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Numerical and experimental propeller noise investigations

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ABSTRACT

The standard propeller has been investigated in model scale, using medium size cavitation tunnel. The hydroacoustic characteristics of propellers under different loading conditions have been investigated. Additionally the presented experimental results have been used for the verification of applied numerical approach. During both numerical and experimental analyses non-uniform inflow propeller's conditions have been adapted. Good correlations of both kinds of results have been noticed and highlighted.

1. Introduction

Nowadays the ship and offshore structure designers must consider both economical and environmental aspects during design process. The environmental aspects should also relate to the radiated underwater noise. Fortunately the understanding of underwater noise mechanisms has increased significantly during recent years for both shallow (Kozaczka and Grelowska, 2013; Grelowska et al., 2013) and deep water systems (Carlton, 2007; Ross, 1976). Although the importance of hydroacoustic phenomena seems to be widely recognized the increase of awareness of ship operators and designers on noise impact on the environment makes that topic still a matter of concern. One of the biggest latest European initiative aiming on better understanding of noise impacts on the marine environment is the AQUO project (〈http://www.aquo.eu/〉). The main objectives of that projects are: better understanding of noise emissions generated by the ship as well as providing improved and validated methods of prediction of noise radiated from operating propeller. Additionally huge number of research and commercial institutes are carrying out their own research programs on that subject.

The Specialist Committee on Hydrodynamic Noise 〈http://www.ittc2014.dk/〉 defines three major classes of underwater noise emissions from vessels:

1. Machinery noise,
2. Propeller noise,
3. Hydrodynamic noise.

The report closing work of the has ITTC Committee have reviewed the current literature related to the underwater noise researches. Based on that work the propulsion system and cavitating propeller are highilighted as the most significant noise sources. The source of noise emissions radiated by a non-cavitating propeller are the vibrations caused by the fluctuations of hydrodynamic forces acting on the propeller (Briancon et al., 2013). The hydrodynamic loadings concern both discrete frequency (tonal) and continuous spectrum (broadband). Generally speaking the blade frequencies correspond to the discrete frequency and the flow fluctuation around the propeller blade to continuous spectrum correspond. The paper of Seol et al. (2005) includes numerical study of non-cavitating and cavitating (blade sheet cavitation) noises of underwater propeller. The flow field is analyzed using potential based panel method. Pressure and sheet cavity fluctuations are used for the Ffowcs Williams–Hawkings formulation to predict far-field noise. Authors confirmed that the cavitating noise is the most prevalent source of underwater noise. Among the various types of cavitation the unsteady sheet cavitation on the suction surface has be depicted as the loudest source of the noise. Sheet cavitation generates noise from 5 Hz to 10 kHz. The fluctuations of large bubble of sheet cavitation are responsible for the low frequency range. High frequency noise is generated by sheet cavity collapse or by shock wave generation.

The aim of current work is to check the application of a medium size cavitation tunnel to the propeller noise measurements and extrapolation of obtained results to full scale data. Since there is a lack of full scale data there is still a need to use validated numerical tools to better understand the full scale effect. This paper intends to demonstrate the applicability of model scale approach to accurate noise prediction. Since numerical investigations on high frequency continuous spectrum are not taken into account in that paper only tonal and low frequency continuous

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spectrum will be analyzed. Two different loading conditions have been taken into account. The model testing investigations are complemented by the numerical simulations.

2. Model scale approach

The best option for every propeller designer is to be able to provide and validate the product by the use of real measurements. This means that the full scale propeller should be delivered and tested. Unfortunately such as approach is not justified from the economical point of view. Instead, different modeling approaches are used. Interaction of operating propeller with the hull can be investigated with the use of large cavitation tunnels where the entire hull model is employed. The alternative to such kind of research is the application of medium size cavitation tunnels. In that case it is possible to use the model of the propeller in appropriate scale where the inflow boundary conditions are simulated by the use of "dummy body". Both the time and cost of the tests can be significantly reduced by the application of medium size cavitation tunnels. The point is to use appropriate methodology to extrapolate the obtained results to full scale. Based on the work of Briancon et al. (2013) and the ITTC report ⟨http://www.http:/ittc.info/⟩ some basic criteria of similarity, that should be listed and checked to perform experimental and numerical analysis of hydroacoustic phenomena, may be defined. In order to be able to carry out correct and accurate model scale tests, three base similarity rules should be employed: geometric, kinematic and dynamic similarities.

Geometric similarity means that both model and real shapes are similar. It is done by application of the scale factor which is defined as a ratio of main dimensions of both geometries.

Kinematic similarity defines the modeling time of investigated phenomena. Fulfilling the kinematic similarity means to ensure similar time rates of flow motions or flow changes.

Dynamic similarity defines the similarity of all forces acting on model and real geometry, which should be proportional.

According to propeller investigations following non-dimensional parameters should be defined:

– **geometric similarity** : $$\lambda=\frac{D_S}{D_M} \tag{1}$$

where λ=scale factor; D_S= propeller diameter at full scale [m]; and D_M=propeller diameter at model scale [m],

– **kinematic similarity** : $$J=\frac{V_a}{nD} \tag{2}$$

where J=advance ratio; D=propeller diameter [m], V_a=advance velocity [m/s], and n=rotational speed [rps];

– **dynamic similarity**:

$$Fn=\frac{V}{\sqrt{gL}} \tag{3}$$

where Fn=Froude number; V= ship speed [m/s], g=gravitational acceleration [m^2/s], and L=ship length [m];

$$K_t=\frac{T}{\rho_0 n^2 D^4} \tag{4}$$

where K_t=thrust coefficient; T= propeller thrust [N], ρ_0=water density [kg/m^3];

$$K_q=\frac{Q}{\rho_0 n^2 D^5} \tag{5}$$

where K_q=torque coefficient; Q=propeller torque [Nm];

$$\sigma=\frac{p_{atm}-p_n+\rho_0 gh}{0.5\rho_0 V^2} \tag{6}$$

Table 1
Main particulars of CP469 propeller.

	Symbol	Unit	CP469
Type of propeller	–	[–]	CPP
Number of blades	z	[–]	4
Diameter	D	[m]	2.26
Hand	–	[–]	left-handed
Pitch ratio at 0.7 R	P/D	[–]	0.942
		[%]	83
Model scale	λ	[–]	10
Blade section type	–	–	NACA 16/a=0.8
Expanded area ratio	–	–	0.673

where σ=cavitation number; p_{atm}=hydrostatic pressure at 0.7[1] of propeller radius above the shaft line [Pa]; p_n=vapor pressure [Pa] and h=submergence level [m];

Based on above mentioned rules following parameters for both numerical simulations and model testing were established (m denotes model scale, s denotes full scale):

Advance speed : $V_{aS}=Jn_S D_S$;

rotational speed : $n_S=\sqrt{\frac{T_S}{\rho_0 D^4 K_t}}$;

Thrust : $T_S=T_M\lambda^3$.

Hydrostatic pressure:

$$p_{atmS}=\sigma 0.5\rho_0(n_S D_S)^2+p_n+\rho_0 g\left(h+0,7\frac{D_S}{2}\right).$$

3. Propeller geometry and flow conditions

Both experimental and numerical tests were conducted for controllable pitch propeller, called CP469. It is four bladed propeller installed on the Navigator XXI research vessel (Bugalski and Hoffmann (2010)). Main particulars of CP469 propeller are listed in Table 1. Both tests were carried out at model scale of the propeller 1:10.

Both numerical and experimental tests were done for the same loading conditions (Tests #1 and #2). The non-uniform inflow conditions were used. Fig. 1 depicts the comparison between the wake fields achieved in cavitation tunnel and applied during numerical simulations. As a reference the wake field measured in towing tank was applied. It is worth to mention that during towing tank tests the real geometry of the Navigator hull was investigated in appropriate model scale. Since in medium size cavitation tunnel the dummy body is applied the quality of simulated wake field is assessed by making its comparison with towing tank result. The axial velocity distribution is presented at various radii of propeller; it can be stated that the axial flow conditions were reproduced correctly and equivalently both in the cavitation tunnel and during CFD analyses. The reasonable level of results agreement was identified.

As it was already mentioned two kinds of loading conditions were considered, characterized by different cavitation number and torque coefficient values. Tables 2 and 3 summarize the details of investigated conditions for first and second case, respectively. The same loading conditions were applied during both experimental and numerical investigations.

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[1] Due to scaling effects it is not possible to fulfill the similarity of the cavitation number in the whole domain so for practical purposes the hydrostatic pressure value at 0.7 of propeller radius is used.