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Benchmark Underwater Radiated Noise Simulations (BURNSi)

ORCA class acoustic and vibration characteristics

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IMPORTANT INFORMATIVE STATEMENTS

BURNSi

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Introduction

Underwater radiated noise of naval and merchant vessels is an important topic with regard to naval operations and environmental requirements. Accurate, valid and reliable mathematical models are required to assess the technical feasibility of these requirements and to develop the technical specifications for ship structures and equipment already in the design phase of a ship building project.

Different source mechanisms such as the transmission of airborne, structure-borne and fluid-borne noise, the radiation of the ship hull and the hydrodynamic behaviour of the flow and propellers contribute to underwater noise levels. A proposal for a series of international workshops on the verification and validation of simulation models for underwater radiated noise produced by machinery and hydrodynamic sources was presented during the 2019 CSSM conference in Kiel [1]. The Benchmark Underwater Radiated Noise Simulations (BURNSi) workshops will be a cooperative effort of the defence organizations of Canada, Germany and the Netherlands.

Information and data of an ORCA-class training vessel, PCT MOOSE, of the Royal Canadian Navy can be made available for this purpose. The required acoustic and vibration data of the ship were measured during dynamic and static noise trials in 2019 and 2020 at the Patricia Bay (Pat Bay) naval acoustic range near Victoria, Canada. These measurements were organized by Defence Research and Development Canada (DRDC) and sponsored by Transport Canada.

For this workshop, participants will be provided with all necessary onboard acoustical data and ship structural information which is typically available during the design phase of a new naval platform. Based on this data set, they will be tasked to perform blind predictions of the ship's underwater radiated noise with the main focus on the noise contribution of the propulsion engine, the diesel generator set and the propeller. During the workshop the prediction results will be benchmarked and compared with measured underwater radiated noise results.

BURNSi

The objective of the BURNSi workshop is to benchmark and validate mathematical simulation tools for the prediction of underwater radiated noise due to machinery and hydrodynamic noise sources.

Technical data and acoustic information of an ORCA class training vessel of the Royal Canadian Navy was gathered during measurement trials with PCT MOOSE at the Pat Bay sound range and is available for this purpose.

Participants of the workshop will be provided with all necessary on board acoustical data and ship structural information, which is typically available during the design phase of a new naval platform:

- Drawings and a CAD model of the ship structure,
- Propeller geometry and hydrodynamic inflow model,
- Technical information of diesel generator and propulsion diesel engine,
- Structure and airborne noise levels,
- Technical information of the resilient mounting systems.

The methodologies used will be shared and prediction results will be benchmarked and compared with measured underwater radiated noise results.

ORCA-class training vessel

The ORCA class patrol vessels are made of steel and have a displacement of 210 tonnes. Two five-bladed fixed pitch propellers, each driven by a Caterpillar 3516B marine diesel engine, provide the necessary propulsion for sailing. Maximum speed is approximately 20 kts. The layout of the machine room is shown in Figure .

Three Caterpillar 3054 DIT diesel generator sets are available for the required hotel load. Only one DG-set is required for sailing and provides a load of 75 kW. Crankshaft speed of the diesel is 1800 rpm.

The propulsion diesel engines and diesel generator sets are fitted via four flexible mounts on the ship foundation. The ship foundations are heavy plate seats, which are supported by the side girders and frames of the ship structure.

A rigidly mounted gearbox between the crankshaft and propeller shaft has a reduction ratio of 2.548. The pinion gear has 31 teeth and the bull gear 79.

The diesel fire pump and the bilge pump were switched off during the runs and the air compressor unit was in standby mode. Rudder movements were limited during the runs in order to avoid hydraulic noise from the steering gear system.

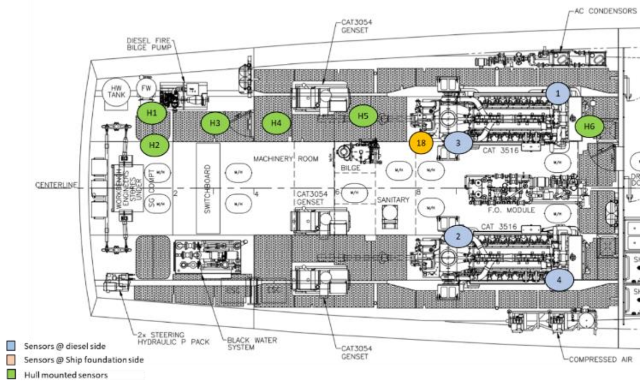


Figure 1: PCT MOOSE machine room and sensor layout

Measurement trials

Measurement trials with PCT MOOSE were carried out in 2019 and 2020 at the RCN's Patricia Bay (Pat Bay) sound range near Vancouver Island. Trial objectives in the trial plan [2] for the measurements in 2020 were defined in order to gather all required acoustic input data for the underwater radiated noise predictions and validation to determine:

- a) underwater noise levels for different sailing conditions.
- b) underwater noise contributions of the propulsion diesel engines, the diesel generator sets and the propeller.
- c) structure-borne noise levels of the propulsion diesel engine, the diesel generator sets and at different hull locations near the main noise sources.
- d) airborne sound levels in the machinery room near the propulsion diesels and diesel generator sets.
- e) foundation transfer functions.
- f) input and transfer mobility of the foundations of the propulsion diesels and diesel generator sets.

The sound range is located in a shallow water area and is equipped with four bottom-mounted B&K 8101 hydrophones, which all have different water depths due to the slope of the sea bottom (Figure 2).

Dynamic runs for the determination of the underwater radiated noise levels at different sailing conditions were carried out at the dynamic range. The platform sailed along a dynamic track line with a heading of 303 degree for west and 123 degree for east runs. The depth of the hydrophones changes a little (1 m) during the day due to the tide.

Port and starboard aspect underwater radiated noise levels were measured at a horizontal distance of 106 meters when the platform sailed along the dynamic track line. Additional runs with an offset of 106 meters towards the North were carried out in order to measure the underwater radiated noise in keel aspect with the north dynamic hydrophone (NDH).

Static trials were carried out in order to determine the underwater radiated noise contribution of single auxiliary such as the diesel generator sets and to measure the sound transfer functions for structure-borne and airborne noise transmission and radiation.

Underwater radiated noise levels were determined in One Third Octave band (OTO) and Narrowband (NB). OTO analysis was conducted in a large frequency range from 3.15 Hz to 80 kHz. Acquisition of Narrowband data was carried out with a bandwidth of ¾ Hz and a frequency range up to 10 kHz. The underwater noise levels are reported in dB re 1 µPa and are normalized to a distance of 1 m taking into account spherical spreading loss.

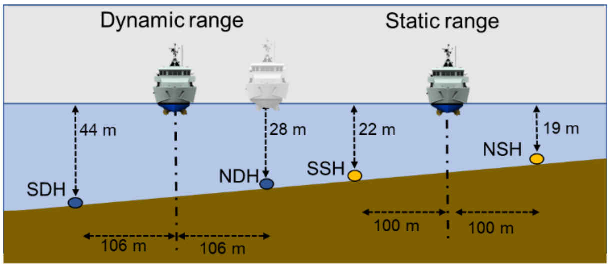


Figure 2: Pat Bay sound range hydrophone positions

On-board data acquisition

Data acquisition during 2019 and 2020 has been done using software and hardware initially developed or selected for DRDC and CSSM trials aboard HMCS Glace Bay in 2018. Some changes have been made since, most notably in the analogue to digital converters (ADC).

The accelerometers were all of the same type, with a +/- 5% range of 0.47 Hz to 4 kHz, and a 3 dB range of 0.17 Hz to 10 kHz. These accelerometers are mounted by a mounting thread to an accelerometer block, which is rigidly attached to the structure to be measured. The blocks were mounted using an instant adhesive gel for the entire trial, except for one, which was mounted using a magnetic mounting for comparison. Each accelerometer has a 3 m BNC cable integral to it, and so extra BNC cabling was used to bring accelerometer signals back to the ADC.

Engine shaft RPM was recorded using two programmable optical tachometers, each with a detectable rotation range of 5 to 500,000 RPM. Before the trial began, reflective tape was installed on the shaft allowing detection of rotation. The rotational speed is captured as a pulse train with frequency related to the RPM, which is translated by the ADC to RPM values for recording.

Vibration injection was done with a Wilcoxon F4/F7 mechanical shaker, with accompanying power amplifier and matching network. It was operated in the F7 operational mode with typical frequency response. The shaker has force and acceleration output to signal leads, which were also connected to the ADC.

The core digital hardware for data acquisition is a National Instruments chassis 9188, and Ethernet-configurable device, which has room for eight different ADC modules. The two ADCs used for BURNSi were the NI9234 and NI9239, selected based on the need for excitation current or not. The ADC sample rate was 25.6 kHz. Time coherence of the measurements is assured by the co-location of the ADCs.

Narrowband data from the ADC stage was output to a laptop over network connection. This acquisition laptop in the machinery space was monitored and controlled for the duration of the trial via remote log-in from another laptop elsewhere in the ship. A DRDC-deployed GPS beacon and time server maintain timekeeping of the entire acquisition network, ensuring that file times for accelerometer data are able to be meshed with other GPS-time based measurements, such as range hydrophone data.

Underwater noise signature

The underwater noise signature was measured for a speed range from 3 to 19 kts with an increment of about 2 kts and at 20 kts. Port- and starboard-aspect radiated noise levels are approximately equal. Broadband cavitation noise in the higher frequency bands was detected around a speed of 8.5 kts and higher.

The noise signature of MOOSE in the frequency range 0 to 50 kHz and a global classification for different sailing speeds is presented in Figure 3. Main components in the signature are tones related to the:

- cylinder firing frequency and harmonics of the diesel generator and propulsion diesel engine,
- gear mesh frequencies of the gearbox and
- blade rate frequencies of the propeller

Tones related to the harmonics of the cylinder firing of the diesel generator dominate the lower frequency bands at low sailing speed. The contribution of the propulsion diesel engine increases as function of speed together with tones related to the propeller blade rate frequencies.

Gearbox related noise was detected over the full speed range. Tones related to the gear mesh frequencies are contributing to the noise signature up to the 5 kHz frequency band.

Contribution of propeller broadband noise at sailing speeds below and around the cavitation inception speed (3-8 kts) is relatively small and raises the noise levels only at frequencies above 2 kHz.

Cavitation noise becomes the dominant broadband noise source at higher sailing speeds and increases the underwater noise levels more than 40 dB in the higher frequency bands.

Underwater noise data will be made available during the BURNSi workshops for validation of prediction results.

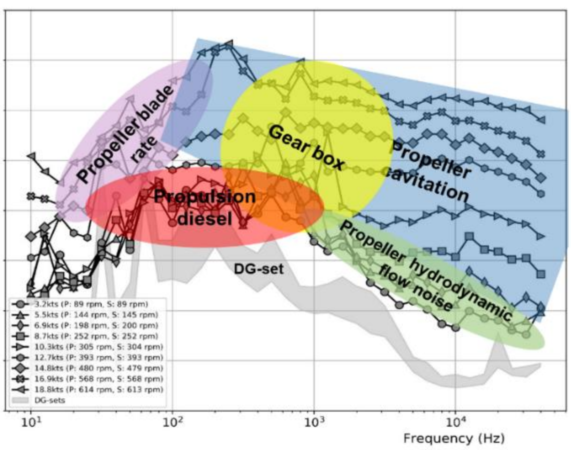


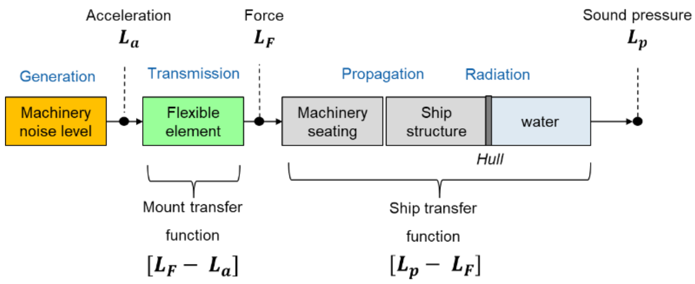
Figure 3: Classification of the main sources contributing to the radiated underwater noise signature

Structural machinery noise and available data for predictions

Machinery noise sources like diesel generator sets and propulsion diesel engines generate structural vibrations, which transfer to the ship hull and radiate into the surrounding water. Besides the structural transmission, also airborne transmission and fluid borne transmission via fluid filled tubes for cooling water or lubrication oil can be an important contribution, which should be considered.

A general way to predict underwater noise levels due to structure borne noise transmission is to split the sound path into three parts:

- Machinery structure borne noise levels L_a at the machinery side of the flexible mounts;
- The mount transfer function, $T = [L_F - L_a]$, which characterizes the dynamic stiffness of the flexible mount and
- The ship transfer functions, $S = [L_p - L_F]$, which involves sound transmission through the ship structure to the hull and underwater sound radiation.



$$L_p = L_a + [L_F - L_a] + [L_p - L_F]$$

Structure borne noise data, the dynamic stiffness of the flexible mounts and detailed drawings of the seating and ship structure will be made available for the underwater noise predictions. In addition, an FEM model of the ship structure will be available.

Structure-borne noise data

Structure-borne noise was measured at the ship hull and at the machine and ship foundation side of the Diesel generator sets and the propulsion Diesels.

Diesel generator sets: Structure-borne noise levels of the diesel generator sets 1 and 2 were measured at a limited number of locations and directions. The noise levels of the diesel generator sets for the mathematical simulations are characterized by means of the power average of all positions and directions. The results show that the averaged levels of DG-set 1 and 2 are approximately equal.

Propulsion Diesel engine: Structure-borne noise levels of the port side propulsion diesel engine were measured above each resilient mount:

- position 1: x, y and z direction,
- position 2: y and z direction,
- position 3: x, y and z direction,
- position 4: x and z direction.

The highest levels occur in the vertical direction. Noise levels of the propulsion diesel engine for the mathematical simulations are characterized by means of the power average of all positions and directions.

Structure borne noise of the propulsion diesel, transmitted via the flexible coupling to the rigidly mounted gearbox is an important contributing sound path for underwater radiated noise. Additionally, the gearbox itself generated strong tones related to the gear mesh frequencies, which were detected in the underwater signature.

Characterization of the resilient mountings

Hammer impact measurements have been performed with various hammer-tips on the Patrol Training Craft Moose. The measurements were done with one of the diesel generators running. Goal of the hammer impact measurements is to determine the mechanical impedance of the foundations of the various machinery. The mechanical impedance is a measure of how much the structure resists motion when subjected to a harmonic force. In case of a resilient mounting: the best isolation of the vibration from the resilient mounted machinery is obtained when the foundations of the resilient mounting are significantly stiffer than the resilient element (Stiff – flexible – stiff).

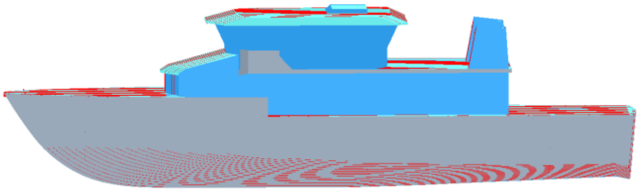
Besides the determination of the input impedance, also the cross impedance has been measured. The cross impedance is a measure of the velocity on the foundation resulting from a harmonic force, applied above the resilient mount i.e. a measure of the isolation characteristics of the resilient element. During the cross impedance measurements, the ship was under dead-ship condition i.e. no Diesel generators were running.

Ship Transfer functions: The ship transfer functions have to be predicted. Sound transmission at low frequency bands is typically calculated by means of Finite Element Methods and Statistical Energy Analysis(SEA). SEA is supposed to be a valid approach for frequencies above a hundred Hertz, depending on the size and stiffness of substructures.

Finite element model

A finite element model (FEM) of the ORCA class training vessel was constructed using the software Trident Modeller (TM) [4] and the engineering drawings of the ship are available in pdf format. The FEM does not include any perforations, pillars, furnishings, machinery, doors, windows, penetrations, hull appendages and the like, which are not expected to affect the outcome of the acoustic finite element analysis (FEA). The current geometrical model may potentially be reduced in extent to increase the frequency range of the acoustic analysis. The superstructure may for instance be removed on the discretion of the FEA analyst. An FEM model of the ORCA class ship with a mesh size of 150 mm and the stiffeners modelled as beam elements and the remaining structures as shell elements is available in Trident, NASTRAN and ANYSYS file formats. The construction of the geometrical model of the FEM is outlined in a DRDC reference document [5]. A geometrical rendering of the ORCA class training vessel, available as a Rhino model and a view of the meshed model are shown in Figure 4.

a)



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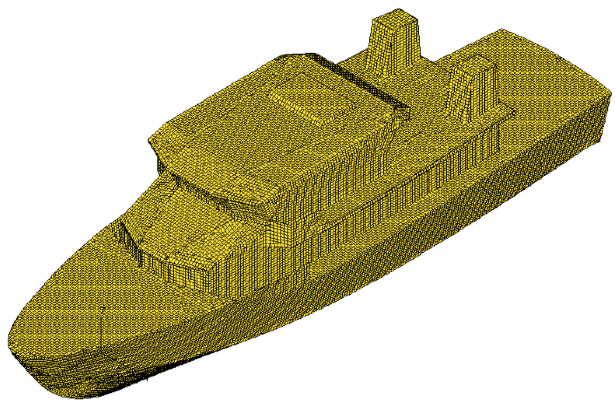

Figure 4: Geometrical rendering of the ORCA class training vessel (a) and the meshed model (FEM) (b)

Way Ahead

The next step will be to prepare the first workshop, comprising all the deliverables, geometrical data for the modelling, select and format the necessary measurement data to serve as input data set for the calculations. After that, participants will be invited for the first workshop, which is expected to be organized in 2022. A follow up after the first available simulation results will be held in 2023.

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[4] Trident Modeller version SubSAS 5.0.2.3 Build: July 7, 2020 by Lloyd's Register Applied Technology Group

[5] Cintosun, E., Trident Modeller Finite Element Model of the ORCA Class Training Vessel, DRDC Reference Document D20-1130-04460, 2021

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13. ABSTRACT/RÉSUMÉ (When available in the document, the French version of the abstract must be included here.) Control and mitigation of underwater radiated noise from Naval and Merchant vessels is an important issue with regards to operational and environmental requirements. Accurate and reliable mathematical models are required to assess the technical feasibility of these requirements and to develop the technical specifications for the ship structure and equipment. A proposal for an international workshop on the verification and validation of these simulation models for underwater radiated noise produced by machinery and hydrodynamic sources was presented during the CSSM conference in 2019. The workshop will be a cooperative effort of the Defense organizations of Canada, Germany and the Netherlands. Information and data of the ORCA-class patrol vessel of the Royal Canadian Navy can be made available for this purpose. The required acoustic data of the ORCA class was measured during dynamic and static noise trials in 2019 and 2020 at the Royal Canadian Navy's Patricia Bay (Pat Bay) sound range near Victoria, Canada. This paper will outline the scope and task of the workshop on Benchmark Underwater Radiated Noise Simulation (BURNSi) models and presents a first impression of the acoustic features of the ORCA measured during the trials at the Pat Bay sound range.