Suppression Of underwater Noise Induced by Cavitation

FP7-314394-SONIC

SONIC Period 1 Report – Publishable Summary

Project Start Date: 1st October 2012
Project Duration: 36 months

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Table of content

1. WP1 - Accurate cavitation noise predictions .................................................. 3
   1.1. Objectives .................................................................................................. 3
   1.2. Work Performed ...................................................................................... 3
   1.3. Impact ..................................................................................................... 5
2. WP2 – Full Scale Validation ........................................................................... 6
   2.1. Objectives .................................................................................................. 6
   2.2. Work performed ........................................................................................ 6
   2.3. Impact ..................................................................................................... 9
3. WP3 – Noise Mapping and mitigation measures .............................................. 10
   3.1. Objectives of Work Package 3 .................................................................. 10
   3.2. Work performed ...................................................................................... 10
   3.3. Impact ..................................................................................................... 12
4. WP5 – Dissemination ....................................................................................... 13
   4.1. Objectives .................................................................................................. 13
   4.2. Work Performed ...................................................................................... 13
   4.3. Impact ..................................................................................................... 13

Table of figures

Figure 1: Spectrogram indicating the variation in measured noise level during one transit of the target vessel past the hydrophone array ........................................................................... 7
Figure 3: Full scale trial propeller cavitation observation during the sea trial ............... 8
Figure 4: Left: snapshot broadband noise map in a synthetic scenario computed using the propagation model in NFMT. Right: noise map computed using the high resolution model RAM................................................................. 10
Figure 5: Mechanical Noise chain breakdown .......................................................... 11
1. WP1 - Accurate cavitation noise predictions

1.1. Objectives

The objectives of WP 1 are:

- Development and validation of accurate tools to predict underwater radiated noise levels of cavitating merchant ship propellers to allow early and efficient judgement of new builds with respect to their noise emissions properties.
- To investigate design aspects to minimise cavitation noise of ships in the design phase.
- To provide detailed information on noise characteristics of existing ship hulls and propeller configurations through case studies.

1.2. Work Performed

Work in WP 1 over the first 18 months has focussed on the development of experimental and calculation procedures to determine the underwater radiated noise levels of ships. Model tests have been carried out at a variety of test facilities to develop the most suitable procedure for that facility. Furthermore, calculations have been done using numerous different approaches to compare the levels of accuracy.

Experimental procedures

Model tests have been done at the following facilities:

- Closed circulating water tunnel HYKAT – HSVA
- Free surface circulating water tunnel LCT – CNR-INSEAN
- Depressurised towing tank and wave basin (DWB) – MARIN
- Free surface circulating water tunnel – Rolls-Royce

During the tests in Task 1.1 the background noise of each facility was measured, noise propagation in the limited spatial restriction of the test facilities was investigated and the noise prediction range was extended to lower frequencies.

HSVA have performed model tests with the VIRTUE container vessel in the HYKAT where cavitation observations, hull pressure pulse measurements, cavitation noise measurements, background noise measurement and noise propagation were performed. The tests were used to extend the frequency range to lower frequencies and to investigate the background noise of the test facility resulting in a transfer function to correct for the background noise. The results will be used in Task 1.2 to develop and improve the computational procedures.

At CNR-INSEAN tests were performed with the STREAMLINE tanker focussing on cavitation observations, noise measurements, background noise measurements and separation of the acoustic and hydrodynamic contributions from near field pressure fluctuations. The tests were used to improve the experimental procedure by measurement of the background noise.
and by implementing a background noise removal technique. The results will be used in Task 1.2 to develop and improve the computational procedures.

MARIN have investigated the acoustic characteristics of the DWB by placing acoustic sources at different positions in the basin. This technique provided insight into the reflection characteristics of the tank. The tests have resulted in a transfer function to correct for the reflection of the tank walls and the water surface. Also the influence of the ship hull on the transfer function has been investigated which will result in a method to predict cavitation noise for a moving ship.

**Computational procedures**

The following modelling techniques were used:

- RANSE, BEM coupling by CETENA and Navantia
- LES and FWH solver by Chalmers
- VL, BEM by HSVA
- RANSE, BEM, FWH solver by CNR-INSEAN
- RANSE, BEM, ETV model by MARIN
- URANS, FWH by Rolls-Royce

The aim of Task 1.2 was to develop numerical tools to predict radiated noise levels for a given propeller hull combination.

CETENA have applied their calculation procedure to the VIRTUE container vessel for model scale. The calculation procedure makes use of existing tools such as ANSYS CFX for the prediction of the flow around the ship hull, PROCAL for the prediction of sheet cavitation, ETV model for the prediction of broadband hull pressures and EXCALIBUR for the prediction of hull pressures. Validation of this procedure will be done in Task 1.3.

CHALMERS and CNR-INSEAN together have developed a computational procedure for the prediction of cavitation induced propeller noise. The hydro-acoustic prediction uses sampled data of a LES prediction, this combination is the most advanced procedure possible with the current computer power available.

HSVA have made advancements in making an existing boundary element method suitable for acoustic analysis by inclusion of retardation functions which are used to predict the underwater radiated noise. The results provide additional insight into the contributions of reflections from various parts of the tunnel which could not be obtained from the measurements performed in Task 1.1.

MARIN have further developed two approaches to calculate underwater radiated noise: the bubble noise prediction model and the Empirical cavitating Tip Vortex (ETV) model. The ETV has been improved by replacing the inviscid vortex model by a viscous vortex model. As a result, the noise predictions for ship speeds below and just above cavitation inception speed
are improved. Both models will be used in Task 1.4 to show the influence of operational changes of a ship on the radiated noise levels.

NAVANTIA have developed a coupling between the hull and propeller flow calculations using START-CCM+ and the acoustic BEM program EXCALIBUR. Simple test cases have been used for proving the working principle of the coupling, subsequently calculations have been done for the VIRTUE container vessel. These test cases showed that the computational procedure is well established and is functioning correctly. Validation of the method will be carried out in Task 1.3.

Rolls-Royce have completed initial tests of employing an aero-acoustic computational procedure for hydro-acoustic prediction of marine propeller noise. The ANSYS Fluent implementation of Ffowcs Williams-Hawkins (FWH) acoustic analogy model was used to propagate noise to far-field from URANS near field hydrodynamics in order to model marine propeller noise in an open water case. Qualitative analysis of this initial work suggests that the URANS-FWH model could be applicable for predicting cavitating propeller noise.

1.3. Impact

In future these tools will help to minimise cavitation noise of ships already in the design phase and to mitigate the noise emission of merchant shipping. The progress of the development of experimental and computational tools for the accurate underwater radiated noise prediction of ships in design stage has been presented on the workshop meetings MS3 and MS4 hosted by MARIN on 26th and 27th of February. The results indicated significant progress in the development and improvement of both types of prediction tools.

The tools will be applied in Task 1.3 and 1.4 for validation and test cases, although some of the procedures may require fine tuning.
2. WP2 – Full Scale Validation

2.1. Objectives

The objectives of Work Package (WP) 2 can be summarised as:

- To set up and populate a database of underwater radiated noise measurements for ships.
- To develop improved models for the radiated noise level/source level for ships that can be used in conjunction with AIS data in noise mapping;
- To perform full scale radiated noise measurements for vessels at sea to:
  - Provide data to populate the noise database;
  - Provide verification of WP1 results;
  - Provide validation data for noise footprints (for WP3).
- To develop processing tools to distinguish the radiated noise contributions due to cavitation and machinery noise;
- To develop and trial techniques for quantifying the radiated cavitation noise based on measurements made with on-board sensors.

2.2. Work performed

**Database**

The data parameters and structure of the database have been defined, based on the currently available literature, and a suitable platform on which the database will operate has been selected. An extensive review of the available literature relating to radiated noise from ships has been undertaken as part of the database development process. Where possible, this data is being used to improve the source level model, however, it has been found that currently available information is limited and of variable quality. This work has highlighted the urgent need to implement guidance on measurement and reporting of radiated noise from ships.

The database has been designed to be scalable to allow significantly more data to be stored than is currently available. In addition, the database platform is designed to be Open Access so that data can be made available to a large group via a web-based interface. It is anticipated that this will be useful to the SONIC project as data can be added as the project proceeds and made available to all partners.

**Improved source level model**

A review of currently available ship source level models has been carried out. Based on this review it is expected that either existing models can be improved or a novel semi-empirical composite model can be proposed. However the information on which to base these source level models is limited due to the scarcity of good experimental measurements, especially on
modern cargo vessels. Hence it is not possible to perform a direct calculation of vessel noise as a function of vessel parameters. Work is therefore focused on the novel approach of using AIS data to infer likely ship operating parameters and how this could be used to improve the ship source level estimation.

**Full scale radiated noise measurements**

The first full scale radiated noise measurements have been undertaken to a level of detail considerably higher than that usually observed. Five partners were involved in the trials, each carrying out different tasks:

- CETENA – off-board radiated noise, on-board hull pressure and engine parameter measurements, cavitation observations, GPS tracking;
- CNR-INSEAN – keeping of trial records including weather and vessel conditions;
- SOTON – trials leader, off-board radiated noise and on-board ultrasonic measurements;
- UNEW – Provision of target and support vessels, on-board pressure and vibration measurement, cavitation observations;
- WARTSILA – engine and hull vibration and hull pressure measurement, engine room and deck airborne noise recordings.

The quantity and quality of information obtained from multiple off-board and on-board measurement systems will allow the characteristics of the test vessel to be described in great detail providing a good basis for the validation of scale model tests and numerical modelling work being undertaken in the SONIC project. In addition, the simultaneous deployment of multiple systems operated by different organisations provides a rare and valuable opportunity to accurately investigate the variability that could be expected from radiated noise trial data.

![Spectrogram indicating the variation in measured noise level during one transit of the target vessel past the hydrophone array](Image)

**Figure 1:** Spectrogram indicating the variation in measured noise level during one transit of the target vessel past the hydrophone array
**Development of tools for separating cavitation and machinery noise**

In order to quantify radiated noise from cavitation using on-board techniques it is necessary to be able to measure only cavitation noise using on-board sensors. The use of signal processing techniques to remove machinery noise from a measured signal will be a key factor in the work carried out in Task 2.4. Due to the similarity in characteristics between machinery and cavitation noise this is a particularly challenging task. However, through a combination of scale tests, theoretical analysis and use of full scale trial data it is expected that good progress will be made towards a solution to the problem during the SONIC project.

**Develop and trial of on-board techniques for quantifying radiated cavitation noise**

The full scale trial using the test vessel has provided a large amount of on-board data from multiple measurement systems. Also, crucially, simultaneous off-board radiated noise measurements were undertaken to allow a correlation between on-board and off-board noise data. It is expected that data from additional trials during the SONIC project will further inform this task. Using the results of Task 2.4 to remove machinery noise from a signal, it is expected that techniques for the estimation of radiated cavitation noise from on-board data can be proposed.

Accurate full scale radiated noise measurements using deployed systems are difficult and expensive to undertake. While they offer the best method to determine the levels of underwater noise generated by shipping, easier and more cost effective methods of ship noise monitoring should be investigated.

The techniques being developed in this task could be used by vessel operators to monitor the levels of radiated noise they are generating in real time via the deployment of relatively inexpensive equipment. This information could be used by the ship’s crew to reduce the levels of radiated noise, if required.

![Figure 2: Full scale trial propeller cavitation observation during the sea trial](image)
2.3. Impact

The database provides a complete overview of the underwater noise measurements. Not all data will be publically available; nevertheless reference will be made to the existence of this data in the database. The full scale radiated noise measurements performed will be added to the database after analysis of the results.

The development of trial techniques and the model to separate machinery noise from cavitation noise will impact the possibilities of measuring the underwater radiated noise of ships during dedicated trials. This will provide better insight into the sound levels in areas of high density shipping or in environmentally vulnerable areas.
3. WP3 – Noise Mapping and mitigation measures

3.1. Objectives of Work Package 3

The objectives of WP 3 are:

- To develop a noise footprint and mapping tool (henceforth abbreviated “NFMT”) suitable for assessing design guidelines intended to minimise the noise footprint of a specified ship design and visualising the total noise from shipping activity in a specified area by adding contributions from individual ships in that area.
- To produce noise maps (spatial noise distribution) suitable for the European Atlas of the Sea by using the NFMT.
- To develop cavitation noise reduction measures without reducing fuel efficiency.
- To develop machinery noise reduction measures without reducing fuel efficiency.
- To assess effect on noise maps of spatial planning of ship traffic using the NFMT.

3.2. Work performed

Noise model

The project started with formulating definitions of noise maps and noise footprints. A noise map is a geographical representation of the Sound Pressure Level (or Sound Exposure Level) due to a set of ships in a specified physical scenario. A noise footprint is a noise map for a single ship and for idealized conditions. In order to compare modeling of underwater ship noise propagation both definitions were tuned between SONIC and AQUO partners. Also a NFMT functional requirement specification document was written. In this document, noise map and footprint related requirements and input and applicability requirements are provided. The NFMT tool development is reaching completion. The tool is capable of reading AIS data, interrogating an environmental database and using this data to generate a noise map for an ensemble of ships, or a footprint representation for a single ship. A very fast acoustic propagation model was adapted for use in the NFMT. This model was validated against a high resolution, but much slower (execution time in the order of days), model.

![Image of noise maps](https://example.com/image)

**Figure 3:** Left: snapshot broadband noise map in a synthetic scenario computed using the propagation model in NFMT. Right: noise map computed using the high resolution model RAM.
The two models show excellent agreement and the resulting noise maps are virtually identical. Biological input to the tool (depth distributions and acoustic sensitivity curves for marine mammals and fish) are provided by the Behavioural Biology Group of IBL (Leiden University, Netherlands) and SMRU Ltd. (Saint Andrews University, United Kingdom). The source level model used for the calculations is provided as output of WP2 (SOTON).

An acoustic modeling workshop was held during a joint meeting of the AQUO and SONIC projects on the 14th of March 2014 at Navantia in Madrid. In cooperation with the AQUO project, four test cases were defined for the workshop, with increasing level of complexity. This workshop indicated good correspondence between noise maps produced by the SONIC project with those of the AQUO project. The workshop was very scientifically insightful for both parties and was a great help for development and validation of noise mapping tools.

Preparations have been made for noise footprint measurements of a ship, to be carried out under WP2 mid-2014. These trials will provide the data required for experimental validation for the footprint modelling capability of the NFMT.

**Mitigation of machinery noise**

Task 3.4 aims at mitigating the noise caused by machinery vibrations. The task covers analysing every single step of the noise from the generation through the propagation path to the receiver, as visualized in Figure 4.

*Figure 4: Mechanical Noise chain breakdown*
WI has investigated theoretically if simple adjustments in the ignition process can affect the excitations to the engine structure reducing the noise transmitted without compromising the fuel efficiency. To better understand how resilient mounts transmit forces from the machinery to the ship foundation, WI has developed a dynamometer to be embedded in the structure of their T200 conical mount. The design is now under evaluation by simulation. And a start has been made investigating acoustic finite element modelling (FEM) of machinery foundation structures.

In the next phases of the project, the NMFT will be validated against footprint measurements carried out under WP2 and shipping noise maps will be made of the North Sea. Two new tasks will start, on the development of cavitation noise reduction measures and the assessment of the effects of spatial planning of ship traffic on noise maps, using the NFMT.

3.3. Impact

Results to date will have impact on the knowledge about the sound level in the oceans. Noise mapping will provide input to policy makers on the severity of the underwater sound near dense traffic lanes or in highly vulnerable areas. The mitigation measures of machinery noise will impact the underwater radiated noise levels from the machinery part.
4. WP5 – Dissemination

4.1. Objectives

A major dissemination activity is the development of guidelines for future regulation on underwater noise emission from commercial shipping. These guidelines shall be based on the knowledge gained in WP 1 to 3 and are intended to support policy makers and authorities to enhance:

- Transparency of future legislation for acceptance by the involved stakeholders,
- Standardisation of the used assessment methods and procedures which have to be agreed by the international maritime industry for application on an industrial scale,
- The introduction of clear and defined assessment criteria consistent with the present state of commercial vessel design and operation technology,
- The establishment of methods to derive underwater noise maps as a basis for ship traffic control measures,
- The knowledge on the effectiveness of underwater noise mitigation measures and their impact on fuel efficiency,
- Guidance on incentives for the reduction, or at least prevention of further increase, of underwater noise from commercial shipping.

4.2. Work Performed

The structure of the guideline document has been set up and a common underwater sound terminology agreed. The guidelines are continuously updated with the comments from draft version reviews by the partners and as soon as relevant findings from WP 1 to 3 are available.

4.3. Impact

The guideline document will support policymakers, authorities and the commercial maritime industry in defining the roadmap and necessary actions for future regulation of underwater noise emission from commercial shipping. Thus it will have a direct impact on the future environmental status of European waters.