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Case Study for the Determination of Propeller Emitted Noise by Experimental and Computational Methods

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ABSTRACT

This paper shows the practical application of different methods to determine propeller noise during the design stage by experiments and computational methods.

Different aspects in the determination of propeller noise characteristics by model tests are shown. Therefore, cavitation tunnel tests are performed for different operating conditions of a propeller mounted behind a container vessel dummy model. The influence of changes in the hydrophone arrangement and the water properties are investigated. Special focus is given to the extrapolation of the experimental results to full-scale.

Besides of model tests numerical propulsion simulations with different CFD-codes are performed. The radiated propeller noise is thereby determined by the Ffowcs-Williams-and-Hawkings-Method. The computational setup is shown. Convergence studies are carried out, varying meshing and numerical parameters in order to check their influence on the acoustics. The numerical results are analysed, compared, discussed and extrapolated to full-scale propeller condition.

Full-scale measurements of a container vessel were carried out for validation. The results of cavitation tunnel tests and numerical simulations are finally compared with these full-scale measurements.

Keywords

Noise, cavitation tunnel experiments, full-scale experiments, CFD, Ffowcs-Williams-and-Hawkings-Method.

1 INTRODUCTION

The level of emitted underwater noise is strongly focused by international organisations and governments due to the rising demand of sea transportation and its impact to marine life (McCarthy (2001), Scott (2004)). Thus a broadband background noise between $100\,Hz$ and $300\,Hz$ is dominating oceans in northern hemisphere. This background noise is assumed to be the far-field "'acoustic waste"' of merchant ships. As the propeller is considered to be one of the major sources for underwater noise of merchant ships, the precise determination of frequencies and sound pressure levels becomes highly important. Consequently, propeller designs have to be evaluated according to their noise impact. A leading aspect of marine propeller noise emission is cavitational behaviour, as it is significantly affecting (pressure) fluctuations in the flow.

In the past, underwater noise was mainly related to navy, research or fishing aspects. For merchant vessels it was only considered when dealing with propeller singing or the comfort of the crew or passengers. For cruise, research and fishing vessels, there are minimum noise criteria defined by the classification societies, who classify them as a "silent" ship (e.g. see DNV, 2010). The noise limiting criteria in these rules are defined by a limiting curve over a frequency range which shall not be exceeded by the emitted sound pressure level (SPL). Usually the SPL is then measured in full-scale by a fixed procedure where the ship is passing a hydrophone with a defined speed. Obviously this procedure is perfect for trial testing, but cannot be used to evaluate the propeller noise during the design. Hence cavitation test procedures and numerical methods have to be developed in order to evaluate the radiated propeller noise directly during the design. Thus a design towards a less noisy propeller is possible.

In this paper, different experimental setups and two different CFD approaches are used to determine the SPL of the propeller of a container vessel (CV).

2 PROCEDURE FOR ANALYSIS AND SCALING OF NOISE

All recorded noise data in this paper are analysed according to the ITTC recommended procedures on model scale noise measurements (ITTC, 2014). Therein noise is referenced as the time varying pressure at a location, usually given as the root mean square:

$$p_{rms} = \sqrt{\frac{1}{T}\int_{-T/2}^{T/2} p(t)^2\, dt} \tag{1}$$

The sound pressure level as quantity of noise is described as logarithmic ratio of p_{rms} and a reference pressure $p_{ref} = 1\mu Pa$:

$$L_p = 10\log_{10}\left(\frac{p_{rms}^2}{p_{ref}^2}\right)\,[\mathrm{dB}] \tag{2}$$

Moreover the time domain signal is transformed into frequency domain using a Fourier Transformation in order to evaluate the SPL at certain frequencies. Additionally a filter can be applied to the stochastical narrow band noise to simplify comparisons. In this paper the 1/3-octave filter is used, in which the bandwidth is equal to 23 % of the centre frequency.

Furthermore background noise (from the running facility or test setup) has to be eliminated from the sound spectrum. Therefore additional noise measurements have to be performed by replacing the propeller with a dummy hub. The correction is based on the differences between both SPLs. If the difference is greater than $10\,dB$ no correction has to be performed, because the propeller noise dominates. If it is smaller than $3\,dB$ the background noise dominates the actual measurement and cannot be used. In between the following expression is used for corrections:

$$L_p'(f) = 10\log_{10}\left[10^{(L_p(f)/10)} - 10^{(L_{BN}(f)/10)}\right] \quad (3)$$

where L_{BN} is the SPL of the background noise measurement.

Additionally wall reflections due to the limited dimensions of the test section have to be eliminated. Therefore an acoustic calibration in a free-field environment is performed with a known sound source. The noise measured in the free-field and in the cavitation tunnel are compared and a transfer function is derived by:

$$L_{p,trans}(f) = L_{p,ff}(f) - L_{p,ct}(f) \quad (4)$$

where the Index ff refers for the free-field and the index ct to the cavitation tunnel SPL. The transfer function is applied to the L_p':

$$L_p''(f) = L_p'(f) + L_{p,trans}(f) \quad (5)$$

Noise levels are influenced by the distance between the observer and the source of noise. Therefore a distance normalisation is additionally applied for far-field noise. The L_p is corrected by the distance between noise source and observer d and a reference value, usually $d_{ref} = 1\,m$, with the following expression for spherical propagation (unrestricted, without boundaries):

$$L_{p,Sphere}''(f) = L_p''(f) + 20\log_{10}\left[\frac{d}{d_{ref}}\right] \quad (6)$$

For cylindrical propagation, which is applied for the cavitation tunnel or other volumes of restricted propagation, the distance normalisation is done by:

$$L_{p,Cyl}''(f) = L_p''(f) + 10\log_{10}\left[\frac{d}{d_{ref}}\right] \quad (7)$$

The noise emitted by the model has to be finally scaled to full-scale. The ITTC gives the following recommendation for the scaling of the L_p'':

$$L_s(f) = L_p''(f) + 20\log_{10}(corr) \quad (8)$$

with

$$\begin{aligned} corr = &\left(\frac{D_S}{D_M}\right)^z \left(\frac{r_M}{r_S}\right)^x \left(\frac{\sigma_S}{\sigma_M}\right)^{y/2} \\ &\cdot \left(\frac{n_S D_S}{n_M D_M}\right)^y \left(\frac{\rho_S}{\rho_M}\right)^{y/2} \end{aligned} \quad (9)$$

The exponents depend on the test setup and are proposed as $x = 1$, $y = 1 \ldots 2$ and $z = 1 \ldots 1.5$, see ITTC (1987). Additionally the frequency has to be shifted in order to correct the different rates of revolutions of propeller n and cavitation numbers σ between model and full-scale:

$$\frac{f_S}{f_M} = \frac{n_S}{n_M}\sqrt{\frac{\sigma_S}{\sigma_M}} \quad (10)$$

When comparing with $1\,Hz$ spectra, the noise has to be finally retransformed into equivalent $1\,Hz$ bandwidth using the following expression:

$$L_{s,1Hz}(f) = L_s(f) - 10\log_{10}(0.23 f_0) \quad (11)$$

3 CASE STUDY

As case study for the measurement and calculation of propeller borne noise a fixed pitch MMG Propeller was chosen. The propeller is designed for a $3600\,TEU$ container vessel. Main data for both, propeller and ship, are given in Table 1.

Table 1: Main data of propeller and ship

Propeller			
Diameter	D	[m]	7.75
Pitch ratio	P/D		0.97
Area ratio	A_E/A_R		0.73
Skew	Θ	[°]	37.9
Blades	z		5

3600 TEU Container Vessel			
Length between perpendiculars	L_{PP}	[m]	223.60
Breadth	B	[m]	32.20
Design draught	T_D	[m]	10.50
Draught for noise measurement	T	[m]	11.52

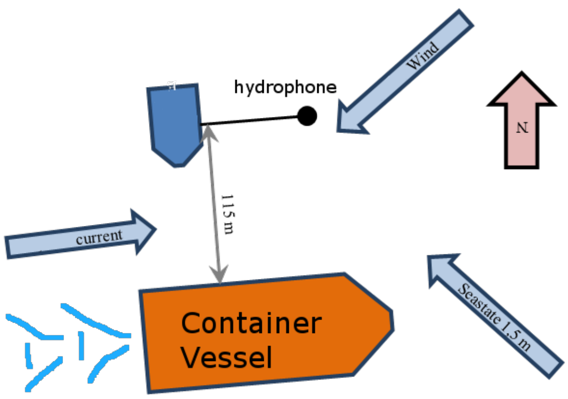

Figure 1: Arrangement of full-scale measurements

For validation purposes full-scale noise measurements have been performed by *DW-ShipConsult* in the English Channel in 2016 (Schuster, 2016). The noise of the propeller was measured with a hydrophone that was positioned next to a measuring assistance boat in a defined distance to the passing container vessel. During the noise measurement the number of propeller revolutions, speed over ground, wind speed, seastate and current were logged. A sketch of the test arrangement is shown in Figure 1. Table 2 gives a summary of the operating condition (OP) of the vessel during the measurement.

Table 2: Operating condition during full-scale measurements (FS)

Parameter		FS
Propeller revolutions	[rpm]	75
Speed over ground	[kn]	17.2
Speed through water	[kn]	14.9
Current	[kn]	2.3
Brake Power	[kW]	11960
Water depths	[m]	64

The measured noise is corrected by elimination of reflections of the sea ground and the free surface. The physical behaviour of the ground and the free-surface was also taken into account in this correction. Since the container vessel was passing the hydrophone, the recorded time domain signal was divided into three parts before transforming it to frequency domain. One part covers the arriving of the vessel, one the passing and one the departing of the CV. The results as given by *DW-ShipConsult* are shown in Figure 2. As can be seen the difference between them is rather small. In the following sections results of experiments and CFD are compared to the full-scale noise of the passing ship.

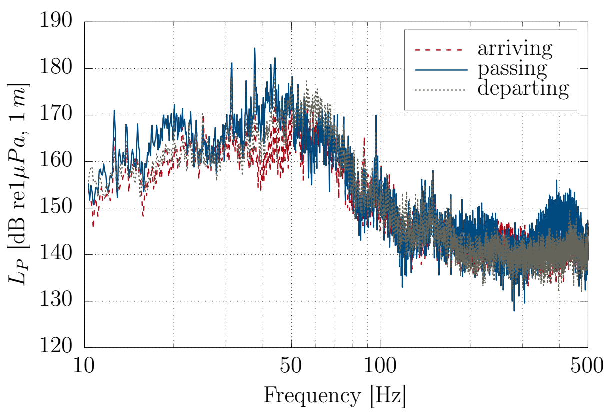

Figure 2: Measured sound pressure levels for a container vessel

4 CAVITATION TUNNEL MEASUREMENT

4.1 Test Arrangement

The measured full-scale noise is used as validation data for evaluation of cavitation tunnel tests at SVA.

The OP of the full-scale measurement does not correspond to the results of propulsion tests and trials. Therefore it is assumed that the rpm of the propeller is the most accurately measured parameter during full-scale measurements. Hence the speed and power of the vessel are corrected for the experiments according to propulsion tests. In Table 3 the propulsion condition for cavitation tunnel tests and CFD simulation are given. In model tests and RANS-simulations a scaling factor of $\lambda = 31$ is used, whereas BEM-simulations are done in full-scale.

Table 3: Corrected operating condition for experiments (EXP)

Parameter		EXP
Propeller revolutions	[rpm]	75
Speed	[kn]	17.2
Delivered Power	[kW]	10560
Thrust coefficient		0.1851
Cavitation number		3.83

The cavitation observation and narrow band noise measurements are performed in the large test section of SVA's cavitation tunnel. A dummy model was used together with additional wake screens in order to reproduce the nominal wake field of the full scale ship, see Heinke (2003) for more information on the procedure. The arrangement of propeller and rudder is similar to the full-scale ship. ITTC (2014) recommend different arrangements of hydrophones for noise measurements. In total four hydrophones are placed on the test arrangement to measure the noise:

- *hy1* is mounted on the dummy model directly above the propeller,
- *hy2* is arranged in a decoupled water box,
- *hy3* is arranged along the direction of flow
- and *hy4* is arranged transversely to direction of flow.

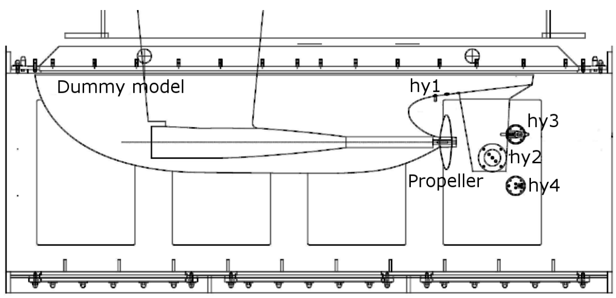

Figure 3: Test setup and hydrophone arrangement for noise measurements

Figure 3 shows a sketch of the overall test arrangement. The cavitation test is run under cavitation number and thrust coefficient identity. The noise measurements have been additionally performed at two different levels of oxygen content ($\alpha/\alpha_S = 40\%$ and 60%) in the cavitation tunnel.

4.2 Results

The measured noise is scaled according to the procedure briefly explained in section 2. The narrow band data is transformed to 1/3-octave band. Additionally the noise is filtered regarding background noise and limited dimensions of cavitation tunnel, following formula (3) and (4).

4.2.1 Spherical Distance Normalisation

The spherical distance normalisation is the recommended procedure by the ITTC for noise measurements (ITTC, 2014), as given in formula (6). Furthermore for the scaling of SPL and frequency the formula (8) and (10) are used. The exponents of correction terms in (9) are chosen as $x = 1$, $y = 2$ and $z = 1.5$. Due to the exponent of $y = 2$ the tip speed scaling is similar to the methods of scaling pressure fluctuations. The exponent x is used for a distance correction, which was already done by the distance normalisation. Hence exponent z is used to trigger the geometric scaling towards the full-scale noise. At the end the 1/3-octave band is retransformed to equivalent $1\,Hz$ band for a better comparison to the results with the narrow band full-scale noise results.

Figure 4 shows the scaled noise measured with all four hydrophones compared with the full-scale measurement in the English Channel. As can be seen there are large differences in SPL between the four hydrophones. While *hy1* (mounted above the propeller) is within the range of the full-scale measurement, the scaled SPL of *hy2* (decoupled water box) underpredicts the full-scale measurements. This also applies for *hy3* and *hy4* (arranged in the flow). The recorded scaled SPL-levels of them are also below the full-scale measurement.

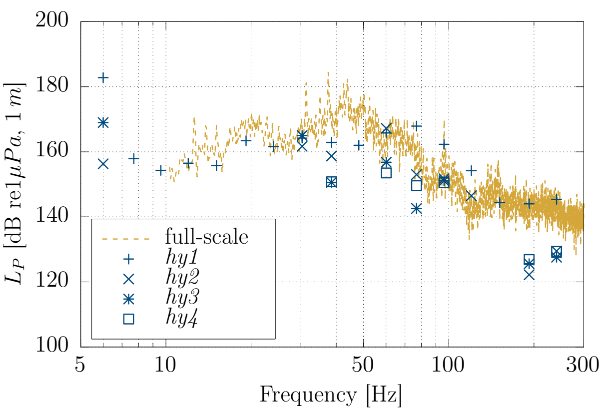

Figure 4: Comparison of full-scale and scaled cavitation tunnel noise measurements as equivalent $1\,Hz$ spectra with $\frac{\alpha}{\alpha_S} = 40\%$ oxygen content, spherical distance normalisation

The tests have been performed at an oxygen content of $\frac{\alpha}{\alpha_S} = 40\%$ and 60% in the cavitation tunnel. The differences between the recorded SPL for both gas contents are rather small. Comparing both tests, the measurements with higher gas content record a smaller SPL over the frequency range, especially when looking on the results of *hy2*, *hy3* and *hy4* (mounted on the cavitation tunnel wall). Due to the higher gas content there are more bubbles in the flow. Hence the noise propagation through the water is more disturbed. Figure 5 shows the scaled results of *hy1* for both examined gas contents. As can been seen the difference is within $3\,dB$, which is due to the small distance between hydrophone and propeller (noise source).

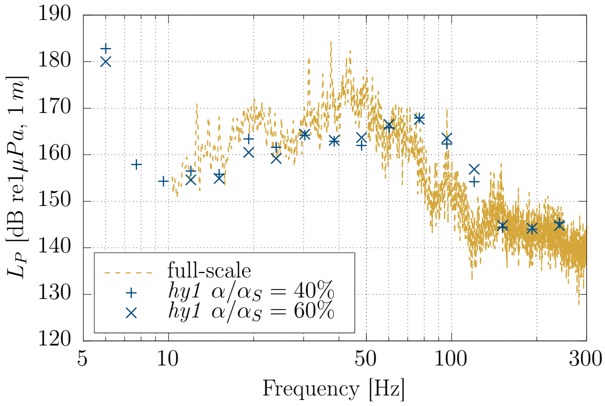

Figure 5: Comparison of full-scale and scaled cavitation tunnel noise measurements as equivalent $1\,Hz$ spectra for *hy1*, spherical distance normalisation

4.2.2 Cylindrical Distance Normalisation

The spherical distance normalisation is usually applied to noise measured in a certain distance. Obviously this is not the case in the restricted environment of a cavitation tunnel. Additionally for using the spherical distance normalisation the exponents of ITTC scaling have to be triggered in order to derive an appropriate result. Therefore the analysis are repeated using a cylindrical distance normalisation as given in formula (7). Due to the limitations of the cavitation tunnel dimensions this might be a more suitable approach. The normalised SPL is in the following again scaled by formulae (8) and (10) to full-scale, but using $x = 1$, $y = 2$ and $z = 1$ as correction exponents (no influence).

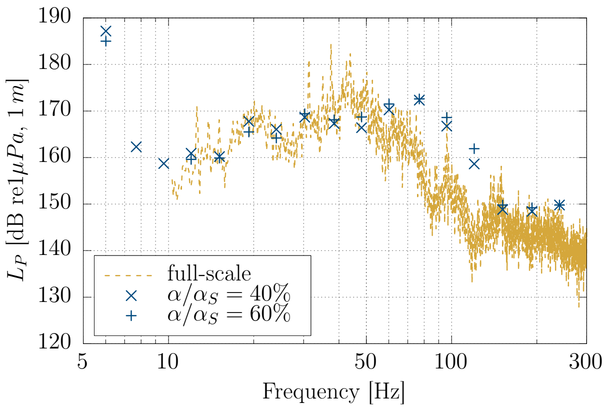

Figure 6: Comparison of full-scale and scaled cavitation tunnel noise measurements as equivalent $1\,Hz$ spectra for *hy1*, cylindrical distance normalisation

Figure 6 shows the SPL as equivalent $1\,Hz$ band for the *hy1*. As already shown for the spherical normalisation the scaled results of the cavitation test fits good with the measured full-scale SPL. Only for frequencies ranging from $70 - 120\,Hz$ the SPL is overpredicted.

Since the scaled measurements with cylindrical distance normalisation do not have to be corrected by triggering the noise scaling exponents x, y and z this procedure is suggested to be used when scaling model data to full-scale SPLs.

4.2.3 Cavitation Phenomena

For the designated propulsion point intermittent tip vortex and suction side sheet cavitation in the angle range $0° < \theta < 60°$ appears. Intermittent tip vortex cavitation behind the propeller blade tip has been observed in the angle range $70° < \theta < 120°$. Figure 7 shows sketches of the cavitation. An angle of $\theta = 0°$ refers to the 12 o'clock position.

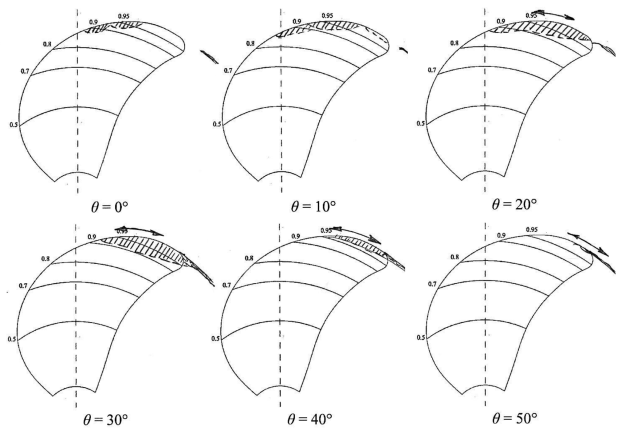

Figure 7: Sheet cavitation on propeller at different blade positions

5 CFD-SIMULATION

Besides the cavitation tunnel test, CFD-simulations are performed in order to calculate the propeller radiated noise. It is essential to be able to evaluate the design according to noise levels directly in the design process. Therefore two different CFD-approaches to estimate propeller noise emissions are shown in the next sections.

5.1 BEM-Simulation

5.1.1 Setup

CFD computations of emitted propeller noise using the BEM-method *pan*MARE are carried out. *pan*MARE is a panel method developed by TUHH (for details see e.g. Berger et al. (2016)). For the simulation the propeller is represented in full-scale. Besides the propeller a flat plate above the propeller simplifying the ship hull is implemented. As the wakefield cannot be reproduced precisely without taking viscous effects into account, it is considered via an external field of velocity derived by model test which is imported close to the propeller plane (see Figure 8). The timestep size is mainly influenced by the stability of cavitation simulation and chosen to $2/3 \cdot 10^{-2}\,s$, which corresponds to a turning angle of $\theta = 3°$ per timestep. In total five revolutions of the propeller were simulated.

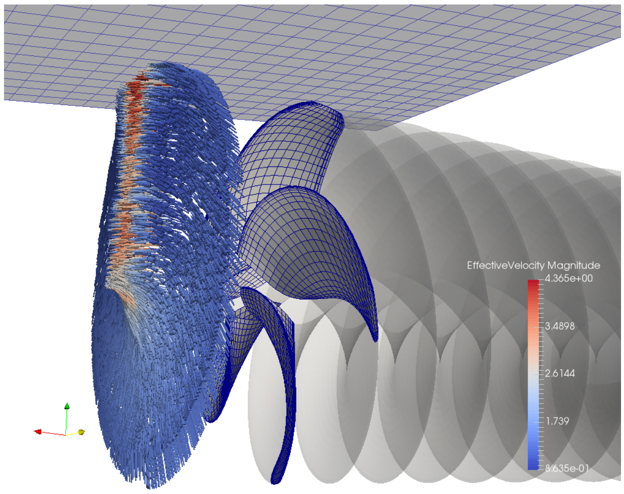

Figure 8: Setup of *pan*MARE simulation

The noise is calculated using the Ffowcs-Williams-and-Hawkings equation according to Göttsche et al. (2017). For recording noise levels, different observers were placed in the simulation domain. They record the noise emitted from the solid boundary of the propeller. When cavitation occurs, the surface of the cavitation bubble is used. One observer was positioned according to cavitation tunnel test *hy1* in the near-field above the propeller. Additional observers were positioned in the far-field along the imagined way of the passing hydrophone according to full-scale measurements. For the analysis results of the observer positioned perpendicular to ship longitudinal axis are used. This position is comparable to the hydrophone of full-scale measurement in closest distance to the passing CV. The number of revolutions of the propeller and the inflow velocity into the computational domain are chosen for the same full-scale propulsion point as given in Table 3.

5.1.2 Cavitation Phenomena

As basis for noise prediction, precise cavitation simulation is assumed to be crucial because high pressure fluctuations are caused by cavitation. As cavitation commonly occurs on merchant vessels in typical operating conditions, noise simulations depend on accurate calculation of cavitation effects.

The characteristic of the cavitation behaviour of the simulated propeller is well predicted. The composition and decomposition of cavitation areas during the blade passage through the wake peak is recomputed also in its extents. In Figure 9 the simulated extent of cavitation is compared with extent of cavitation measured at SVA cavitation tunnel. Cavitation computed with BEM method is marked red. The figure is underlain by measured cavitation extents in black color.

5.1.3 Results

The simulations with BEM-code *pan*MARE were done in full-scale. Hence no scaling has to be applied. Anyhow the calculated sound pressures have to be transformed to the 1/3-octave and equivalent $1\,Hz$ band. Furthermore a distance normalisation has to be taken into account. For different points in the simulation domain, different types of distance normalisation have to be conducted. According to model test normalisation, spherical normalisation is appropriate for near-field observers, whereas cylindrical normalisation seems to be reasonable for far-field observers in restricted flow regimes. The results of comparison between full-scale measurements, cavitation tunnel measurements and BEM-based simulation with spherical normalisation are shown in Figure 10 and Figure 11.

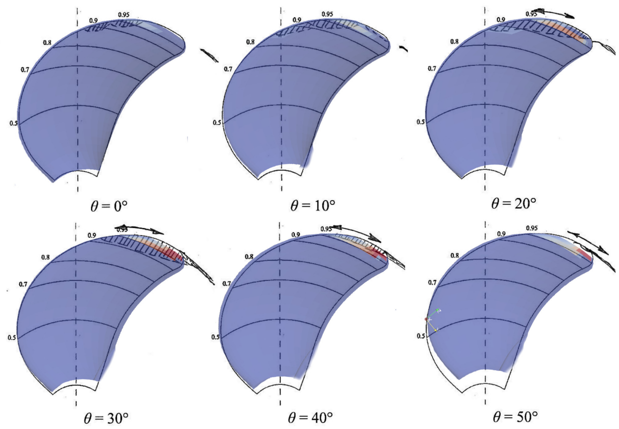

Figure 9: Comparison *pan*MARE calculated and SVA measured results of cavitation during blade passage

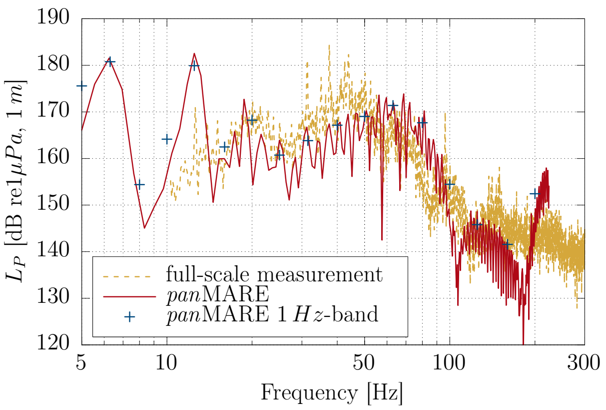

Figure 10: Comparison of full-scale and far-field noise recorded with *pan*MARE

It can be seen, that the curve progression of sound level measured in full-scale can be reproduced qualitatively well by BEM calculations. Further the quantitative accordance of simulation results with full-scale measurements is very satisfactory as well. Small deviations in sound pressure level can be found in the area around 50Hz. In this area additional noise sources besides the propeller may have significant influence on full-scale measurements. Especially sound peaks in the measurements cannot be recalculated in BEM-simulations. High sound pressure peaks are calculated for the 1^{st} harmonic of blade frequency at $6.25\,Hz$ and the 2^{nd} harmonic of blade frequency at $12.5\,Hz$. For the far-field simulation the SPL at the 2^{nd} harmonic of blade frequency is overpredicted by calculation.

Altogether a very good accordance of full-scale measurements, cavitation tunnel tests and BEM-simulation is achieved.

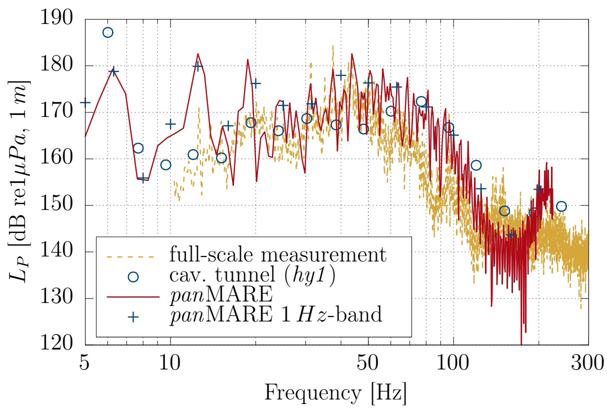

Figure 11: Comparison of full-scale and SVA *hy1* results with near-field noise recorded with *pan*MARE

5.2 RANS-Simulation

Preliminary RANS-calculations are performed in addition to the BEM-simulations.

5.2.1 Setup

For the RANS-Simulation the open-source-code *open-FOAM* (OF) (OpenCFD, 2017) is used. The propulsion is performed as a double body simulation neglecting the free-water-surface. The ship and propeller are simulated in model-scale. For recording of noise the Ffowcs-Williams-and-Hawkings-Method was implemented into OF by Krüger and Kornev (2015). During the simulation an observer recording the propeller noise is placed at the scaled distance of the full-scale measurement (far-field). An additional observer is placed at the same position as *hy1* of the cavitation tunnel test. Figure 12 shows the computational domain for the CFD simulation, marking also the position of the noise observer. Within the implemented Method, during the simulation run the pressure fluctuations are logged and finally converted into frequency domain using a Fourier-Transformation.

For the given case study in total three different meshes are used. They consist of tetrahedron cells and vary between 2.7 and 12.5 million cells. In all meshes the boundary layer along the ship-model and the propeller is built with prism-layers, having a non-dimensional wall distance of $30 < y^+ < 100$ next to the wall. For turbulence modeling the kΩ-SST-model is used. Simulations are performed with the solver *pimpleDyMFoam*, neglecting cavitation effects.

The timestep is arranged by keeping the courant number constant, which results in a timestep of $\approx 1 \cdot 10^{-4}\,s$. Therefore the noise is captured only for six propeller rotations, in order to safe computational efforts. In the simulation the propeller is rotating with fixed rpm using OFs sliding grid interface. Figure 13 shows an example of the coarse mesh in the aft part of the ship including the rotating propeller domain. The propeller is run at the same thrust as in the full-scale propulsion point written in Table 3. Convergence of propeller thrust and torque is already reached with a medium size mesh of 4.7 million cells. Therefore only results from medium size mesh are shown in the following.

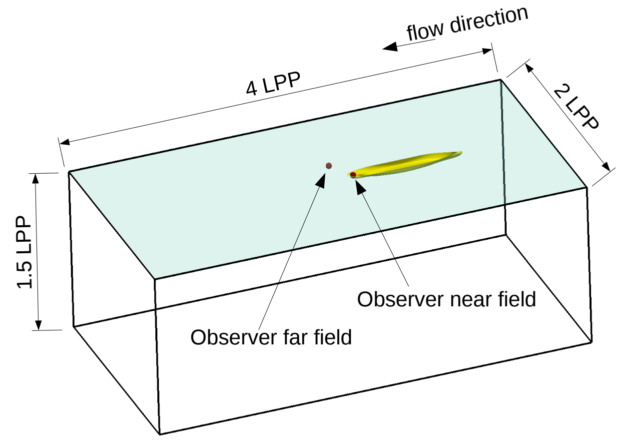

Figure 12: Computational domain for CFD-simulation of propeller induced noise

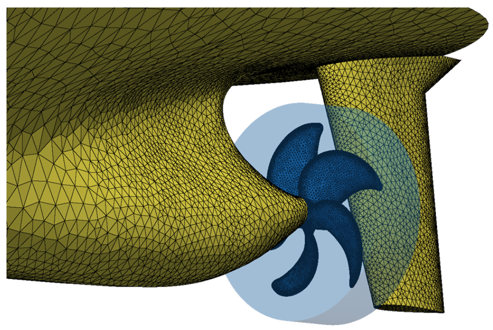

Figure 13: Example tetrahedron mesh at the aft part of ship

5.2.2 Results

Noise in the RANS-simulation is similar to the cavitation tunnel experiments recorded for model-scale, so it follows the same procedure as written in section 2 for scaling to full-scale. Of course it is neglected the background noise (formula (3)) and free-field (formula (4)) correction. Anyhow for the RANS result also the question arises on how to perform the distance normalisation. Therefore both spherical and cylindrical approach for distance normalisation are performed when post-processing the results of the RANS-simulation without cavitation modeling. The scaling is performed analog to the cavitation tunnel measurements using formula (9) with exponents $x = 1$, $y = 2$ and $z = 1$.

Figure 14 shows the different scaled SPLs. Labels with the ending "cyl." refer to cylindrical distance normalisation using formula (7), the ending "sphere" refers to spherical distance normalisation using formula (6). Results are plotted for the far-field observer and the near-field observer. As can be seen for the spherical distance normalisation the recorded noise of far- and near-field observers is almost normalised to the same SPL, while using cylindrical distance normalisation the difference in SPL between both observers is large. Contrary to the restricted environment of the cavitation tunnel in the RANS simulation the spherical distance normalisation has to be used, even for observers in restricted volumes directly above the propeller.

Figure 14 compares also the RANS-results with the measured full-scale SPL. It can be seen that the RANS-calculation deviates from the full-scale measurements: While the SPL from full-scale measurement has humps and hollows, the SPL of the RANS-Simulation is continuously decreasing with increasing frequencies. The RANS-simulation overpredicts the measured SPL in the frequency range, even though cavitation is not modeled in the RANS calculation.

Additional computations have to be performed in order to investigate the differences in the result of the RANS simulation compared to the measurements. The influence of numerical parameters, like e.g. numerical schemes and timestep have to be checked. Furthermore the computation have to be repeated with cavitation modeling. This will be future research work. The missing cavitation effects could be the reason for the smooth trend of the noise over the frequency range. It has to be additionally noticed that blade frequencies above 2^{nd} order are not visible in the narrow band.

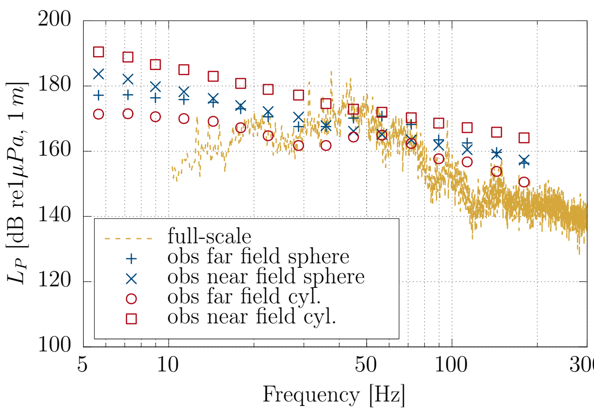

Figure 14: Comparison of full-scale and scaled noise from RANS simulation without cavitation modeling

CONCLUSIONS

This paper shows different experimental and computational approaches for determination of noise radiated by marine propellers. The results are compared with full-scale measurements. Therefore special focus is given on the scaling procedure.

Cavitation tunnel tests are performed measuring the noise with four hydrophones mounted in different positions. It is shown, that the hydrophone mounted above the propeller delivers the best result compared with full-scale measurements. The SPL of the full-scale measurement could be soundly reproduced by the experimental setup. Hydrophones mounted on the cavitation tunnel walls directly in the flow or in a decoupled water box are more effected by background noise and oxygen content. It has to be concluded, that a cylindrical distance normalisation should be used, since no correction with the exponents is necessary for scaling.

Two CFD-approaches are performed in order to calculate the noise emission of the propeller. In both cases the Ffowcs-Williams-and-Hawkings-Method is used for noise calculation.

Preliminary tests for noise propagation with RANS-Methods are performed using *OpenFOAM* to simulate the propeller in model-scale without cavitation. It is shown that for the RANS-simulation a spherical distance normalisation has to be used before scaling to full-scale. In the simulation differences in SPL to the full-scale measurement occur. Even though cavitation is not considered the noise is overpredicted. Therefore the RANS simulation has to be further improved. Cavitation is to be considered in the future. Also the numerical schemes and timestep dependency has to be investigated more deeply. This will be realized in further research activities.

The BEM-Solver *pan*MARE simulates the propeller in full-scale with cavitation. Thereby the cavitation phenomena is similar to the cavitation tunnel tests. Furthermore it is shown, that the measurements are well reproduced using a spherical distance normalisation for a far-field as well as for a near-field observer. The BEM-Solver is neglecting reflections of noise by the rudder and hull. The effect of appendages on the emitted noise has to be further evaluated.

To summarize the full-scale measured noise of a container vessel could be soundly reproduced experimentally by cavitation tunnel tests and numerically by using the BEM-solver *pan*MARE.

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