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PROPELLER NOISE

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ABSTRACT

Propeller cavitation is one of the most important noise source on board ships. Therefore, an accurate calculation of this noise would be very useful. Cavitation noise is very difficult to predict, and empirical calculation based on model or full-scale measurements or theoretical predictions may be considered. Our model allows to calculate noise radiated by a propeller using different methods: i) Use of full-scale measurements: At full-scale, pressure fluctuation measurements are performed on the hull above the propeller during sea trials. A monopole is then used to modelise propeller source in order to calculate noise; ii) Use of a statistical model (Available at an early design stage): semi-empirical approach. A comparison between the different calculations of propeller noise is presented.

1 - INTRODUCTION

Propeller noise and more specifically cavitation represents, when it is developed, a strong onboard and underwater noise source. Therefore, it is very important to predict accurately propeller noise in order to provide adequate insulation solutions in the aft part of the ship.

Studies to predict hull pressure fluctuations have been carried out, but the development of theoretical programs strongly depends on the accuracy of the estimation of the cavitation volumes at any blade position; which is not easy to predict.

Therefore, till now, empirical and semi empirical reliable methods are often used. Such methods are described in this paper; 2 different approaches for propeller noise calculation are available within the program:

- Empirical calculation (based on full-scale measurements) of propeller noise.
- Statistical method of propeller noise calculation: semi-empirical approach.

2 - PROPELLER NOISE CALCULATION BASED ON FULL-SCALE MEASUREMENTS

2.1 - Use of pressure fluctuation measurements on the hull

The noise generated by a cavitating propeller is mainly due to volume variations. Currently, this dominant pressure component may be approximated by a fixed oscillating monopole. This equivalent sound source is located in the upper part of the upper blade of the propeller.

At the very beginning of a ship project, pressure fluctuation measurements are performed in cavitation tunnel (use of models of propellers) in many points above the propeller.

During the sea trials of the ship, pressure fluctuation sensors are positioned in the hull straight above the propeller in order to study the noise radiated by the propeller (modelised by a fictitious monopole). The sensors are positioned in locations where the highest pressure fluctuations were measured at model. From those measurements, we determine the volume velocity Q of the equivalent monopole:

$$P^2 = \left(\frac{\rho \cdot f \cdot Q}{2}\right)^2 \left(\frac{1}{r_1^2} + \frac{1}{r_2^2}\right)$$

where:

- P: Pressure measured on the hull (Pa)
- ρ: Volume mass of water (kg.m^{-3})
- Q: Volume velocity of the equivalent monopole
- r_1, r_2: Distance between the equivalent monopole and the propellers (m)

2.2 - Use of vibration measurements in the aft part of the structure

The calculation of volume velocity of the propeller is carried out from vibration measurements in the aft structure of the ship, above the propellers.

This implies the knowledge of a transfer between propeller sound source and vibrations measured in the aft structure. This model is also based on the use of the equivalent monopole to modelise propeller sound source.

Transfer between propeller sound source and vibrations generated in the aft part of the ship.

This transfer is determined experimentally. Practically, a reciprocal transfer is measured by exciting the aft part of a deck (above the propeller). We measure the noise radiated in the water with an hydrophone positioned 1 meter behind and at 0.8 radius above the center of the propeller (following the model of the equivalent monopole).

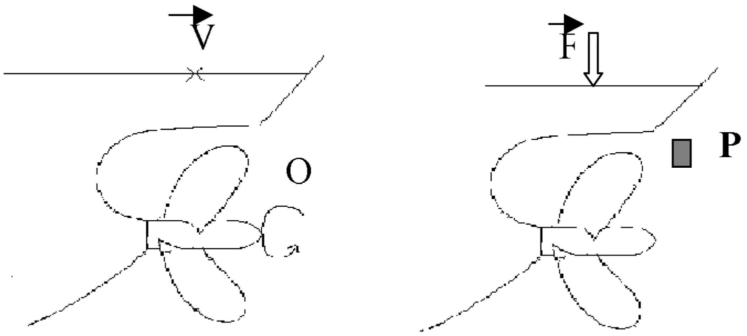

Figure 1.

Therefore, we measure the following transfer:

$$T = \frac{P_{hydro}}{F_{deck}}$$

with:

- P_{hydro}: Measured pressure (Pa)
- F_{deck}: Injected force (N).

Calculation of the volume velocity of the equivalent monopole

And, using the reciprocity principle:

$$T = \frac{P_{hydro}}{F_{deck}} = \frac{V_{deck}}{Q_{propeller}}$$

we establish:

$$L_Q = L_V - L_T - 10 \cdot \log_{10}(Nb)$$

where

- L_V (dB) = 20log$_{10}$(V/1E-6): Vibration measurement (V in m.s^{-1})
- L_T: Transfer measurement at the same point
- Nb: Number of propellers

Cavitation noise envelop

Our software also calculates a theoretical envelop of propeller noise which defines an asymptote of noise radiated by a given propeller:

$$\mathrm{Lp}\,(\mathrm{dB}) \leq 63 + 10{\cdot}\log_{10}\left(\frac{\mathrm{B}\cdot\ \mathrm{D}^4\cdot\mathrm{N}^3}{\mathrm{f}^2}\right)$$

- B: Number of blades
- D: Propeller diameter (m)
- N: Rotation velocity of the propeller (/s)
- f: Frequency (Hz)

3 - STATISTICAL METHOD FOR PROPELLER NOISE CALCULATION: A SEMI-EMPIRICAL APPROACH

This model uses volume velocities calculated from measurements and hydrodynamic as well as geometric characteristics of a given propeller in order to calculate the volume velocity of this propeller.

The volume velocities calculated from pressure fluctuations measurements or from vibration and transfer measurements are placed in a database.

In order to calculate the volume velocity of a new propeller using a statistical approach, the following data are taken into account:

- Geometric and hydrodynamic characteristics of the propeller
- Volume velocities of the database used to calculate regression coefficients of the statistical model

This model allows to perform the calculation at an early design stage.

The statistical basic model is the prediction formula of volume velocity of a fictitious equivalent monopole in the position of the upper part of the blade in the upper position given in [1].

Our model is based on the same calculation, but new regression coefficients are determined for each propeller:

- Propeller characteristics (geometry and hydrodynamic), pressure fluctuations measurements and associated noise calculations are placed in a database
- To calculate determine the noise of a given propeller, different measurements are extracted from the database: The user choose in the database the different propellers (i.e. choice of propeller parameters and volume velocity) he wants to take into account for the new calculation. Depending on the similarity of the new propeller with chosen propellers, weightings are given to each measurement selected. He may give a weighting coefficient to every measurement taken into account for the calculation regarding similarity between the characteristics of the new propeller and those of the propellers taken into account for the calculation, or attribute the same weighting to every propeller.

A calculation of new regression coefficients is then performed by the program. To obtain an accurate model, the database has to be as exhaustive as possible and enlarged each time measurements are carried out.

4 - RESULTS AND DISCUSSION

Different propeller noise predictions were carried out for cruise ships. A comparison between these predictions and the calculation of propeller noise established from pressure fluctuations is presented here for one of our cruise ship.

The elements to be compared are the following:

- Propeller noise calculation from pressure fluctuation measurements on the hull
- Use of the statistical model given in[1]: calculation with fixed regression coefficients
- Use of the statistical model: calculation with adapted regression coefficients

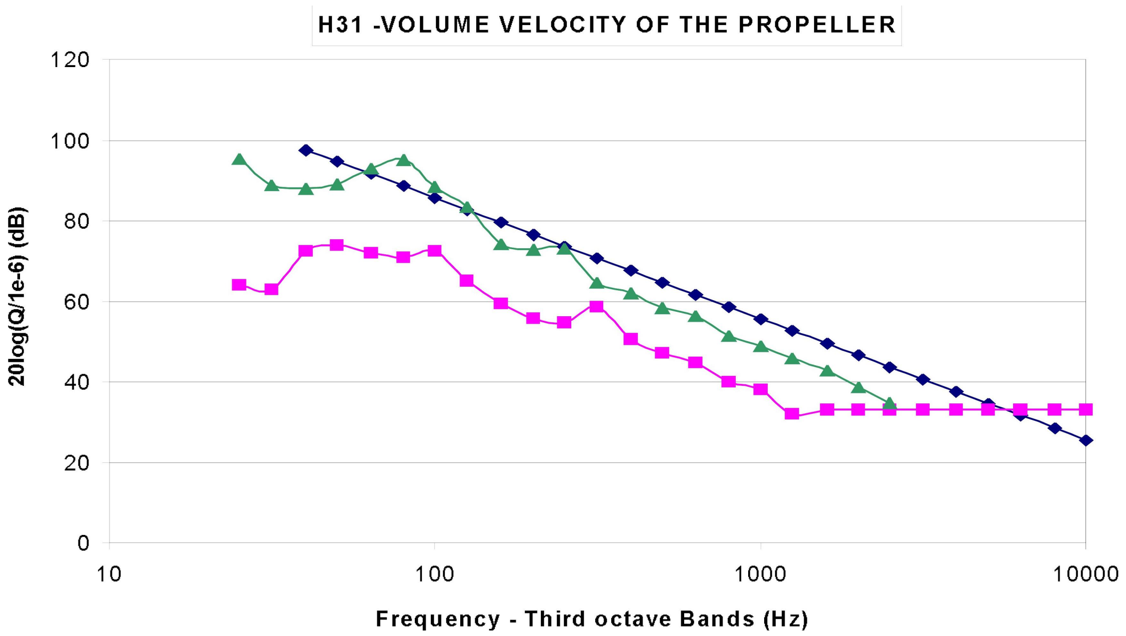

Figure 2: Comparison of calculations of volume velocity of a propeller.

- Gray: cavitation envelop;
- Pink: statistical calculation with fixed regression coefficients (see [1]);
- Green: calculation from pressure fluctuation measurements

The cavitation envelop is a bit higher than the measured volume velocity but gives a good estimation of it. The statistical calculation with fixed regression parameters underestimates the noise of this propeller.

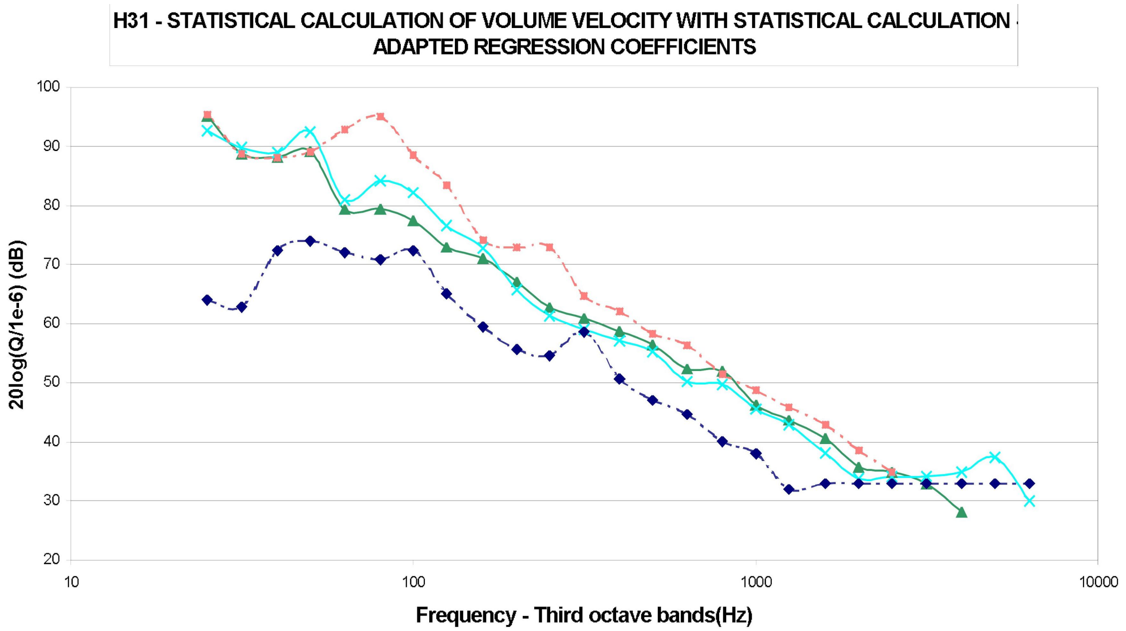

Figure 3: Comparison of calculations of volume velocity of a propeller; use of the new statistical calculation.

- Gray: statistical calculation with fixed regression coefficients

- Green: statistical calculation with adjustable regression coefficients:
  Choice of all propellers of the database and use of Similarity weighting coefficient: The software determines a similarity coefficient between various hydrodynamic and geometric coefficients of propellers chosen in the database and those of the new propeller
- Light blue: statistical calculation with adjustable regression coefficients:
  All propeller type: Choice of all propellers of the database and use of propeller type weighting: Every propeller chosen in the database has the same weighting coefficient (weighting inversely proportional to the number of measurements by propeller type)
- Light brown: calculation from pressure fluctuation measurements

The volume velocity determined from statistical calculation tends to underestimate the volume velocity of this propeller, however, it gives a good approximation of the propeller noise, and the estimations are better than the calculation carried out with the previous statistical model (fixed regression coefficients). The results will be even better when the database will be enlarged; which will enable to find out more easily a reliable criteria of choice of propellers in the database.

The model presented here tends to improve the semi-empirical statistical determination of volume velocity by adapting the regression coefficients to each new propeller. The comparison and correlation shown in this paper between this semi empirical model and the calculation carried out from pressure fluctuation measurements encourage the use and improvement of this method.

ACKNOWLEDGEMENTS

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