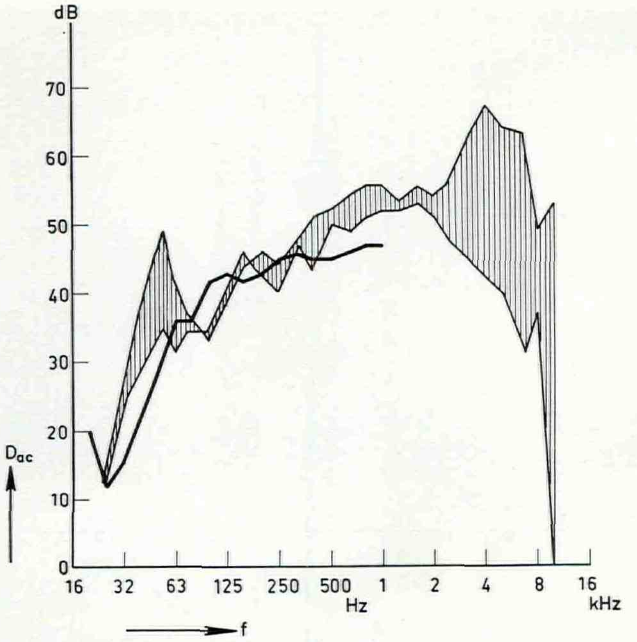



Fig. 6. Comparison of model with full-scale results of airborne sound transmission from casing to cabin. Hatched area comprises typical full-scale level differences; fully drawn curve is obtained in model.

several variations of the model have been investigated. It was found that the mass of the vibration pick-up (accelerometer) has a great influence on the measured values of $L_v$ as could be expected. Endevco (2) 226 type 2.8 gram pick-ups have been used for the results of figure 7. Extending the decks in fore-and-aft direction and applying damping layers had only a minor influence on $V_{cb}$. Decreasing the bending stiffness of the models of the cross-band (wooden) bulkheads increased the agreement appreciably; the one piece hard-

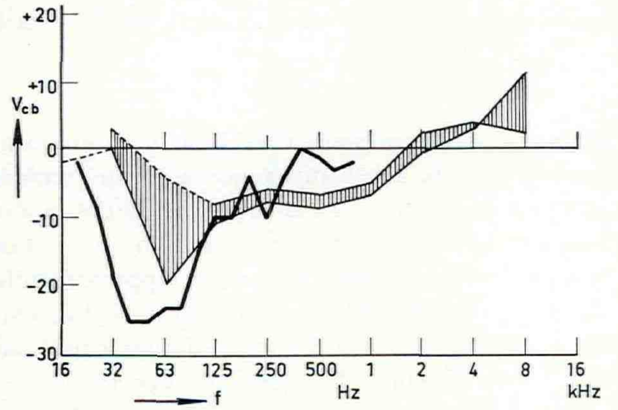



Fig. 7. Comparison of model with full-scale results of structureborne sound transmission from casing to cabin. Hatched area comprises typical full-scale level differences; fully drawn curve is obtained in model. As in figure 6 radiated sound pressure in model is greater than in ship's cabin. There is no explanation as yet.

board panels used originally were cut in three parts afterwards in conformity with the prototype.

The model engine room casing was excited at the I-beam shown in figure 4; the vibrations of the model casing were measured at several positions between boat deck and shelter deck and averaged. It turned out, as could be expected, that the position of the measuring accelerometer and the mode of excitation of the model is of great influence on the value of the level difference $V_{cb}$. For a reliable comparison between model and prototype corresponding excitation modes should be chosen very carefully therefore. It is thought that the differences between model and prototype as shown in figure 7 will be due to the difference between the model excitation by means of an electrodynamic exciter and the prototype excitation by means of the main engine. Nevertheless it was thought worthwhile to perform a fourth experiment, viz. resiliently mounting a model exhaust pipe. The insertion loss, i.e. the improvement compared with rigidly mounting, unexpectedly turned out to be rather small for the higher frequencies. Below approximately 200 Hz the insertion loss is some 10 to 15 dB, but for higher frequencies only some 6 dB could be measured. It remains to be investigated whether this result is typical or not.

## 5 Conclusions

1. Relatively inexpensive model experiments on the acoustical properties of steel ship structures are practicable and very instructive.
2. The reliability of this type of models should be investigated further:
   *a.* similarity of model cabin bulkheads and lining, required extension of decks etc.
   *b.* in the real ship excitation experiments more similar to those in the model should be performed.
   *c.* Also this model experiment suggests for large sea-going dieselpropelled ships that the airborne sound path from engine room to accommodation is not very important.
   *d.* The insertion loss due to resiliently mounting a model exhaust pipe into the model casing was some 15 to 6 dB; this approximates presumably the improvement aboard ships of the type investigated, if only the structureborne sound paths were blocked. If more reduction is wanted the airborne paths must be treated too.
   *e.* The first noise reduction measure for the

accommodation in such ships is therefore: uncoupling the structureborne sound paths like exhausts and other piping connected to the casing.

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5. See [3.] Chapter 8, table 8 II.

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