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Review

# Propeller underwater radiated noise: A comparison between model scale measurements in two different facilities and full scale measurements

G. Tani [a,*], M. Viviani [a], J. Hallander [b], T. Johansson [b], E. Rizzuto [c]

[a] Department of Naval Architecture, Marine Engineering, Electrical Engineering, Electronic Engineering and Telecommunication Engineering (DITEN), University of Genoa, Genoa, Italy
[b] SSPA, Gothenburg, Sweden
[c] Department of Civil, Chemical and Environmental Engineering (DICCA), University of Genoa, Genoa, Italy

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ABSTRACT

The prediction of propeller induced pressure fluctuations and underwater radiated noise is a subject of great and increasing interest in marine engineering. Nevertheless, the full-scale prediction of these negative effects, even though based on dedicated model scale tests represents still a challenging task. This is due to different phenomena, among which scale effects on cavitation and ship wake, confined environment and near field effects in model tests play an important role; the analysis of these problems is made difficult by the rather limited amount of available data from sea trials and to the complexities of the phenomena, most of which related to cavitation on the propeller blades, that are present in the measurements carried out in cavitation tunnels, depressurized towing tanks or circulating channels.

In the present work, the subject has been studied with reference to a four blades conventional CP propeller of a coastal tanker.

Cavitation tunnel tests have been carried out in two rather different facilities, at UNIGE cavitation tunnel and at SSPA large cavitation tunnel.

Results from model scale tests processed with different treatments are then compared with full scale measurements performed by SSPA on the same propeller in terms of cavitation extension and radiated noise.

The analysis is aimed at assessing the effectiveness of different experimental setups, testing procedures and scaling laws.



**Contents**



* Corresponding author. Tel.: +39 3492952682.
*E-mail address:* giorgio.tani@edu.unige.it (G. Tani).

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**Nomenclature**

| | |
|---|---|
| $A_E/A_O$ | expanded area ratio |
| $B$ | breadth [m] |
| $D$ | propeller diameter [m] |
| $DO_2$ | oxygen content level [ppm] |
| $J$ | advance ratio $\left(J = \frac{V_A}{nD}\right)$ |
| $K_Q$ | torque coefficient $\left(K_Q = \frac{Q}{\rho n^2 D^5}\right)$ |
| $K_T$ | thrust coefficient $\left(K_T = \frac{T}{\rho n^2 D^4}\right)$ |
| $K_P$ | non dimensional pressure coefficient $\left(K_P = \frac{P}{\rho n^2 D^2}\right)$ |
| $L_{KP}$ | level of non dimensional pressure coefficient [dB re $10^{-6}$] |
| $L_{KPN}$ | net level of non dimensional pressure coefficient [dB re $10^{-6}$] |
| $L_P$ | sound pressure level [dB re 1 $\mu$Pa$^2$/Hz] |
| $n$ | shaft revolution rate [RPS/RPM] |
| $p$ | pressure [Pa] |
| $P_\infty$ | undisturbed pressure [Pa] |
| $P_{ref}$ | acoustic reference pressure ($P_{ref}=10^{-6}$ [Pa] in water) |
| $P/D$ | pitch to diameter ratio |
| Q | propeller torque [Nm] |
| r | distance from the acoustic source [m] |
| $r$ | radial coordinate in propeller reference system [m] |
| $R$ | propeller radius [m] |
| $Re$ | Reynolds number $Re = \frac{nD^2}{\nu}$ |
| $T$ | propeller thrust [N] |
| $T_{SHAFT}$ | draft at propeller centre line [m], without considering stern wave |
| $T_{TIP}$ | draft at propeller tip at 12 o'clock position [m], without considering stern wave |
| $V_A$ | advance velocity [m/s] |
| $V_S$ | ship speed [kn] |
| $V_\infty$ | free stream velocity [m/s] |
| $w$ | wake fraction |
| $Z$ | number of blades |

*Greek symbols*

| | |
|---|---|
| $\alpha$ | oxygen content [ppm] |
| $\theta$ | blade angular position [°] |
| $\lambda$ | geometric scale |
| $\eta_O$ | open water efficiency $\left(\eta_O = \frac{J}{2\pi}\frac{K_T}{K_Q}\right)$ |
| $\nu$ | kinematic viscosity [m$^2$/s] |
| $\rho$ | water density [kg/m$^3$] |
| $\sigma_N$ | cavitation index based on propeller revolutions with reference pressure at propeller centreline $\left(\sigma_N = \frac{P_{ATM}+\rho g T_{shaft}-P_V}{0.5\rho n^2 D^2}\right)$ |
| $\sigma_{NTIP}$ | cavitation index based on propeller revolutions with reference pressure at propeller tip at 12 o'clock $\left(\sigma_{NTIP} = \frac{P_{ATM}+\rho g T_{TIP}-P_V}{0.5\rho n^2 D^2}\right)$ |

## 1. Introduction

Marine propeller performances steadily increased during time, due to the introduction of more accurate design and analysis procedures and under the pressure of more demanding requirements to the designer. Among such requirements, along with the traditional call for high efficiency and avoidance of erosive cavitation, new requests are set, regarding the control of other undesired effects, like structural excitation and noise radiated by the propeller.

In the recent past stringent requirements in terms of radiated noise have been mainly applied to "high added value ships" (passenger ships, mega yachts, oceanographic ships, naval ships, etc.). Nowadays the radiated noise control is gaining importance also for merchant ships, due to increasing attention to the enforcement of acceptable working and living conditions on board and to the limitation of the environmental impact of shipping on the marine fauna.

From the point of view of the numerical prediction and modelling of cavitation, Computational Fluid Dynamics (CFD) represents certainly a powerful and promising tool, but the same difficulties about the complexity of the phenomena involved above recalled in the context of model experiments apply even more to theoretical predictions. As a matter of fact, CFD has proved to be successful in predicting cavitation extent and also inception [30], however it does not appear, at the moment, ready to provide reliable results on the mentioned effects (in particular as regards noise radiation) and still needs experimental inputs to set up the models.

Many physical aspects are involved in propeller functioning and noise generation and need to be scaled: ship wake field, propeller performances, cavitation inception and extension, bubble dynamics, noise propagation, noise scaling, etc.

The scaling and prediction of cavitation noise from model scale experiments has been studied by many authors. Blake and Sevik [2] presented a detailed summary of the main issues regarding model scale propeller noise measurements in different facilities, focusing on requirements for the facilities themselves and the instrumentation. In their work, also possible shortcomings or unwanted effects of different experimental setups are discussed.

One of these effects is the influence of the confined environment on the noise measured in model scale, due the intrusive influence exerted by the restricted boundaries of the test facilities. This influence is clearly absent in full scale and needs to be 'filtered away'. The effect is related to the length of the noise wave of interest in respect to the dimensions of the test sections, and is therefore relevant in almost all model scale facilities, even though it potentially affects more a small facility like the UNIGE cavitation tunnel. From this point of view, the use of transfer functions for the characterization of the single model scale facilities has been suggested by ITTC in [8,9,11]. Actually it allows to take into account the effect of the confined environment. Very limited examples of comparisons between model and full scale measurements, however, are available in literature, due to their confidential nature, which may regard both the object of measurements and the facility in itself.

As a part of the present work, the effect of the adoption of a transfer function on measurements carried out at the UNIGE cavitation tunnel will be discussed. The transfer function was measured through a dedicated experimental campaign, following the procedure reported in [18].

As regards the actual effect of scale, Blake [3] presented general scaling laws for different kinds and extensions of cavitation. This study is based on the definition of non-dimensional generalized spectrum functions suitable to represent cavitation noise for certain conditions; the obtained laws were successfully applied for the prediction of noise radiated by the propeller of a research vessel.

An exhaustive discussion on noise and pressure pulses scaling and comparison with full scale measurements was also presented by Bark in [1]. In his discussion Bark demonstrated the effectiveness of scaling laws usually adopted in full scale noise prediction (ITTC 1987 scaling laws). He pointed out also some additional issues. In particular, the problem of cavitation intermittency was underlined and as a solution it was suggested for full scale effects to compute