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Propeller Acoustic Measurements in Atmospheric Towing Tank

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Abstract: The study describes the implementation of experimental procedure for measuring the hydrodynamic noise generated by model scale marine propellers in atmospheric towing tank. The towing carriage and conditions have not been altered admitting the existence of considerable background noise. The feasibility analysis included experimental and theoretical study of the background noise at the operating conditions. Some considerations about the uncertainty of the results are also presented. The experimental equipment, set up and procedure for measuring the acoustic pressure around model ship propeller and/or hull is also described. Simultaneous measurements with various differently positioned hydrophones at multiple hydrodynamic conditions permitted to evaluate the background and propeller/hull generated acoustic field at a range of frequencies. An appropriate treatment of the recorded time series characterised the background disturbances and permitted to obtain net results with sufficient signal to noise ratio, mostly from narrowband spectral analysis. Results for the impact of the hull presence on propeller acoustic field are presented and discussed. The extrapolated results are compared informatively with full scale measurements. The research presented in this article is a result of the Collaboration agreement on underwater acoustics between CEHIPAR and ITM and is partially funded by the European Commission project AQUO (Achieve Quieter Oceans by Shipping Noise Footprint Reduction), Seventh Framework Programme, Grant number 314227, FP7-SST-2012.1.1-1.

Keywords: model marine propellers and hulls, model tests, experimental acoustics, noise, towing tank.

1 INTRODUCTION

The modelling and prediction of the noise generated by the ships and marine structures is of increased interest due to the environmental impact consisting of health and comfort problems for the humans and disturbance of serious consequences for the marine life. This latter has been observed worldwide and the former is experienced daily by crew and passengers (See SILENV Project D3.1).

There are few regulations limiting the noise and vibrations for special ships and conditions but the tendency is to introduce rules for commercial vessels and areas. These limitations cannot be expanded widely because of the age of the fleet requiring serious investments to improve and also due to the lack of reliable prediction tools capable to assure the accomplishment of the rules by the new-built vessels.

One of the goals of the research projects co-financed of the European Commission is to promote the development of experimental and numerical tools for reliable prediction of the noise and vibrations during the project stage of the vessel. One of those project is called SILENV completed in 2012 and there are currently going on two such projects named AQUO and SONIC.

There are several sources of noise and vibrations in a contemporary ship, but this study is limited to the hydrodynamic underwater noise generated by the propeller alone and in presence of the hull at standard navigation conditions.

Model scale hydrodynamic tests of marine vehicles were becoming indispensables to guarantee the propulsive, sea-keeping and manoeuvring characteristics of the ships at design stage. Nowadays more requirements begin to be imposed on the ships that should be satisfied before the ship is constructed.

The existing model test facilities and equipments fail to model all the parameters that would assure similarity with the full scale ship conditions. Closer modelling can be achieved in a depressurized towing tank as it permits more complete hydrodynamic similarity, still leaving not satisfied the mechanical and acoustical ones. This kind of facility is a big investment, expensive to maintain and exploit that is why only very few exist worldwide. An example of applying a depressurized tank in ship acoustics is shown in Kooij & De Bruijn (1982), Bosschers et al. (2013).

As the noise contribution of the propellers is more pronounced at cavitating conditions, the Cavitation Tunnels are the most used facilities for such kind of tests. The interaction between the propeller and the hull is crucial for the study of noise, so a better choice are the big size tunnels that permit to locate inside a full hull model and in the same time model correctly the cavitation. An example of such an installation is given in Fréchou et al. (2001). Nevertheless, the small and medium Cavitation Tunnels are also used to carry propeller acoustic tests taking into account the propeller hull interaction only as a non-uniform flow (wake) upstream of the propeller using wake screens or dummy

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models (Atlar et al. (2001), (Wills 1989), (Bertetta et al. 2011), (Yuasa et al. 1986), (Sevik 1996). A weak points of these facilities is the absence of free surface that is known to contribute, although less than the cavitation, to the whole acoustic field as well the reverberation of tunnel’s walls.

There are only a few attempts to measure the propeller noise in atmospheric tank due to the incomplete modelling that leads normally to non-cavitating condition. In addition, the towing carriage is a strong source of background noise. The choice of such facility in the present work is justified by the need to produce non-cavitating acoustic propeller data for CFD validation purpose and can be of interest when the propeller is generally non-cavitating, contributing to distinguish the non-cavitating part of the noise produced by a cavitating propeller. The interaction with the hull is also better modelled in towing tank.

2 EXPERIMENTAL FACILITIES AND EQUIPMENT

2.1 Towing Tank Specifications

Acoustics measurements were performed at CEHIPAR’s calm water towing tank (CAT), the main particulars of this facility are shown in the following figure:

![Figure 1. CAT facility](image1)

From acoustic point of view, the CAT facility is considered as acoustic channel with free surface opened at its extremes and rectangular cross-section (vertical sides and flat bottom). The structural arrangement is adjacent to a terrain allowing acoustic transmission between water and the ground. This leakage was calculated through the analysis of the experimental results.

2.2 Hydrophones Support System

The four hydrophones used to measure the noise, are placed outside of the propeller slipstream in different positions shown in Figure 2 and Figure 3. The non-dimensional distances from each hydrophone to the centre of the propeller are shown in Table 1:

![Figure 2. Hydrophones arrangement](image2)

<table>
<thead>
<tr>
<th>Hydrophone Nº</th>
<th>Distance to propeller origin/Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.80</td>
</tr>
<tr>
<td>2</td>
<td>1.42</td>
</tr>
<tr>
<td>3</td>
<td>1.44</td>
</tr>
<tr>
<td>4</td>
<td>5.44</td>
</tr>
</tbody>
</table>

Hydrophone 1 is placed at the propeller disc plane, hydrophones 3 and 4 are located downstream. Their sensitive elements are projecting upstream. Only hydrophone 2, placed upstream has its sensitive element projecting downstream. Further in the text they will be referenced as H1, H2, etc. (see Figure 2).

For a fix positioning of the hydrophones during the tests a support structure has been designed and constructed. This structure is fixed to the carriage. The propeller dynamometer and the model ship are also fixed making compatible the measurements with both configurations (OW, open water and SP, self-propulsion). Figure 3 shows CAD view of the installation design with both configurations together and the photos in Figure 4 - the structure installed on the carriage.

![Figure 3. Tests arrangement](image3)

![Figure 4. Hydrophones support installed in both configurations (left: OW and right: SP)](image4)

The support made of steel and the hydrophones were fixed to the structure through steel cylinders coupled with rubber toric joints. The cylinders were fixed to the structure in a way permitting to adjust the positions of the sensors.

A fifth hydrophone was installed fixed on a pole in the tank bottom (not shown). Although the background noise due to the movement and vibrations of the rest of the
hydrophones has been avoided in this hydrophone, the results of measurements using that one are not presented here because of the weakness of the signal.

2.3 Measurement Equipments Specifications

Commercial 21 mm hydrophones and compact-low noise conditioning charge amplifiers were used to measure the underwater signals.

2.2.1 Hydrophones and conditioning charge amplifier specifications

The hydrophone model used was RESON TC4040 (Figure 5 left). It was chosen due to the many advantages it offers: Flat frequency receiving response over a wide frequency range (±2 dB from 1 Hz to 80 kHz). Its ceramic sensor element ensures high stability and performance, resistant to fresh water but also to other liquids like oil. Other core specifications are listed below:

- Receiving voltage Sensitivity: -206 dB re 1 V/µPa (56 µV/Pa).
- Omnidirectional horizontal directivity (±2 dB) at 100 kHz.
- Vertical directivity: 270º (±2 dB) at 50 kHz.

Each hydrophone was connected to individual conditioning charge amplifier, in order to obtain high resolution signal responses at low frequency ranges. The RESON EC6067-CCA1000 charge amplifier provides low-noise responses and enables the use of long cables between sensors, without affecting their sensibility. The amplifier has an operating frequency range from 1 Hz to 1 MHz and the output gain can be selected from 0 to 32 dB.

2.2.2 Hydrophone calibrator

Calibrating pistophone GRAS 42AC (Class 1 L and ANSI S1.40-1984), Figure 5 right, was used to generate precise sound pressure (Source Level of 134 dB re 20 µPa, at 250 Hz) for the low frequency process of hydrophones calibration in air.

2.4 Acoustic Properties of the Facility

The limitations of facility in comparison with open sea conditions consist in the presence of two vertical walls parallel to the sound source course and the depth of the water column is limited to a few meters. Only the longitudinal dimension allows almost free field condition for the acoustic field to be achieved. Acoustically, this represents a rectangular cross-sectional waveguide (Figure 6) where the transversal eigen modes could be excited with enough source level.

Fortunately, the acoustic features of the channel boundaries are far from ideal and their acoustic impedance is not infinite related to the acoustic impedance of water. This allows the sound to fly out of the channel to the surrounding ground, especially in the low frequency range (under 200 Hz). Some preventive checks have been made from the temporal files recorded during the experiments, searching for echo traces from the temporal autocorrelation of the signals. The results of this check show that only for very high speeds of the towing carriage echoes are perceptible beyond 150 Hz. In Figure 7 some of these temporal correlation curves are shown.
2.5 Background Noise Sources and Characteristics

The first experimental results revealed that the acoustic background of the towing tank under real operation conditions would be the most important problem for achieving a feasible acoustic measurement. The drive system of the carriage and the sliding of the assembly on the rails mounted on top of the lateral walls generated a high level underwater acoustic background. Additional background noise is generated by the flow around the proper hydrophones. It was reduced by locating the H2 pointing downstream. The most outstanding features of this acoustic background were:

1) Spectra with a striking tonal structure;
2) Amplitude and frequency dependence of the spectrum discrete components upon the speed of the carriage;
3) Significant amplitude and frequency dependence upon the measuring position of the hydrophone.

In view of these, it was considered to obtain first the average narrowband acoustic background for each hydrophone, with the speed factor decoupled from the processed signal. For this, the time signals obtained were normalized with respect to its maximum amplitude. Then, the Cross Spectral Density (CSD) was calculated for all possible combinations of pairs of towing speeds. Eight configurations, which would suppose 64 pairs, minus the autocorrelation cases, not considered, result in 56 pairs to be analysed. Finally, the result for each hydrophone was once more normalized to its maximum value. Accordingly, the average Cross Spectral Density (discrete) for the \( n \)th hydrophone is obtained from Eq. (1):

\[
(SPL_{hh}(l))_n = \left( \sum_{x=1}^{8} \sum_{y=1}^{8} \frac{CSD_{xy}(l)}{56} \right)_n,
\]

where the discrete spectrum \( CSD_{xy}(l) \) is calculated for each pair \((x, y)\) of tested speeds according to Eq. (2):

\[
CSD_{xy}(l) = \left( \Delta T \cdot \sum_{m=1}^{M} X_m(l) \cdot Y_m(l) \right) / M \cdot W_f,
\]

being \( X_m(l) = FFT(x_m(r)) \) and \( Y_m(l) = FFT(y_m(r)) \) the \( m \)th FFT periodogram of the corresponding series of data \( x_m(r) \) and \( y_m(r) \) extracted from the recorded files; \( M \) is the total number of series of data used; \( W_f \) a correction factor corresponding to the selected time window (Hamming window in our case); and \( \Delta T \) the sampling time of the signal acquisition process. The final frequency resolution obtained in the signal analysis process is given by the known Equivalent Noise Band Width factor (ENBW). Its resulting value was 0.10322 Hz.

The average background CSD spectrum for H2 is shown in Figure 8. Similar behaviour with more or less tonal lines was observed for the rest of hydrophones. Quite different spectrum was obtained from the signals of H5, shown in Figure 9.

As expected H5 presented lower number of background tonals, although a set of strong tonal components was observed in the range of 200 – 240 Hz. This could be due to the excitation of a vertical mode in the underwater acoustic waveguide of the tank. Casually H5 was positioned in a depth where this mode had strong amplitude.

3 TEST CONDITIONS

3.1 Objectives

The objective of the study is to quantify the acoustic field around the propeller alone and in presence of the hull in atmospheric model conditions and to evaluate the contribution of the hull to the whole field at specific hydrodynamic conditions.
3.2 Experimental Setup
The support structure with the hydrophones and the OW dynamometer or the hull, as shown in Figure 3 and Figure 4 are used to measure the noise around the propeller. The majority of the hydrophones are located close to the source, as low signal was expected in the non-cavitating propeller cases. The structure was adapted for both open water and behind the hull functioning of the propeller.

In the OW case the propeller is mounted on the shaft of the dynamometer, while for the SP, it is mounted on hull shaft. In both cases the background noise is registered without propeller but rotating shaft.

Additionally, vertical and lateral accelerometers were fixed in the stern part of the hull in order to detect possible vibrations as additional source of underwater noise. As expected, only low accelerations were detected thus permitting not to consider the hull vibrations as significant additional noise source.

3.3 Description of the Tested Configuration
The above described equipment and procedure are applied to the propeller and hull of the case selected in AQUO project of a 60 m length training research vessel, propelled by a 2.26 m of diameter 4 bladed controllable pitch propeller. The wooden hull model was manufactured in CEHIPAR and the propeller – provided by CTO – Poland. The scale factor is 10. Photos of both models are shown on Figure 10 below.

![Figure 10. Hull & Propeller models](image)

The detailed geometry of the tested configuration is a confidential part of the project.

3.4 Test Conditions
The propeller and the hull models had been tested previously at OW and SP conditions applying Froude similarity to the full scale case. To reproduce the SP of the ship the same combinations of hull speed and revolutions of the propeller have been used during the acoustic tests. The hull was kept fixed to the carriage to assure constant distance of the hydrophones from the acoustic sources. For most of the tests the propeller blades were set to one of the two pitch positions called “high pitch” – HP0 corresponding to the design pitch and “low pitch” – HP1. This choice reflects two possible real conditions as the ship engine is generally working at fixed shaft revolutions.

The conditions and designation of selected sets of tests is given in Table 2 below:

<table>
<thead>
<tr>
<th>Setting Nº</th>
<th>Basic test</th>
<th>Pitch</th>
<th>Speed [m/s]</th>
<th>Hz</th>
<th>Speed [kn]</th>
<th>Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>SP</td>
<td>P0</td>
<td>1.95</td>
<td>11.10</td>
<td>12.00</td>
<td>3.62</td>
</tr>
<tr>
<td>17</td>
<td>SP</td>
<td>P1</td>
<td>1.15</td>
<td>10.10</td>
<td>7.10</td>
<td>3.40</td>
</tr>
<tr>
<td>8</td>
<td>OW</td>
<td>P0</td>
<td>1.07</td>
<td>11.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>OW</td>
<td>P1</td>
<td>0.58</td>
<td>10.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>SP</td>
<td>P0</td>
<td>0.00</td>
<td>5.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>OW</td>
<td>P0</td>
<td>0.00</td>
<td>5.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 NOISE MEASUREMENTS TECHNIQUE
4.1 Calibration Process
Correct calibration of the transducers is required to get a reliable response from each of the sound sources to study. Using the pistophone, at static ambient pressure of 101.3 kPa, no further correction factors need to be applied.

The operating procedure is straightforward: Each hydrophone was fitted into the coupler of the pistophone and the constant sound pressure level produced was recorded. Since the output level of a pistophone depends on the static ambient pressure, the use of a barometer was needed, showing directly the correction factor in dB. The barometric correction at a given altitude very seldom varies by more than ± 0.2 dB. The calibration of the hydrophones in air is adequate for this work at least in the low frequency range of the acoustic spectrum, where the impedance and response of the hydrophones are equivalent to the underwater case.

4.2 Acoustic Noise Descriptors
As the noise emitting source is continuous the evaluation method chosen for calculating the noise level is by time averaging. In the wideband range one descriptor used is the SPL, that is the acoustic pressure level (in dB re 1 μPa) averaged over 1/3 octaves bands. Moreover, this average level can be further normalized in respect to the bandwidth of each 1/3 octave filter in which case the descriptor is SPL_{1/3 octv} expressed in (dB re 1 μPa/Hz). The relation between them is given by (ITTC 2013):

\[
SPL_{1/3 \text{ Hz}} = SPL_{1/3 \text{ octv}} - 10 \cdot \log_{10}(0.23 \cdot f_0), \tag{3}
\]

where \( f_0 \) is the central frequency of the band.

Both, the background and the acoustic signature of the emitter are expected to include some discrete lines over its general continuous spectrum. This was the reason to perform a very narrow band analysis of the recorded signals in order to distinguish between tonal components of the background and tonal components radiated by the source under study. The acoustic descriptor selected is the
Power Spectral Density (PSD) of the acoustic signal, expressed in dB re.1 µPa²/Hz and calculated using the following expression:

$$PSD_{xx}(f) = \left(\Delta T \cdot \sum_{m=1}^{M} |W_m(f)|^2\right) / M \cdot W_f$$  \hspace{1cm} (4)

The parameters in the Eq. (4) should be interpreted in the same sense that Eq. (2). The PSD curves obtained depend upon the real frequency resolution (ENBW) used for the analysis. The finer the spectral analysis, the higher the amplitude will be, as the product of PSD and ENBW must be constant and equal to the mean value of the signal at each frequency. It is recalled that ENBW being 0.10322 Hz defines a quite narrow band analysis.

Another frequently used descriptor is the dimensionless pressure, obtained from the pressure using the expression:

$$K_p = \frac{p}{\rho n^2 D^2},$$  \hspace{1cm} (5)

where p is the measured pressure in Pa and reduced to 1 m from the propeller centre; \(\rho\) is the water density in kg/m³; n is the rotational velocity of the propeller in rps (revolutions per second) and D is the diameter of the propeller in meters. The corresponding level, in dB, is then:

$$L_{K_p} = 10 \cdot \log_{10} \left( \frac{K_p}{K_{REF}} \right),$$  \hspace{1cm} (6)

where \(K_{REF} = 10^{-6}\).

When \(K_p\) is used instead of \(p\), the acoustic descriptors, SPL and PSD transform, respectively in:

$$SPL_{K_p} \text{ in dB re. } K_{REF}/Hz,$$  \hspace{1cm} (7)

$$PSD_{K_p} \text{ in dB re. } K_{REF}/Hz$$  \hspace{1cm} (8)

### 4.3 Correction for Background Noise

The presence of a significant underwater background prevents the exact measurement of the underwater noise emitted by the source. To limit the error that could be associated with this measurement in a noisy environment it is necessary to apply a correction for background noise. The criterion (ITTC-2013) was used in this work and consists of the following rules. First the level difference \(\Delta L\) is defined as:

$$\Delta L = SPL_{K_p+bck} - SPL_{bck} = 10 \cdot \log_{10} \left( \frac{P_{K_p+bck}}{P_{bck}} \right)^2,$$  \hspace{1cm} (9)

Then, depending on the value obtained there are three options, namely

$$\begin{cases} 
\text{if } \Delta L > 10 \text{ dB, } SPL_{K_p+bck} = 10 \cdot \log_{10}(\frac{P_{K_p+bck}}{P_{bck}}) \rho \text{Pa} \\
\text{if } 3 \text{ dB} < \Delta L < 10 \text{ dB, } SPL_{K_p+bck} = 10 \cdot \log_{10}(10^{0.1\rho_{K_p+bck} / 10} - 10^{0.1\rho_{bck} / 10}) \\
\text{if } \Delta L < 3 \text{ dB, } SPL_{K_p+bck} \text{ is discarded}
\end{cases},$$  \hspace{1cm} (10)

The graphic results shown in this article have been all obtained according to this criterion. When the third condition was satisfied, the corresponding point was directly omitted from the respective curve.

### 4.4 Geometric Reduction Law for the Net Pressure

The results obtained for the net noise pressure from each hydrophone are reduced to a reference point in space. The propagation law applied to the acoustic waves that propagate from the measurement point to the reference distance (usually 1 m) is a delicate issue to treat. The far field of a sound source is reached at a distance from it which depends on its geometric dimensions and the sound wavelength \(\lambda\). In this regard, if D is the diameter of a circular source (the rotating propeller, in this case) a criterion commonly accepted considers the range given by \(r_p = 2D/\lambda\); a reference distance from which it can be assumed that the far field is well developed. For the case presented in this article and if quasi-free field condition is assumed, the positions of all hydrophones fall in the acoustic far field and the spherical propagation law can be applied, at least for low frequencies. There are other criteria that would situate the first three hydrophones in the near field.

Further conceptual complications can arise when the complete moving model (hull + propeller) is considered as the real acoustic source. On one hand, the size of the real source is larger; on the other, the propagating medium is moving and turbulent. Clearly, these phenomena can disturb the previous consideration about the acoustic far field. Nevertheless, as this topic is still under discussion, the spherical law of propagation has been adopted.

### 4.5 Estimation of Uncertainty in the Experimental Results.

The method selected to estimate the measurement error was based on the standard deviation of the spectral curve (PSD) for a representative experimental case. For this, a temporal file recorded during the experimental work was divided into ten sections of equal length. Then, the FFT-PSD spectra of each temporal section were extracted and, from these ten frequency curves, the PSD of the standard deviation was calculated for all the frequencies in the spectral range of interest. Figure 11 and Figure 12 show the confidence interval for the PSD curves of Setting 11 and Setting 12, respectively using the standard deviation for the experimental results.

![Figure 11. PSD curves for visualization of the measuring confidence interval. Setting 11](image)
The main conclusion that can be extracted from the two previous figures is that the measuring error can be very important in absence of a strong signal, in the general noise field, but just in the tonal lines emitted by the propeller this deviation is less than 1%.

The uncertainty of the results is also evaluated using repeatability tests. The precision tolerance is then estimated in 1dB.

5 RESULTS AND COMMENTS
The results of the measurements for the net sound pressure level and/or its power spectral density at the conditions given in Table 2 for model scale are presented in Figure 13 through Figure 27 for H2. The conditions are marked implicitly through the setting number. In 1/3rd octave presentation, in many cases, as one shown in Figure 14, part of the spectrum is omitted due to high level background, while the narrowband analysis permits to distinguish the contribution of the configuration tested in almost the whole spectrum.

The SP condition for two pitch settings (HP0 and HP1) is presented from Figure 13 to Figure 20.

Figure 12. PSD curves for visualization of the measuring confidence interval. Setting 12

Figure 13. Total and background 1/3 octave Kp SPL level for Setting 12

Figure 14. Net 1/3 octave Kp SPL level for Setting 12

Figure 15. Net narrow band PSD level for Setting 12

Figure 16. Net narrow band PSD level for Setting 12. Low frequency region

Figure 17. Total and background 1/3 octave Kp SPL level for Setting 17
The following figures show the spectra for the open-water case in both pitch conditions:
In the above figures clear tonals are observed corresponding to the blade passing frequencies (BPF), at least until the 4th BPF. At higher frequencies tonal lines of similar order as the BPF’s are present. A broadband spectrum is also present for all the cases at frequencies, mostly higher than $10^3$ Hz.

As expected in this atmospheric case, the level of the noise is higher for the higher pitch compared to the lower pitch condition (Figure 20 and Figure 27). The higher pitch presents clearer dominance of the BPF’s harmonics, while for the lower pitch discrete lines of similar level appear all around the spectrum (Figure 19). As the loading of the blades in both cases is quite similar, a possible case of this is the significant difference of the pitch of the tip and trailing vortices.

The presence of the hull affects the noise due to the propeller mostly at medium range frequencies ($10^2$ - $10^3$ Hz) approximately. This effect is observed for the SP conditions (not shown) as well as in static hull condition, as can be seen in Figure 28. This should be due to the diffraction from the hull and the additional turbulence noise generated by the latter at this range of the spectrum.

There is some difference in the measured pressure level transferred to 1 m depending on the hydrophone position. This is shown in Figure 29 for the case OW setting 11.

It can be seen that significant difference is observed for H2 mainly at the first blade harmonic. It is concluded that for the rest of the spectrum H2 represents roughly the mean behaviour, thus justifying its choice.

The next Figure 30 and Figure 31 represent an attempt to compare the model scale result extrapolated using the formula adopted by the ITTC-2013 with full scale measurements carried out by CTO-Gdansk and kindly processed for this comparison by UNIGE. This is not a strict validation case because of the lack of full modelling (Euler similarity is not satisfied), but it was an opportunity for comparison and is not meaningless because, as reported, the propeller is only slightly cavitating.

The case of full scale measurements presented in the figures was called WP1 and is the closest but not identical in conditions to setting 12 of the model tests.

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As shown, general correlation between the prediction and the full-scale measurement exist. It is to be noted that the low frequency tonals are not seen in the full scale spectrum, as well as the peaks just above 1 kHz detected in model test.

Another estimation of the results included in AQUO project is the comparison with the model scale results carried out by UNIGE in their Cavitation Tunnel and although this again is not a strict validation, we expect to obtain some more information about the viability of the results. In an initial comparison (not given) it seems that our results tend to overestimate the SPL in comparison with UNGE, as is also seen in comparing with the full scale measurement.

6 CONCLUSIONS
Careful acoustic characterization of towing tank facility was carried out permitting to reveal the spectral lines of the background noise due to various sources and the proper characteristics of the tank. It was concluded that the propeller and hull noise can be distinguished from the background mostly using very narrow band analysis. The wide range of conditions tested with a chosen model propeller and hull are partly presented in the previous paragraphs. The typical acoustic results at SP and OW conditions are shown where the expected blade frequency lines appear.

The acoustic fields of the propeller alone and in presence of the hull at different conditions gave interesting information about its influence. Results are also obtained for the impact of the pitch variation on the noise field around the propeller.

As expected, the extrapolated model test results cannot be used for precise quantitative estimation of the full scale far field noise of the ship but can give some qualitative idea about it. Nevertheless the results of the tests can serve for validation purposes of numerical models run at the same physical conditions.

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