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ACOUSTIC SOURCE STRENGTH OF PROPELLER CAVITATION

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SUMMARY

The acoustic source strength i.e. the volume velocity of propeller cavitation for six single-screw ships are presented. Plotting the data in the form of dimensionless volume velocity and as a function of the cavitation number based on the rotation speed and the immersion depth, a certain differentiation can be made with respect to the quality of the propeller. For two ships also the transfer of propeller noise into accommodation will be discussed with the aid of the ratio of the sound pressure in a particular cabin and the volume velocity of the propeller.

INTRODUCTION

The noise aboard ships is partly due to the cavitating propeller(s). Especially in the aft-end, where in many modern ships the accommodation is placed the propeller is recognized as a major low-frequency sound source. The Noise-Rating number in those spaces is mostly determined by the octave frequency bands of 31 Hz, 63 Hz, 125 Hz. The well-known acoustic measures, such as the floating floor, are not very effective at those low frequencies. It is for this reason that the ship designer will always look for a more quiet propeller. Moreover, the transfer of propeller noise through the ship construction is difficult to predict, since a proper separation of source strength of the propeller cavitation and the transfer of the noise is difficult to realize. In the first place a good definition of the excitation mechanism due to propeller cavitation is needed. The requirements for such a description should be: unique and independent of the ship's construction. One of the promising possibilities is to represent the propeller cavitation by an equivalent single monopole located near the hull in the propeller plane. The physical arguments for choosing this kind of representation have been outlined in a number of publications ([1], [2]). The description comes very close to a representation in terms of cavity growth and collapse during a blade rotation. This volume variation of the cavity is essentially the cause of the large sound pressures generated in the water near the propeller, which gives rise to hull vibrations. These volume variations especially those that are called "sheet cavitation", can be theoretically calculated from the wake field inflow and the propeller geometry, and it is rewarding to observe that calculation and experiments concerning the monopole source strength are very close for blade-rate frequencies [3]. The source strength of this equivalent monopole can be measured with a technique based on the acoustic reciprocity principles. We give a short exposé in the next section. With the aid of this method a number of merchant vessels has been investigated. The sizes of the propellers and ships covered a wide range.

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It is an interesting exercise to compare the source strength of the propeller cavitation for the various ships and to see which variation in source strength can be observed. A by-product of the present method is the direct measurement of noise transfer from the propeller to the accommodation. In this paper we present data for two ships with various cabins.

MEASURING METHOD

An electro-acoustical transducer such as a loudspeaker is placed in a cabin, somewhere in the aft-end. The loudspeaker is used both as a source and as a microphone (receiver). In the first part of the experiment the ship is not sailing but is located in the harbour. The loudspeaker is then used as a source and with the aid of a number of hydrophones placed on the propeller blades, the transfer function, being the ratio of the measured sound pressure underwater p to the input current i of the loudspeaker, is determined ($= p/i$). In the second part of the experiment the ship is sailing. The same loudspeaker as has been used in the transfer function measurements is now employed as a sound receiver. The open circuit voltage e due to the propeller noise is determined. The principle of reciprocity gives a simple relation for the equivalent monopole source strength of the propeller cavitation, viz.

$$U_{eq} = \frac{e}{p/i}$$

(cf. Figure 1)

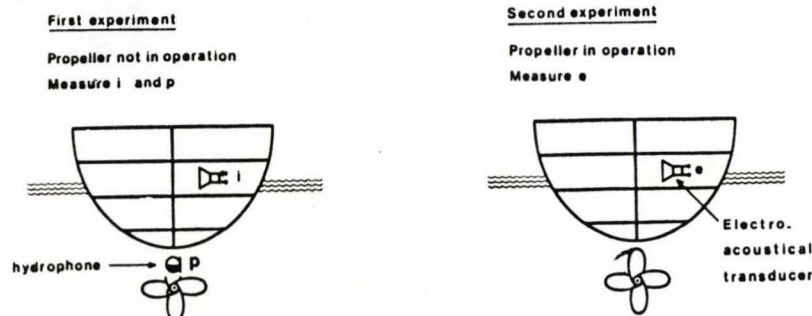


Fig. 1: Test procedure for determining the volume velocity of propeller cavitation

There are quite a few experimental traps like the elimination of undesired background noise in transfer function p/i . Moreover, a major difficulty is that the source, i.e. the propeller cavitation is not a true point source, but has a finite extent. The centre of the cavitation region is hardly known so the placing of the hydrophone being the assumed source centre, somewhere in the propeller plane is rather arbitrary. It also appears that the quantity p/i underwater taken for one cabin position is quite dependent on the hydrophone position so it is useful to take more hydrophone positions into account and to average the sound pressures underwater. In this way a reasonably unique transfer function will be found.

Another transfer function, which is of importance for the direct comparison of sound transmission to cabins on various ships is the ratio of the sound pressure in the cabin and the volume velocity of the propeller. This quantity is only dependent of the ship's construction since the excitation mechanism of the hull is eliminated by taking into account the volume velocity. In this way different ships can be compared with respect to noise transmission through the aft-end from the propeller to the cabin.

ACOUSTIC TRIALS

Six single-screw ships have been investigated. The size of these ships and the trial speeds covered a fairly wide variety. The propeller of the coaster (no. 5) was a controllable-pitch propeller, but was mainly used in a fixed pitch-setting. It is interesting that the two coasters, 4 and 5, were more or less identical ships along the propulsion machinery and the propeller were very much different. Table 1 presents a survey of the main parameters.

Ship	Type	length a.o. in meter	dead weight tonnes	propeller			
				diameter in meter	blades	rpm during trials	speed during trials knots
1	container	225	32825	7,0	5	110	22,5
2	cargo	82	3500	3,1	4	130/196	8/12
3	cargo	82,50	3650	3,2	4	193	12
4	coaster	65,80	1567	1,75	4	375	9,5
5	coaster	65,80	1567	2,10(cp)	3	296	9,5
6	oceanographic vessel	90,15	2800	3,4	6	120/160	12,0/15,5

Table 1: ships used for acoustic trials.

SOURCE STRENGTH OF VARIOUS PROPELLERS

The volume velocities determined by Eq. 1 have been analysed in narrow frequency bands and after that recalculated to 1/3-octave-bands. The frequency range was 20-250 Hz. Unfortunately the lower side of the frequency range could not be extended to blade-rate frequencies of 10-20 Hz, because the transducer was not strong enough to generate observable sound pressures underwater. For two ships (5 and 6) we present data in figure 2 and 3

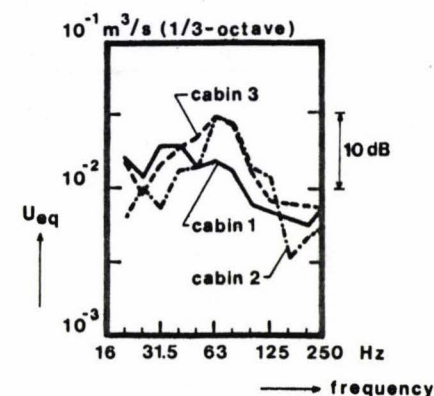


Fig. 2: Volume velocity as a function of frequency for ship 5

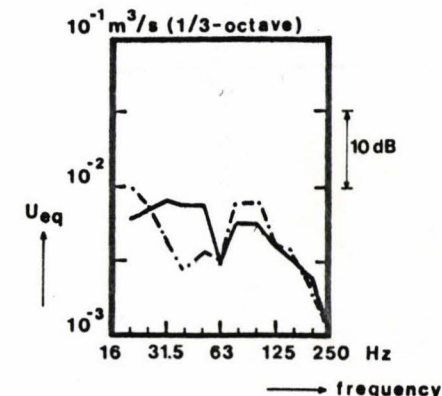


Fig. 3: Volume velocity as a function of frequency for ship 6. speed: 15,5 knots

The volume velocities have been determined from a number of spaces on main and poop deck. As can be expected from the measuring method there is some variation in the source strength determined from the various cabins on one ship, although theoretically the same volume velocity for any position in the ship should be found. The average presents certainly a good picture of the acoustic source strength of the propeller cavitation.

For the coaster with the cp-propeller the maximum of the volume velocity lies at $3 \cdot 10^{-2} \text{ m}^3/\text{s}$ in the 1/3-octave band of 63 Hz. For the oceanographic vessel this maximum is lower, viz. $10^{-2} \text{ m}^3/\text{s}$, although the speed and the propeller/ship size is higher than for the coaster. This might indicate a criterium for the quality of the propeller with respect to cavitation. Actually, the propeller of the oceanographic vessel was made according to a special design with an elaborated hydrodynamic testing programme. In order to facilitate a proper comparison between various propellers it appears useful to correct for different rotation speeds and diameters. By dividing the volume velocities averaged over a frequency-band of 20-250 Hz by the factor $D^3 N$ (D =diameter, N =rotation speed, rev./s) the volume velocity is converted to a dimensionless number. The factor D^3 indicates that the cavity volume is proportional to a cubic dimension of the propeller size, which seems reasonable: the larger the propeller, the larger the cavity volumes. The rotation speed indicates how many times per second a cavity will be generated. Another parameter which is characteristic for the cavitation is the so-called cavitation-number

$$\sigma_n = \frac{p_{\text{atm}} - p_v + \rho gh}{\frac{1}{2} \rho_{\text{water}} (\pi ND)^2}$$

where h = tip immersion depth, p_{atm} = static pressure, p_v = vapour pressure. This number indicates a measure of the maximum susceptibility of the outer sections of a propeller blade to form back sheet cavitation. For every ship the dimensionless volume velocity and the cavitation number have been calculated and plotted in one figure. (cf. fig. 4)

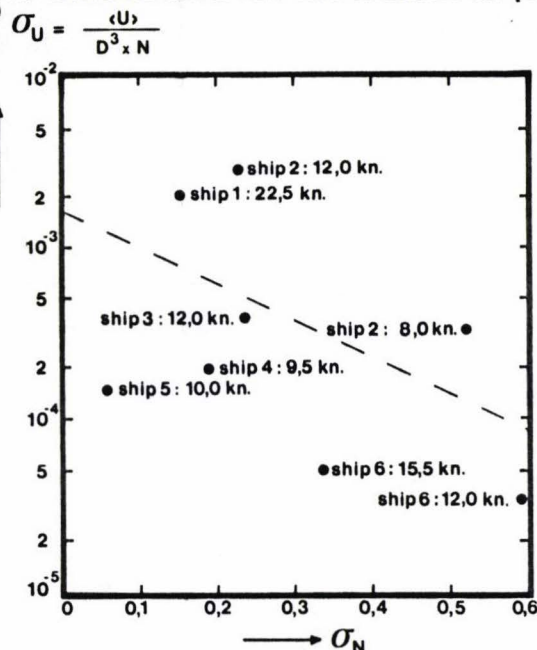


Fig. 4: Dimensionless volume velocity of six ships as a function of cavitation number

It is tempting to draw a line through the eight points. The assumed line divides the picture into two regions: the lower region could indicate the propeller which are better than the average while the upper part indicates rather bad propellers. This agrees with the practical experience in those ships. The oceanographic vessel is considered very good, while the container ship was known for its excessive vibrations.

A parameter which seems of much importance is the wake non-uniformity parameter as has been defined by Fitzsimmons [4] in his evaluation of acceptable excitation forces in ships in dependence of cavitation number and wakefield. We have no information about the wake non-uniformity of the present ships, but a better insight into this parameter might lead to a better understanding why certain propellers fall in a specific region.

SOUND TRANSMISSION

For the two ships (5 and 6) we have also determined the quantity $\langle p \rangle / \langle U \rangle$ for the 1/3-octave frequency bands between 20-250 Hz, where $\langle p \rangle$ is the root-mean-square sound pressure in a certain cabin and $\langle U \rangle$ is the r.m.s. volume velocity of the propeller in 1/3-octave frequency bands. This quantity indicates a transfer function, in which higher values means more sound transmission. The results for the oceanographic vessel (fig. 5) are about 10 dB lower (thus better) than for the coaster (fig. 6).

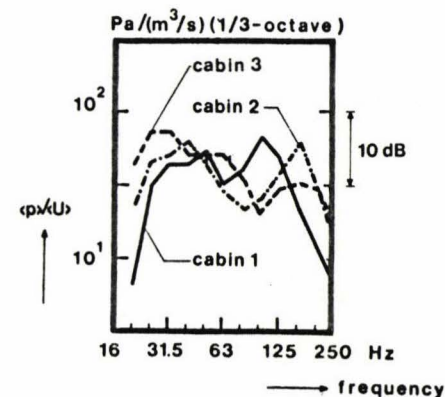


Fig. 5: Transfer function $\langle p \rangle / \langle U \rangle$ for ship 5.

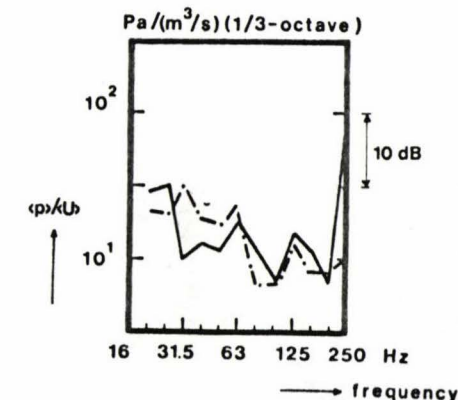


Fig. 6: Transfer function $\langle p \rangle / \langle U \rangle$ for ship 6.

This is remarkable since the distances from cabin to propeller are rather equal. In general it appears that the position of the cabin relative to the propeller is not very relevant for one ship but only the distance matters. Compare in figure 5 the results for cabin 3 which lies a deck higher than cabins on 1 and 2 which are located more in front of the propeller. The two cabins on the oceanographic vessel give transfer functions which are rather equal since they are on the same deck.

CONCLUSION

1. The use of dimensionless volume velocity for the acoustic source strength of propellers appears promising, since experimental data for six propellers can be arranged in such a way that a differentiation can be made with respect to the quality of the propeller.
2. The proper separation of source strength and sound transmission by the above described reciprocity technique can lead to a better understanding of the sound transmission of propeller noise through the stern.

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