Ocean Engineering ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

# Propeller cavitation noise investigations of a research vessel using medium size cavitation tunnel tests and full-scale trials

Batuhan Aktas [a,*], Mehmet Atlar [a], Serkan Turkmen [a], Weichao Shi [a], Roderick Sampson [a], Emin Korkut [b], Patrick Fitzsimmons [a]

[a] School of Marine Science and Technology, Newcastle University, Newcastle upon Tyne NE1 7RU, UK
[b] Istanbul Technical University, Faculty of Naval Architecture and Ocean Engineering, 34469 Maslak-Istanbul, Turkey

ARTICLE INFO

*Article history:*
Received 29 June 2015
Accepted 23 December 2015

*Keywords:*
Underwater radiated noise
Propeller cavitation noise
Experimental hydrodynamics
Cavitation tunnel noise predictions

ABSTRACT

The rising environmental awareness of various adverse emissions by commercial shipping has recently targeted Underwater Radiated Noise (URN) due to its potential impact on marine mammals. Amongst the various sources on-board a commercial ship, cavitation is the dominating one following its inception. In order to ensure acceptable noise levels for sustainable shipping, accurate prediction of the noise signature is vital. Within this framework, a widely utilized method for full-scale noise prediction is to conduct model tests in cavitation tunnels and to extrapolate to full-scale.

The aim of this paper is to provide invaluable URN data of a full-scale vessel and its prediction using cavitation tests from a medium-sized tunnel to evaluate the prediction methodology. Extrapolated URN data based on the tunnel tests was compared with the data obtained from the full-scale trials with The Princess Royal in order to assess the prediction methodology. The comparisons indicate that, whilst the ideal experimental approach is to conduct such involving tests with a full-hull model in large cavitation tunnels, the medium size facilities using dummy-hull models with wake screens, can still provide a very useful means for the URN investigations with a rapid turn around and an economical way of conducting such tests.



## 1. Introduction

Over the past half century the volume of commercial shipping has experienced an increasing trend due to increasing ship size, service speed and number of ships operating (Hildebrand, 2009). This trend has resulted in significant elevation of various emissions by the seagoing vessels. In order to ensure sustainable shipping, various anthropogenic impacts have been targeted by environmentalists, in particular, underwater radiated noise (URN) from commercial shipping. URN has been known to propagate over long distances from the source, especially at low frequencies where the propagation losses are small due to the low sound absorption rate of the water medium (Fisher and Simmons, 1977). The low frequency band (10–100 Hz) for ships contains the tonal frequency components such as propeller blade passing frequencies (BPF) and engine firing frequencies. This low frequency band may overlap and mask the communication frequency band of marine mammals and hence adversely affecting their fundamental living activities (Hildebrand, 2005). Originating from these concerns the international organizations and committees, such as International Maritime Organization (IMO) and Marine Environmental Protection Committee (MEPC) (IMO, 2011; MEPC, 2009) have made calls and initiated activities to study the URN from commercial shipping to help in the development of potential guidelines and regulations. Moreover, the EU has established the Marine Strategy Framework Directive (MSFD) to investigate and implement programmes of measures which are designed to achieve or maintain 'Good Environmental Status' in the marine environment (Van der Graaf et al., 2012).

Shipping noise originates from various sources on board a vessel. Amongst these sources, propeller cavitation usually dominates the overall radiated noise spectrum above the inception threshold (Ross, 1987). In other words after cavitation inception and well developed cavitation is experienced by the propeller, a significant increase in level occurs across the entire frequency band of the URN spectrum (Abrahamsen, 2012; Arveson and Vendittis, 2000). In turn, the cavitation noise overshadows the other contributing sources and dominates the overall URN spectra. Whilst it is not possible to avoid cavitation for efficient commercial ships at service speed conditions, various full-scale URN measurements have shown room for improvement. Among the same type of vessels full scale measurements have shown up to 20 dB

* Corresponding author. Tel.: +44 191 208 6726.
*E-mail address:* b.aktas@ncl.ac.uk (B. Aktas).

http://dx.doi.org/10.1016/j.oceaneng.2015.12.040
0029-8018/

difference in the measured noise levels (McKenna et al., 2012; MCR, 2011; Wales and Heitmeyer, 2002). This may suggest that the current practice of ship design can be further scrutinized in terms of the URN characteristics of the ships and hence may lead to minimizing the impact on ever-increasing ambient noise levels in the world's oceans (Renilson Marine Consulting Pty Ltd., 2009).

In order to tackle the above concerns a reliable and accurate prediction of URN at an early design stage of ships is essential. The current state of the art methods for the URN predictions utilize experimental methods based mainly on cavitation tunnels, semi-empirical methods based on statistical databases and computational fluid dynamics (CFD) methods with significant simplifications. Although computational power has been increasing at an exponential pace, URN prediction using the CFD method is at its infancy and requires coupling of as many as five different codes as reported e.g. in (Wijngaarden, 2005). While recent developments in the CFD field, which are based on the incompressible Reynolds Averaged Navier Stokes (RANS) equations coupled with the Ffowcs–Williams Hawkings (F–HW) equation, have made the URN predictions possible, this approach still needs further development in terms of the accuracy of the predictions as well as the cost of the computational resources (ITTC, 2014). Semi empirical methods are based on a number of different approaches; some being developed based on data from the World War II period. These early methods over predict the URN levels of preset-day commercial ships (Okamura and Asano, 1988) due to developments in the field of propeller design (Brown, 1976; Ross, 1987). More recently introduced semi-empirical methods are commercially confidential, being based on simple models for which various coefficients have been derived from large databases of full scale noise measurements (e.g. Raestad, 1996). By considering the additional complexities associated with the numerical modelling of the propeller cavitation, perhaps, the most reliable current prediction method may be that based on the experimental methods (ITTC, 2014)

Outside the research vessel and naval communities, publicly available information is scare for both full-scale URN levels and cavitation tunnel based predictions. Furthermore such data, which are publicly available, are either unsatisfactory due to a lack of information on the main particulars of target vessels and their operating conditions and/or measurement technique and methods used to collect the data (Bark, 1985). Allied with this unfavorable status the complementary information, which can enhance the understanding of the noise emitting mechanisms such as cavitation observations, pressure pulse measurements, is even more scarce thus creating a large gap in the current state of the art.

Within the above framework, in complementing the European R&D activities on the subject of URN from commercial shipping, several collaborative European R&D projects have been underway (e.g. SILENV, AQUO, SONIC) under the 7th Framework Programme (FP) of the EU. Amongst them Suppression Of Noise Induced by Cavitation (SONIC) has brought together 12 world-leading hydrodynamic institutes, noise experts, propeller designers, universities, European shipyards and marine biologists to develop guidelines to assist in regulating the underwater noise emitted by shipping in the North Sea (SONIC, 2012). The project participants have developed techniques to model cavitation noise computationally and experimentally, for use by vessel operators to monitor the shipping noise. The participants have also mapped the spatial distribution of the URN caused by a single ship (a noise footprint) and sets of ships in an area (a noise map). To do this, the project partners have been measuring ship radiated noise both on and off board to test these measurements in full-scale trials at sea. Ultimately, the SONIC project will contribute to validating different prediction methods for ship URN and to developing cavitation noise models to help the classification and regulations of ships based on their noise footprints. In the long term, such information is also expected to assist in the development of guidelines for the future design of low-noise ships.

As part of the SONIC project activities, the prediction of full-scale URN spectra has been investigated based on model tests in different sizes and types of experimental facilities. In those investigations, Newcastle University was involved in a full-scale trial campaign conducted jointly by the project partners to measure the URN levels from the research catamaran "*The Princess Royal*". The full-scale trial campaign was conducted in the North East coast region of England (Blyth) in September 2013 and involved various on-board and off-board measurements. The campaign included the collection of the URN data from suspended arrays of hydrophones, fluctuating hull pressures, vibration pick-ups and propeller cavitation observations. Following the trials, some of these full-scale runs were simulated experimentally in the medium size cavitation, "*The Emerson Cavitation Tunnel*", by using a 1:3.5 scale dummy model of the starboard demi-hull. The experimentally measured URN levels were extrapolated using the ITTC procedure (ITTC, 1987) to compare with the full-scale measurements. The comparisons also included the cavitation observations in both the full-scale and model scale.

Based upon the above background the aim of this paper is to provide invaluable URN data from a full-scale target vessel and its prediction using medium size cavitation tunnel tests to evaluate the prediction methodology by making use of the data generated as part of the collaborative SONIC project activities.

In order to satisfy the above aim, following this introduction, Section 2 of the paper describes the experimental facilities and set-up including the Emerson Cavitation Tunnel (Section 2.1), general particulars of The Princess Royal and her propellers (Section 2.2), and details of the wake simulation activities (Section 2.3) as part of the model test procedures. In Section 3, the selected full-scale trial runs and corresponding tunnel test conditions are described. Section 4 presents the details of the noise measurements. This include a description of the equipment and analysis procedures as well extrapolation of the noise characteristics to the full-scale for comparisons with the full-scale noise data (Section 4.1). The results are presented in Section (4.2) and discussed in Section (4.3). Finally, Section 5 presents the overall conclusions obtained from the investigation.

## 2. Experimental facilities and setup

### 2.1. The Emerson Cavitation Tunnel

The experiments were carried out in the Emerson Cavitation Tunnel (ECT) of Newcastle University, which has a measuring section of $3.1 \times 1.21 \times 0.8\ m^3$ ($L \times B \times H$), as shown in Figs. 1 and 2. More detailed information about the tunnel and its details can be found in (Atlar, 2011).

### 2.2. Main particulars of the princess royal and propeller

The Princess Royal is a displacement type of Deep-V catamaran, which was designed in-house and built locally, as described in detail by (Atlar, 2000). During the experiments, the starboard demi-hull of the vessel was used as a basis for simulating the hull wake based on the well-known "dummy-hull" approach usually adopted in small and medium size cavitation tunnels. The model scale factor of 1:3.5 was set by considering various limiting factors such as avoiding an undesirable blockage effect, achieving a reasonable Reynolds number range for minimizing the scale effects and achieving a respectable size for avoiding practical size limitation. At this scale, the demi-hull was too long (5.39 m) to fit the tunnel's test section and had to be truncated down to 3 m. The truncation