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Experimental Study on the Reduction of Underwater Radiated Noise from Propeller Cavitation of Commercial Vessel

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Abstract: This study aims to estimate a possible reduction of Underwater Radiated Noise (URN) by the modification of propeller design and the introduction of a flow control device for Aframax tanker. The measurements of URN have been performed at cavitation tunnels of two institutes, SSMB and KRISO. The source level decreased over the whole frequency range with the low noise propeller and flow control fins under the normal operation condition with 85% main engine load. The change of propeller geometry led to more effective reduction in the low frequency region corresponding to the blade passing frequency. The amount of noise reduction by flow control fins is more evenly distributed over the tested frequency range and smaller than the gap by the propeller change. In contrast, the frequency range of noise reduction of both applications was concentrated in a specific region around 1kHz in model scale and 100Hz in full scale under the quiet cruise condition. More than 10dB noise reduction is accompanied by a propulsive efficiency loss, and the re-designed propeller is a better solution considering the amount of noise control level and the resultant propulsion efficiency.

Keywords: Underwater Radiated Noise; Cavitation; Propeller; Wake Control Device

1. Introduction

The underwater radiated noise (URN) from commercial ships has become an important issue because it is a major source of noise that harms the marine environment, especially marine mammals. Ship design for a lower noise emission is one of the important countermeasures. The main question is feasible design methods and possible amount of noise reduction at a frequency band interested. Sakamoto and Kamiirisa [1] investigated the noise reduction effect of a high skewed propeller, and Lee et al. [2] reported the installation of propeller cap fins during ship retrofit could reduce URN level based on full-scale URN measurements. Hallander et al. [3] also found the most favorable operation condition of controllable pitch propeller for cavitation noise reduction from systematic model tests in cavitation tunnel. In this research, the flow control fins and the propeller designed to suppress cavitation on the blade were introduced to decrease URN level. The URN levels of these design applications were compared by the noise measurements at the cavitation tunnel of Samsung Ship Model Basin(SSMB) and Korea Research Institute of Ships & Ocean Engineering(KRISO). The noise measurement results with the re-designed fins and propeller showed promising effect on URN reduction.

2. Test method and design configurations

The noise measuring system consists of 3 hydrophones in SSMB and 45-channel hydrophone array in KRISO as shown in Figure 1. The measured sound pressure level, L_p in formula (1) was transformed to a

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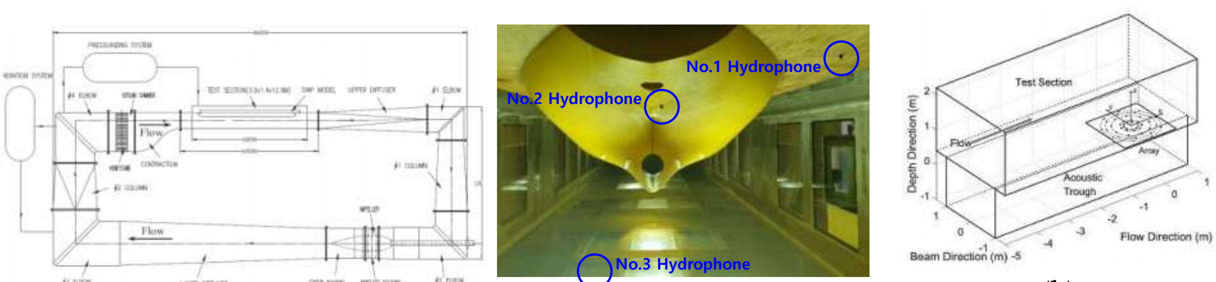
source level, L_s at the reference distance 1m as described in Park et al. [4] following the ITTC's guideline [5]. The transfer function of each cavitation tunnel was measured with a known source and considered as the formula (2). The 'low frequency scaling method' of ITTC [5] was used as the formula (3), and *f*/*n*/*D*/*Re* means frequency/propeller rotational speed/diameter/Reynolds number ($Re=\pi n D^2/\nu$) respectively with subscripts '*m*' for model scale and '*s*' for full-ship scale. The exponent *k* is defined as 0.0 for the transit condition of the normal operating condition with 85% engine load, and 0.3 in SSMB and 0.4 in KRISO for the quiet cruise condition with a reduced ship speed.

Two model propellers were used in the comparison test in SSMB. Propeller A is a baseline design, and propeller B has a larger blade area and higher skew angle in order to decrease the cavitation and resultant radiated noise. The radial distribution of pitch and camber is also adjusted in the propeller B for a noise control. The tested model ship has two sets of flow control fins optimized to have the highest propulsive efficiency with an endurable cavitation level. This is a baseline design denoted as 'Fin A', and the new arrangement of flow control fins was chosen to make a more homogeneous wake field into a propeller. This design denoted as 'Fin B' is one set of fins both in port and starboard side having higher angle of attack to the streamline in front of fins as described in Table 2.

$$L_p = 10log_{10}\left(\frac{p^2}{p_{ref}^2}\right), \tag{1}$$

$$L'_p = 10log_{10}\left[10^{(L_{ps+n}/10)} - 10^{(L_{pn}/10)}\right], \qquad L_s = L'_p + TF = L'_p - 10log_{10}\left(\frac{p_r^2}{p_i^2}\right) \tag{2}$$

$$\frac{f_s}{f_m} = \frac{n_s}{n_m}\left(\frac{Re_s}{Re_m}\right)^{0.5k}, \qquad \Delta L_s = 10log_{10}\left[\left(\frac{n_s D_s}{n_m D_m}\right)^3\left(\frac{D_s}{D_m}\right)^3\left(\frac{Re_s}{Re_m}\right)^{1.5k}\right] \tag{3}$$



(**a**) (**b**)

Figure 1. The configurations of cavitation tunnel and noise measuring system: (**a**) cavitation tunnel of SSMB (left) and location of hydrophones (right); (**b**) hydrophone arrays in cavitation tunnel of KRISO

Table 1. Principal dimensions for tested propellers

	Model Diameter	Number of Blades	Expanded Area Ratio	Pitch Ratio at 0.7R	Skew Angle	Propulsive Efficiency
Propeller A	245.0mm	4	0.463	0.812	22.0˚	Base
Propeller B	245.0mm	4	0.606	0.804	32.5˚	-3%

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Table 2. Specification on the arrangement of flow control fins

Fin A : 1st Fin 10° / 2nd Fin 10°	Fin B : 1st Fin 30° (1st fin only)
Propulsive Efficiency : Base	Propulsive Efficiency : -4%

3. Analysis of test results and conclusion

The comparison on noise levels was performed according to the test conditions described in Table 3. The developed sheet cavitation with strong tip vortex was observed at the propeller blade of the design baseline (Propeller A with Fin A) under the transit condition. Similar but reduced strength of cavitation occurred when Fin B was applied, and intermittent and small sheet cavitation occurred when the baseline propeller was replaced with Propeller B. No cavity was observed when new fins or new propeller were applied under the quite cruise condition.

The scaled source levels of SSMB and KRISO are similar as shown in Figure 3, and this corresponds to the identical cavity patterns in the test results of both institutes. The patterns of noise reduction with Fin B are little bit different but both test results show 3-10dB of decrease from 10Hz to 1kHz. As presented in Figure 4, Propeller B made larger decrease of noise level than that of Fin B over the entire range in the transit condition. This deviation was especially increased in the low frequency band corresponding to the blade passing frequency. In contrast, the reduction was concentrated on the region near 100Hz in the quiet cruise condition both in propeller and fin cases. However, this could play an important role by lowering a hump peak of spectrum related with the propeller tip vortex cavitation.

Table 3. Test conditions

	Transit (85% engine load)			Quiet Cruise (22% engine load)		
	Prop. A + Fin A	Prop. A + Fin B	Prop. B + Fin A	Prop. A + Fin A	Prop. A + Fin B	Prop. B + Fin A
[1]$\boldsymbol{K_T}$	0.173	0.170	0.175	0.162	0.159	0.165
[2]$\boldsymbol{\sigma_{n0.7R}}$	2.377	2.342	2.337	5.626	5.547	5.505

[1] $K_T = \rho n^2 D^4$, [2] $\sigma_{n0.7R} = (p - p_v)/(0.5\rho n^2 D^2)$ at 70% radius higher than propeller shaft center

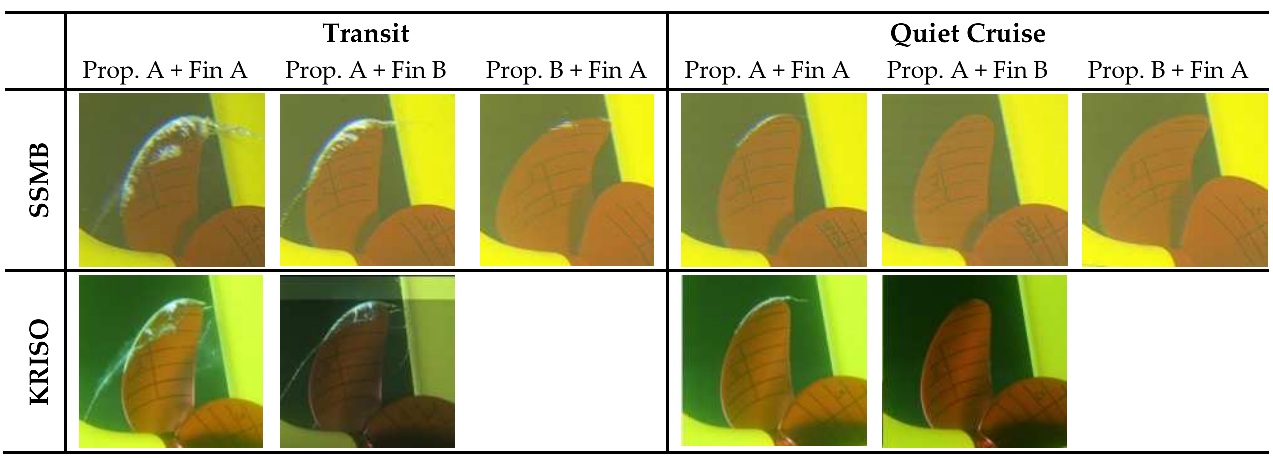

Figure 2. The cavity observation on the propeller at blade angle of 30º at each test condition

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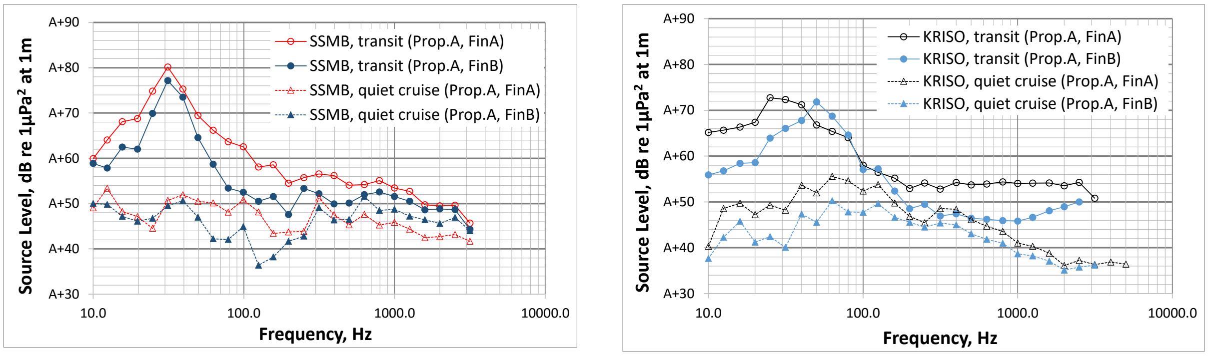
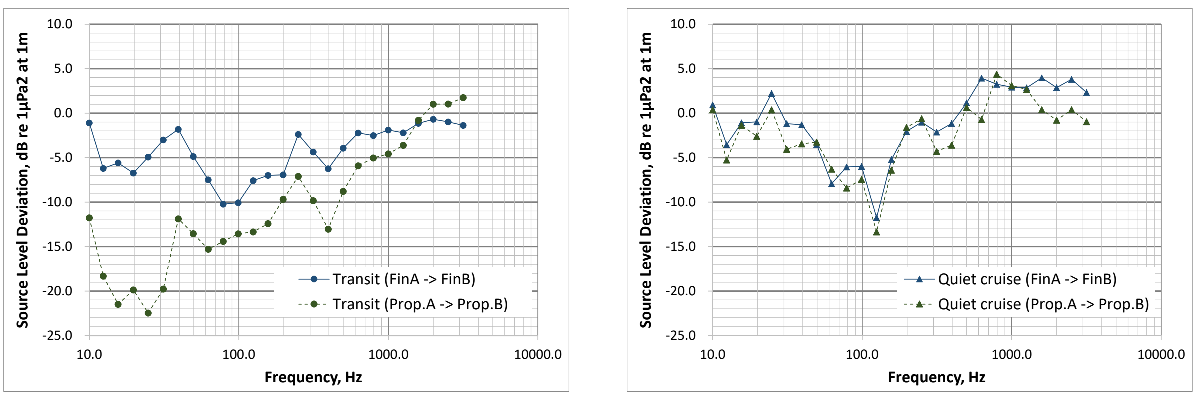


(a) (b)

Figure 3. 1/3 octave band level of propeller noise source; (a) comparison test result of fin designs at SSMB (b) comparison test result of fin designs at KRISO



(a) (b)

Figure 4. Noise reduction by fins and propeller; (**a**) Transit condition; (**b**) Quiet cruise condition

The large amount of noise reduction up to 20dB has been achieved and this costs a decrease of propulsive efficiency specified in Table 1 and 2 based on a numerical simulation. A propeller re-design is recommended as more effective method of URN reduction causing a smaller loss of propulsion efficiency.

References

1. Sakamoto, N.; Kamiirisa, H. Prediction of near field propeller cavitation noise by viscous CFD with semi-empirical approach and its validation in model and full scale. *Ocean Engineering* **2018**, *168*, pp.41-59
2. Lee, B.K. et al.; Underwater noise comparison of pre- and post-retrofitted MAERSK G-class container vessels. Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, **2017**, report no. MPL TM-616
3. Hallander, J.; Karlsson, R. and Johansson, T. Assessment of underwater radiated noise, cavitation and fuel efficiency for a chemical tanker, Proceedings of OCEANS'15, Genova, Italy, 2015
4. Park, C. et al. A validation study of the model test method for propeller cavitation noise prediction. *Ocean Engineering* **2020**, *213*, 107655
5. ITTC, 2017. Model Scale Noise Measurements, Recommended Procedures and Guidelines, 7.5-02-01-0

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